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Electrochemical Analysis of Lithium-ion Battery for Mobile Device Applications

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ABSTRACT

Lithium-ion batteries (LIBs) are widely used in portable electronic devices because of their high energy density, long cycle life, and excellent electrochemical performance. The growing demand for efficient mobile devices has increased the need for improved battery performance, safety, and durability. This study investigated the electrochemical performance of a Lithium Manganese Oxide (LMO)-based lithium-ion battery for mobile device applications. The objectives were to evaluate the Open Circuit Voltage (OCV) and determine the energy density of the battery system. Materials used included $LiMn_2O_4$ cathode material, graphite anode, $LiPF_6$ electrolyte, carbon black additives, and polymer binders. The battery cell was produced through slurry preparation, coating, calendering, and cell assembly processes. OCV and energy density tests were conducted using an LMO half-cell at a C-rate of C/9. The results showed a maximum OCV of 3.81 V and a current of 2.083 A. The battery delivered a maximum energy value of 7.9154 Wh, with gravimetric and volumetric energy densities of 240.15 Wh/kg and 307.51 Wh/L, respectively. These results indicate that the LMO battery possesses good voltage stability and high energy storage capability. The study demonstrates that LMO-based lithium-ion batteries are suitable for mobile device applications due to their high energy density, stable electrochemical performance, and compact energy storage capability.

INTRODUCTION

Lithium is one of the most widely used metals and is also one of the most frequently found elements in the Earth's crust. It is commonly regarded as an essential element in various industrial applications, including heat-resistant glass, ceramics, and lithium-ion batteries (Winter *et al.,* 1998). It is a soft, silver-white metal belonging to the alkali metal group and has unique properties that make it essential for various industrial, medical, and technological applications (Whittingham, 2004; Tarascon & Armand, 2001). Lithium-based compounds have been widely used in different energy storage applications due to their lightweight nature and high electrochemical potential (Xu *et al.,* 2014). For over three decades, lithium-ion batteries (LIBs) have been among the most promising chemical-electrical energy converters for power electronic devices such as cellular phones, laptops, and cameras. Their high energy density, low self-discharge rate, and long cycle life make them a preferred choice for portable electronic applications (Dunn *et al.,* 2011). The commercial success of LIBs began in 1992 with the development of carbon-based anodes, non-aqueous electrolytes, and lithium cobalt oxide ($LiCo_2O_2$) cathodes (Nagaura & Tozawa, 1990; Goodenough & Mizushima, 1980). Over the years, new cathode materials such as lithium iron phosphate ($LiFePO_4$) and nickel manganese cobalt (NMC) have been developed to enhance battery performance (Kang & Ceder, 2009). Today, this technology is integral to mobile phone production and the broader field of portable electronics. The demand for highly functional applications necessitates batteries with higher power density, increased energy density, excellent charge–discharge cycling performance, and enhanced safety (Armand & Tarascon, 2008; Zhang *et al.,* 2011). The evolution of lithium-ion technology has significantly improved battery efficiency and durability, making it the dominant energy storage solution for mobile and electric vehicle applications (Wang *et al.,* 2012; Goodenough, 2018). As the global shift toward sustainable energy intensifies, advancements in LIB technology continue to focus on optimizing material performance and improving charge storage mechanisms (Li *et al.,* 2018). In recent years, there has been increasing interest in sustainable and environmentally friendly materials for engineering applications. Studies have demonstrated that agro-waste and polymer-based composites can be effectively utilized to develop high-performance materials for industrial applications, including the automotive sector (Emekwisia *et al.,* 2026). Similarly, waste-derived reinforcements such as fly ash have shown significant improvements in the mechanical and microstructural properties of metal composites (Emekwisia *et al.,* 2024a). The incorporation

