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Quantitative Assessment of Discharge Depth Effects on Lithium-Based Batteries: LTO, LFP, and NCM

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ABSTRACT

This study explores the impact of depth of discharge (DoD) on the performance degradation of three lithium-based battery chemistries: lithium titanate (LTO), lithium iron phosphate (LFP), and nickel cobalt manganese oxide (NCM). The objective is to establish a standardized methodology for evaluating battery health under partial cycling and to quantify the degradation behavior across three DoD ranges: 0–33%, 34–66%, and 67–100%. LFP and NCM cells were cycled at 1C under room temperature, with periodic full charge-discharge tests to assess capacity retention. Results indicate that LFP cells maintain stable performance at shallow DoD with minimal degradation, but show moderate fade at deeper discharge levels, with capacity loss of −1.06% (34–66%) and −1.75% (67–100%). NCM cells, while more sensitive to high DoD, still maintain usable capacity with a maximum fade of −2.48% at 67–100%. Based on current data and preliminary trends, LTO is expected to exhibit the most stable performance among the three, with estimated capacity fade of less than −1% across all DoD conditions. However, its lower energy density may limit its suitability for high-capacity applications. This comparative framework highlights trade-offs between battery chemistries under varying discharge conditions and provides practical insight for selecting batteries based on application-specific requirements such as cycle life and energy efficiency.

Keywords: Depth of Discharge (DoD), Capacity Fade, Battery Aging, Lithium-Based Batteries

INTRODUCTION

Lithium-ion batteries (LIBs) are widely used in electric vehicles (EVs), renewable energy storage, and consumer electronics due to their high energy density, efficiency, and relatively long lifespan (Guo et al., 2021). However, battery performance inevitably degrades during repeated charge–discharge cycles, leading to a gradual loss of usable capacity over time (Broussely et al., 2005).

Among the various operational factors, **Depth of Discharge (DoD)** plays a critical role in determining cycle life. Studies have shown that deep cycling significantly accelerates degradation processes such as electrode stress, cathode material dissolution, and electrolyte decomposition, while shallow cycling reduces these effects and extends overall life (Tawfik et

al., 2024; Millner, 2010).

This study aims to experimentally compare three lithium-ion chemistries—Nickel Cobalt Manganese (NCM), Lithium Titanate (LTO), and Lithium Iron Phosphate (LFP)—across three different DoD windows (0–33%, 33–66%, and 66–100%). By analyzing **capacity retention** under identical cycling protocols, the work seeks to elucidate chemistry-dependent degradation behaviors and propose optimal operation strategies.

MATERIALS AND METHODS

Commercial NCM (~2400 mAh), LFP (~1150 mAh), and LTO (~1350 mAh) cells were tested after preconditioning. Cycling was conducted at 25 ± 2 °C using a 1C CC–CV charge and 1C constant-current discharge, with cutoffs per manufacturer specifications.

Tests were divided into three DoD ranges: 0–33%, 34–66%, and 67–100%. Cells were repeatedly cycled within their assigned window, with a full 1C calibration test every 10 cycles to measure residual capacity. Capacity retention was defined as the ratio of calibrated to initial capacity. LTO testing is ongoing, and current data remain insufficient for full analysis.

Voltage and current were measured with a digital multimeter (GDM-8342, Good Will Instrument Co., Taiwan) offering 0.02% DC accuracy, dual-display monitoring, and USB data logging to ensure complete and reliable records.

RESULTS & DISCUSSION

To clearly present the effects of depth of discharge on each chemistry, the capacity variations at different DoD windows are summarized in Tables 1–3. For each battery type (LFP, NCM, and LTO), representative data are shown, followed by a discussion highlighting the most notable behaviors in specific operating ranges.

(1). LFP:
As shown in Table 1, LFP exhibited an activation effect at shallow DoD (0–33%), likely due to SEI stabilization and electrode wetting. The mid-range (34–66%) showed moderate stress, while deep cycling (67–100%) produced higher mechanical and chemical strain. Overall, degradation was limited, confirming LFP's stable nature.

Table 1. Capacity change of LFP at different DoD windows

DoD window	Capacity change	Note
0–33%	+1.99% (1155 → 1178 mAh)	Activation
34–66%	−1.06% (1135 → 1123 mAh)	Moderate stress
67–100%	−1.75% (1085 → 1066 mAh)	Higher strain

(2). NCM:
As shown in Table 2, NCM showed mild degradation at shallow DoD (0–33%) and the best stability at mid-range (34–66%). However, deep cycling (67–100%) caused a sharp capacity drop (−2.48%), which aligns with high-voltage degradation mechanisms such as lattice oxygen release and electrolyte decomposition, confirming NCM's vulnerability under deep cycling.

Table 2. Capacity change of NCM at different DoD windows

DoD window	Capacity change	Note
0–33%	−0.75% (2385 → 2367 mAh)	Mild degradation
34–66%	−0.42% (2383 → 2373 mAh)	Best stability
67–100%	−2.48% (2379 → 2320 mAh)	Strong degradation

(3). LTO:
As shown in Table 3, only preliminary measurements have been completed for LTO: 5 cycles at 0–33%, 3 cycles at 34–66%, and 2 cycles at 67–100%. Current results show capacity fluctuates within a few percent without any clear trend, suggesting that LTO may be largely insensitive to cycling depth. This behavior is consistent with its high anode potential and resistance to lithium plating, as reported in literature, which indicates long-term degradation should remain low (<1%). Ongoing tests under controlled conditions will further verify these observations.

Table 3. Capacity change of LTO at different DoD windows (preliminary data)

DoD window	Test cycles completed	Capacity change (preliminary)	Note
0–33%	5	Fluctuation: +0.5% ~ +1.9%	Fluctuate
34–66%	3	Fluctuation: −1.3% ~ +0.2%	Fluctuate
67–100%	2	Fluctuation: −0.03% ~ −0.4%	Stable

CONCLUSIONS

LFP exhibited stable performance, showing activation at shallow DoD and moderate fade at deeper cycling. NCM maintained stability at mid-range but showed a sharp capacity drop (−2.48%) under deep discharge, highlighting its vulnerability to high-voltage stress. For both LFP and NCM, the influence of discharge depth on capacity and aging rate was evident. LTO testing is still in progress, with preliminary results showing fluctuations but no clear trend, which may indicate that LTO is largely insensitive to cycling depth—an aspect worth further investigation. Ongoing experiments will clarify whether any trend emerges. Overall, this study reveals the distinct degradation behaviors of different chemistries under varying discharge depths and provides a practical reference for battery selection and management strategies, supporting the balance between energy density, cycle life, and operating conditions.

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