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Capacity and Second-Life Potential of Lithium-Ion Cells Recovered from Disposable E-Cigarettes for Distributed Micro-Energy Storage

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Abstract- The widespread adoption of disposable electronic cigarettes has created a rapidly growing waste stream containing embedded lithium-ion batteries. In most cases, these batteries are discarded together with the device once the e-liquid reservoir is depleted, despite the possibility that the electrochemical lifetime of the cell significantly exceeds the functional lifetime of the product. This study investigates the residual capacity and reuse potential of lithium-ion cells recovered from discarded disposable e-cigarettes and evaluates their potential relevance for distributed micro-energy storage applications.

A total of 115 lithium-ion cells were collected from used devices and classified by their standardized cylindrical cell format (e.g., 13300, 14500). Following visual inspection and voltage screening, 102 cells were tested using a standardized constant-current charge-discharge protocol at 0.2C (C-rate) within the voltage range of 4.2-3.0 V. The experimental results show that 87.3% of the tested cells retained more than 85% of their nominal capacity, with an average remaining capacity of 89.8%. Only 3.9% of the tested cells exhibited a remaining capacity below 70%.

These results indicate that a considerable share of lithium-ion batteries discarded with disposable consumer electronics remain technically functional and could be repurposed in low-power applications such as IoT devices, educational platforms, and small distributed storage modules. The findings highlight the importance of systematic collection, classification and diagnostic approaches for small-format lithium-ion batteries in order to support circular economy principles and reduce unnecessary loss of critical battery materials.

Keywords - battery diagnostics, circular economy, nano distributed energy storage, state of health

I. INTRODUCTION

The rapid growth of disposable electronic cigarettes has introduced a new stream of lithium-ion battery waste. These devices are typically discarded once the e-liquid is depleted, although the embedded batteries often remain electrochemically functional. This mismatch between product lifetime and battery lifetime represents a significant inefficiency. This study investigates the residual capacity of such batteries and evaluates their potential for second-life applications in sustainable energy systems.

II. BACKGROUND AND RELATED WORK

A. Lithium-Ion Battery Degradation and State of Health

Lithium-ion batteries are widely used in portable electronics due to their high energy density, low self-discharge rate, and relatively long cycle life. However, their performance degrades over time due to a combination of electrochemical and mechanical processes [1-2]. The primary ageing mechanisms include the formation and growth of the solid electrolyte interphase layer on the anode, structural degradation of electrode materials, and loss of active lithium inventory. These processes lead to a gradual reduction in available capacity and an increase in internal resistance over the battery lifetime.

Battery condition is commonly described using the concept of State of Health (SoH), which is typically defined

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as the ratio of the current capacity to the nominal capacity of a new cell. In practical applications, capacity retention is one of the most widely used indicators of battery health, particularly in cases where detailed electrochemical diagnostics are not available. Previous studies [3-4] have shown that lithium-ion batteries can retain a significant portion of their initial capacity even after extended use, depending on operating conditions such as temperature, charge-discharge rates, and depth of discharge.

In small consumer devices, including disposable electronic cigarettes, batteries are often operated under relatively moderate conditions, which may limit the extent of degradation. As a result, a considerable fraction of such batteries may remain in good electrochemical condition at the time of disposal.

B. *Lithium-Ion Batteries in Disposable Consumer Electronics*

The rapid growth of disposable electronic devices has introduced a new category of lithium-ion battery waste. Disposable e-cigarettes represent a particularly relevant example, as they integrate a lithium-ion cell into a single-use product whose operational lifetime is determined primarily by the consumption of e-liquid rather than by battery degradation.

Typical batteries used in disposable e-cigarettes have nominal capacities in the range of approximately 300-1000 mA·h and operate at nominal voltages around 3.7 V. Despite their relatively small size, these cells are fully functional electrochemical energy storage devices, often comparable in performance to rechargeable cells used in other portable electronics.

Previous studies have shown that a large proportion of such batteries retain a high fraction of their nominal capacity at the time of disposal. This observation is further supported by the experimental results presented in this study. In that study, most tested cells exhibited capacity retention above 85%, suggesting that their electrochemical lifetime significantly exceeds the functional lifetime of the host device. This mismatch between product lifetime and battery lifetime represents a key inefficiency in current consumption patterns.

C. *Second-Life Batteries and Circular Economy*

The concept of second-life batteries has gained increasing attention as a strategy to improve resource efficiency and reduce environmental impact. Second-life applications involve repurposing batteries after their initial use, typically in less demanding applications where reduced performance is acceptable [5].

Most research on second-life batteries has focused on large-format lithium-ion batteries, particularly those used in electric vehicles. After their automotive use, such batteries are often repurposed for stationary energy storage applications, where requirements for power and performance are less stringent.

In contrast, relatively limited attention has been paid to the second-life potential of small-format lithium-ion batteries from consumer electronics. However, the increasing volume of such devices suggests that they may represent a non-negligible resource, particularly when considered in aggregate.

From a circular economy perspective, extending the useful life of batteries reduces the need for raw material extraction and decreases the environmental burden associated with battery production and disposal. Even small batteries may contribute to material efficiency if collected, tested and reused systematically [6].