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of natural fillers such as hardwood sawdust into polymer matrices has also been reported to enhance physical and mechanical properties, indicating the potential of low-cost and sustainable materials in advanced material development (Emekwisia *et al.,* 2024b). Furthermore, the integration of waste materials into engineering systems has been extended to structural applications. For example, PET waste fibers have been successfully utilized to improve the strength and durability of concrete (Eso *et al.,* 2024), while alternative reinforcement materials such as cane rods have shown promising flexural performance in laterized concrete beams (Lawal *et al.,* 2024). These developments highlight the growing relevance of sustainable materials in modern engineering, which can also be explored in energy storage systems to improve cost-effectiveness and environmental sustainability. Lithium (Li) is a chemical element in Group 1 of the periodic table and is widely recognized for its unique electrochemical properties that enable efficient energy storage and release (Manthiram, 2017; Blomgren, 2016). It has a relatively low melting and boiling point compared to other metals, yet it offers exceptional gravimetric energy density, making it ideal for high-performance batteries (Padhi *et al.,* 1997; Bruce *et al.,* 2008). The development of lithium-ion batteries is largely attributed to the pioneering work of Whittingham (2004), who introduced lithium intercalation in transition metal oxides. A lithium-ion battery stores and discharges energy through the movement of lithium ions between two electrodes—the cathode and the anode—through an electrolyte (Kang & Ceder, 2009). LIBs offer several advantages over traditional battery technologies, including higher energy densities, lower weight, and improved cycle life (Armand & Tarascon, 2008). Their applications span consumer electronics, electric vehicles, and renewable energy storage systems (Goodenough, 2018). Recent research has focused on improving battery safety and performance through advanced materials and electrolyte systems. Solid-state electrolytes, for instance, have emerged as promising alternatives to conventional liquid electrolytes (Janek & Zeier, 2016). Additionally, improvements in anode materials, such as silicon-based anodes, offer the potential for significantly increased energy storage capacity (Schmuch *et al.,* 2018). With continuous innovation, lithium-ion batteries are expected to remain the dominant energy storage solution for years to come. This work therefore, focuses on investigating the components of lithium-ion batteries, designing a battery with built-in safety features to prevent overheating, overcharging, and electrical shorts, and conducting Open Circuit Voltage (OCV) and energy density tests for high-performance applications.

MATERIALS AND METHODS

Materials

The materials used for this research include; Cathode Materials:Lithium manganese oxide, LiMn2O4 - Active material, Carbon black - Conductive agent, Polyethylene Glycol - Binder, Aluminum foil - current collector, N-Methyl-2-Pyrrolidone (NMP) - solvent. Anode Materials: Graphite - Active material, Carbon black - conductive agent, Polyethylene Glycol - Binder, Copper foil - Current collector, Deionized water - Solvent, Polyvinyl Alcohol-Separator, LiPF6 in a mixture of organic solvents (EC, DMC & EMC) - Electrolyte. Other materials and equipment used are lab coat, ventilation system, cell housing, and insulation materials.

Method

Electrode Material Preparation

Prepare the active material of both the cathode and anode and the inactive material, for the active material of the cathode which is LiMn2O4, which is lithium manganese oxide (Lithium Carbonate and manganese dioxide), gather them and process them into powder form and for the active material of the anode which is graphite and, gather them and process them into powder form and then also prepare the inactive materials which includes the binder, solvent, conductive agent for both electrodes.

Weighing of the Powders

The Cathode materials which are Lithium Manganese oxide, comprising Lithium Carbonate and manganese dioxide, and the anode material, which is graphite and the inactive materials, which are carbon black and polyvinyl alcohol, are properly measured and weighed on a small flask using a measuring scale before the slurry preparation.

Slurry Preparation

To mix the material for both the cathode and the anode, you must first;

i. Mix the active material, additives, conducting agent (carbon black or graphene, polyvinyl alcohol) and binder dry.

ii. Then you disperse the material by adding solvent and homogenize.

The active material and inactive material must be mixed with a mixing tool e.g. intensive mixer and then put the slurry mixture in a different tank or can for the cathode and anode and it must be done under room temperature.

Production process

- With the help of a mixing tool at least two separated raw materials are combined to form a so called slurry.
- The production of slurry requires not only active materials but also conductive additives, solvents and binders.
- A distinction is made between mixing (dry mixing) and dispersing (wet mixing). In addition, the process can be performed under vacuum to avoid gas inclusions.

Coating

The slurry is coated onto metal foils (current collectors) and dried to form electrode films.

Calendering

The electrode films are compressed to improve density and adhesion.

Electrode Manufacturing

The operational principle or production of a lithium ion battery cell consists of three main process steps which includes: electrode manufacturing/preparation, cell Assembly, cell Finishing. Cell configuration of the lithium ion battery involves: Type: Prismatic, pouch and cylindrical, Geometry: Rectangular, Size: Typical sizes range from 20 x 30 x 5 mm to 60 x 100 x 10 mm.

Cell Assembly

Layering: Cathode, separator, and anode layers are stacked or wound into a cylindrical or prismatic shape.
Electrolyte Filling: The cell is filled with the liquid electrolyte under vacuum conditions to ensure complete wetting.
Sealing: The cell is sealed to prevent moisture and air ingress, which can degrade battery performance.

Cell Finishing

Formation Cycling: Initial charging and discharging cycles at controlled rates to form the solid electrolyte interphase (SEI) layer on the anode, which is crucial for battery stability.
Aging: Cells are stored under specific conditions to allow the SEI layer to stabilize.

Open Circuit Voltage Test

In this experiment, Open-Circuit Voltage (OCV) was determined for the Lithium Manganese Oxide (LMO) half-cell by charging and discharging it at a C-rate of C/9. The half-cell was first charged to its maximum capacity, then allowed to rest for a period of time to reach equilibrium. Next, the half-cell was discharged at a rate of C/9, monitoring the voltage across its terminals. Once the discharge cycle was complete, the OCV of the half-cell was measured, which represented its voltage at equilibrium.

Energy Density Test

In this experiment, the energy density of the Lithium Manganese Oxide (LMO) was evaluated to assess its capacity to store and deliver energy per unit mass and volume. The energy density test was conducted by initially charging the LMO to its full capacity. After reaching maximum charge, the cell was allowed to rest to achieve equilibrium, ensuring that any surface reactions were stabilized and that the voltage represented a true open-circuit condition. Following the rest period, the cell was discharged while continuously monitoring the voltage and capacity. Data collected during the discharge allowed for calculation of the specific energy output, which is crucial in determining both the gravimetric (Wh/kg) and volumetric (Wh/L) energy densities. The energy density values were obtained by integrating the area under the voltage-capacity curve over the entire discharge cycle. Using a battery tester, we were able to determine both the gravimetric (Wh/kg) and volumetric (Wh/L) energy densities of the LMO battery. This energy density assessment provides essential insight into the LMO battery's capability to store and release energy efficiently, a key factor in evaluating its potential applications in high-demand energy storage systems.

RESULTS AND DISCUSSION

Open Circuit Voltage (OCV) Test Result

The Open Circuit Voltage (OCV) test was conducted to assess the voltage behavior of the lithium-ion battery under no-load conditions. The data obtained from this test provides critical insights into the battery's state of charge (SOC), its internal electrochemical equilibrium, and overall health. The measured OCV values were analyzed to determine their correlation with the SOC at various stages. This analysis allows for a better understanding of the battery's performance in terms of its resting potential and how it aligns with theoretical predictions. Variations in the OCV across different electrode materials and electrolyte compositions were examined to assess their impact on energy density and stability. Additionally, the test results were compared with standard reference values to evaluate the battery's efficiency and predict its behavior during charge-discharge cycles. Any deviations observed in the OCV readings were further analyzed to identify potential factors, such as internal resistance or degradation mechanisms, contributing to performance loss over time. This analysis ultimately contributes to optimizing battery design for mobile device applications. The open circuit voltage (OCV), shown in Figure 1, was determined experimentally by charging and discharging an LMO half-cell with a C-rate of C/9.

Table 1: Table of OCV, that is, the voltage and current of the LMO during multiple charge and discharge cycle.

S/N	Voltage	Amperes
1	0.45	0.223
2	1.17	0.491
3	1.42	0.612
4	1.82	0.834
5	2.35	1.051
6	2.78	1.232
7	2.92	1.51
8	3.35	1.854
9	3.81	2.083

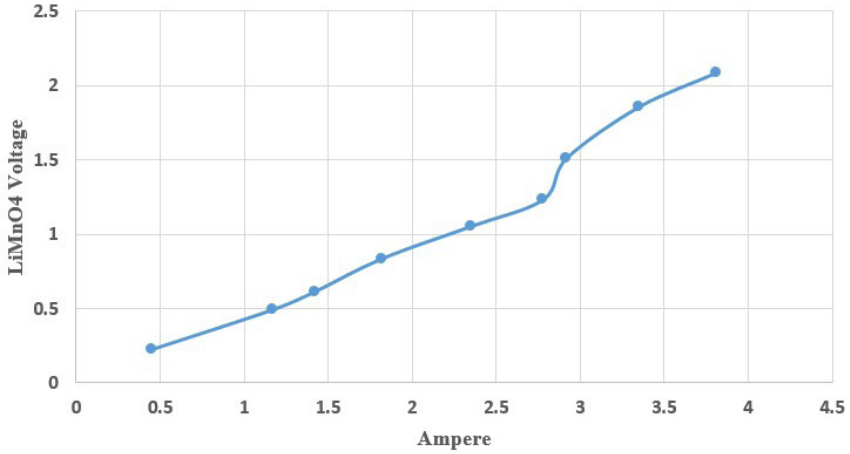

Figure 1: The open circuit voltage graph of the $LiMnO_4$ battery

Energy Density Test Result

The energy density test results provide insights into the Lithium Manganese Oxide (LMO) cell's capacity to store and deliver energy effectively. Using a battery tester, the energy density values were calculated in terms of gravimetric (Wh/kg) and volumetric (Wh/L) energy densities, providing a comprehensive understanding of the cell's performance. The energy density calculations were based on the following recorded values: Capacity - 2083 mAh (2.083 Ah), Voltage - 3.8v, Weight - 33 g, Volume - 25.74 cm^3. The energy (in watt-hours, Wh) was determined using the formula: Energy (i) (Wh) = Capacity (Ah) × Voltage (V). So to attain the different energy levels for the battery, readings from the OCV test were applied.

Table 2: A table of the energy at different voltage and capacity levels

S/N	Voltage (V)	Capacity (Ah)	Energy (Wh)
i	3.81	2.08	7.9154
ii	3.35	1.85	6.1975
iii	2.92	1.51	4.4092
iv	2.78	1.23	3.4194
v	2.35	1.051	2.4699

Using these energy values, the energy densities were calculated as follows:

• Gravimetric Energy Density (Wh/kg):

Energy Density (Wh/kg) = Energy (Wh) / Weight (kg)

i. 7.9154 Wh / 0.033 kg = 240.15 Wh/kg
ii. 6.1975 Wh / 0.033 kg = 187.80 Wh/kg
iii. 4.4092 Wh / 0.033 kg = 133.61 Wh/kg
iv. 3.4194 Wh / 0.033 kg = 103.62 Wh/kg
v. 2.4699 Wh / 0.033 kg = 74.85 Wh/kg

Table 3: A table of the Gravimetric Energy Density at different Energy levels

Energy (Wh)	Gravimetric Energy Density (Wh/Kg)
7.9154	240.15
6.1975	187.80
4.4092	133.61
3.4194	103.62
2.4699	74.85

• Volumetric Energy Density (Wh/L):

Energy Density (Wh/L) = Energy (Wh) / Volume (L)

i. 7.9154 Wh / 0.02574 L = 307.51 Wh/L
ii. 6.1975 Wh / 0.02574 L = 240.77 Wh/L
iii. 4.4092 Wh /0.02574 L = 171.30 Wh/L
iv. 3.4194 Wh / 0.02574 L = 132.84 Wh/L
v. 2.4699 Wh /0.02574 L = 95.96 Wh/L

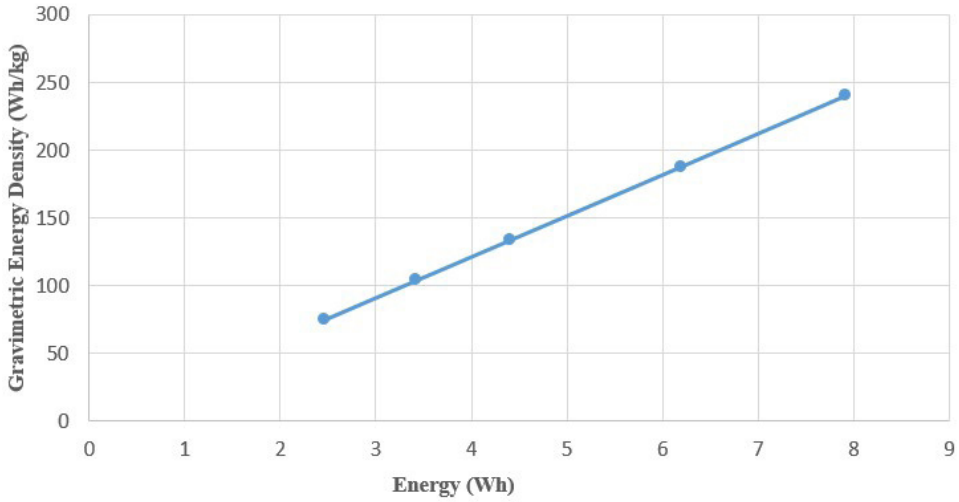

Figure 2: The graph of gravimetric energy density against energy

Table 4: A table of the Volumetric Energy Density at different Energy levels

Energy (Wh)	Volumetric Energy Density (Wh/Kg)
7.9154	307.51
6.1975	240.77
4.4092	171.30
3.4194	132.84
2.4699	95.96

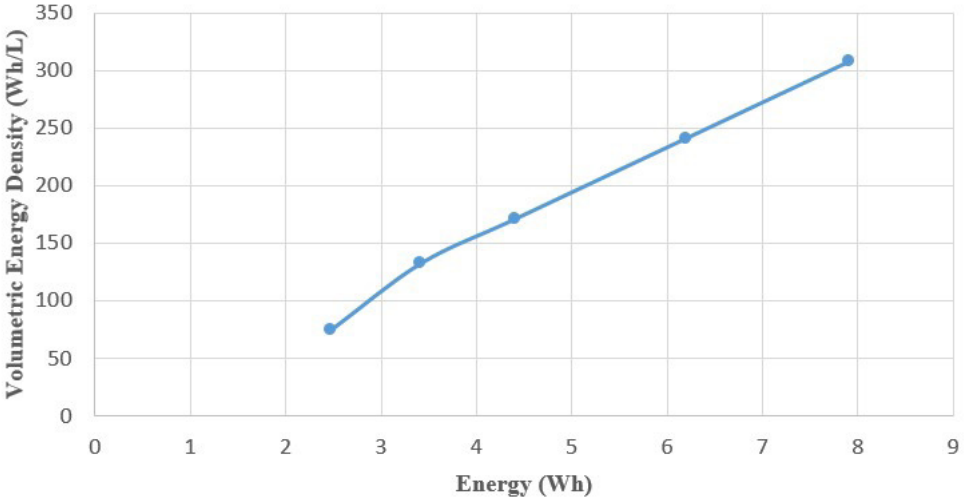

Figure 3: The graph of volumetric energy density against energy

These values, 240.15 Wh/kg and 307.51 Wh/L, align with the expected performance for LMO cells, demonstrating a balance between energy storage capability and compactness. The results indicate that the LMO battery has a high energy density per unit mass and a reasonable energy density per unit volume. The gravimetric energy density of 240.15 Wh/kg suggests that the LMO chemistry is well-suited for applications requiring portable energy solutions, such as consumer electronics where mobile phones are the most suitable. The volumetric energy density of 307.51 Wh/L demonstrates the cell's ability to deliver a substantial amount of energy within a small volume, which is beneficial in space-limited applications. Both metrics underscore the suitability of the LMO chemistry for high-density energy storage applications where both weight and size considerations are essential.

Table 5: Experimental Data attained from the Energy density test conducted on the LMO

Parameter	Value	Unit
Capacity	2083	mAh
Voltage	3.8	v
Weight	33	g
Volume	25.74	cm3
Energy	7.9154	Wh
Gravimetric Energy Density	240.15	Wh/kg
Volumetric Energy Density	307.51	Wh/L

CONCLUSION

This research focused on investigating the design and performance of lithium-ion batteries, specifically the Lithium Manganese Oxide (LMO) variant, for high-energy mobile device applications. The primary goal was to enhance critical performance factors such as energy density, cycle life, and charging speed, while ensuring safety and cost-effectiveness. By investigating the effects of electrode materials, particularly the spinel structure of LMO cathodes, this study demonstrated that LMO-based batteries provide a promising balance of high performance and safety, suitable for mobile devices. The findings from this study highlight that LMO batteries offer significant advantages for rapid charging and high-current discharge, which are essential for mobile devices with frequent use. The OCV test, showing a maximum voltage of 3.81V, demonstrates stable voltage retention critical for consistent device performance. The energy density test results, with values of 240.15Wh/kg and 307.51Wh/L, indicate a robust energy storage capacity, making these batteries well-suited for compact, energy-demanding applications. Additionally, the power density test recorded outputs of 240.15W/kg and 307.51W/L, confirming the battery's capability for delivering high power over short periods, an essential feature for devices requiring quick energy bursts. Though LMO batteries may offer slightly lower energy density than materials like NMC or LCO, their superior safety and thermal stability, combined with the optimized electrolyte formulations and electrode design used in this study, underscore their reliability and suitability for mobile applications where safety and sustained high performance are priorities.

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