D. *Distributed Nano-Energy Storage Systems*

The transition towards more decentralized energy systems has increased interest in distributed energy storage, including small-scale and modular storage solutions. While most distributed storage systems are based on relatively large battery units, there is growing interest in nano-scale storage for applications such as IoT devices, sensor networks, and low-power autonomous systems.

Although individual small-format batteries provide limited energy, large numbers of such cells could theoretically be aggregated into distributed storage systems. This concept is analogous to virtual power plants, where many small resources are combined to provide system-level functionality.

In this context, recovered lithium-ion cells from disposable devices could represent a potential resource for experimental or niche applications in distributed micro-energy storage. However, practical implementation requires reliable methods for battery screening, classification and safety assurance [7].

E. *Research Gap*

While lithium-ion battery degradation and second-life applications have been extensively studied in the context of large-scale energy storage, there is a lack of experimental data on the condition and reuse potential of small-format batteries recovered from disposable consumer electronics [8].

This study addresses this gap by providing experimental data on the residual capacity of lithium-ion cells extracted from disposable e-cigarettes and evaluating their potential role in second-life applications within sustainable energy systems.

III. MATERIALS AND METHODS

A. *Sample Collection and Preparation*

The experimental dataset consisted of 115 lithium-ion cells recovered from discarded disposable electronic cigarettes. The devices were collected through voluntary contributions during the period September to December 2024.

Only cells that met the following criteria were included in the sample:

- clearly identifiable battery format markings,
- intact safety membranes,

- no visible mechanical deformation, corrosion, or leakage.

Cells exhibiting physical damage or safety risks were excluded from the study.

The disassembly of e-cigarette devices was performed manually using insulated tools to prevent short circuits. Each battery was carefully removed from the device housing and labelled with a unique identification number ranging from 1 to 115. The entire disassembly process was conducted in accordance with standard electronic waste handling safety procedures, including the use of protective eyewear and non-conductive work surfaces.

The distribution of battery formats in the collected sample is shown in Fig. 1.

Fig. 1. Collected samples.

B. Battery Types

The collected sample included several commonly used lithium-ion cell formats: (Fig. 19

- 13300 format - 51 cells (44.3%),
- 14500 format - 20 cells (17.4%),
- 13350 format - 20 cells (17.4%),
- other formats - 24 cells (20.9%).

The two most common formats (13300 and 14500) accounted for 61.7% of the total sample, which is consistent with typical disposable e-cigarette device configurations.

C. Experimental Setup

Battery capacity measurements were performed using a 150 W DC electronic load-based battery tester, capable of controlling discharge current and cutoff voltage while recording the discharge profile and total capacity in milliampere-hours (mA·h).

All experiments were conducted under controlled laboratory conditions:

- temperature: 20 ± 2 °C,
- relative humidity: 40-60%.

These conditions were maintained to ensure measurement consistency, as battery performance is known to be temperature-dependent.

The experimental setup is illustrated in Fig. 2.

D. Testing Procedure

The testing protocol consisted of four main stages.

1) Initial Inspection and Voltage Screening

Each cell was visually inspected, and its initial voltage was measured using a digital multimeter. Cells with an initial voltage below 3.2 V were excluded from further testing due to safety concerns related to deep discharge and potential instability during recharging.

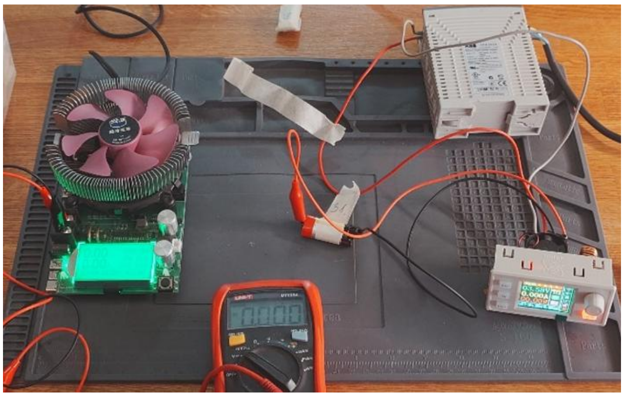

Fig. 2. Experimental setup.

A total of 13 cells were excluded at this stage and classified as untested.

2) Charging

The remaining 102 cells were charged using a constant current-constant voltage (CC-CV) method. Charging was performed using an XY6509S DC-DC converter powered by an ABB CP-E 24/2.5 power supply.

The charging current was set to 0.2C, which is a standard moderate-rate charging condition for lithium-ion cells. Here, 1C (C-rate) corresponds to a current equal to the nominal capacity of the cell (in A), resulting in a full charge or discharge in one hour. At a discharge rate of 0.2C, the charge process lasted approximately five hours, assuming nominal capacity. The maximum charging voltage was 4.2 V.

3) Discharging and Capacity Measurement

After charging, the cells were discharged using an ATORCH 150 W electronic load tester under controlled conditions.

Discharge parameters:

- discharge current: 0.2C (C-rate),
- voltage range: 4.2 V to 3.0 V.

During discharge, the tester recorded the voltage profile and calculated the total delivered capacity in milliampere-hours (mA·h).

4) Capacity Retention and Classification

The remaining capacity of each cell was calculated by comparing the measured capacity to the nominal capacity specified for the battery.

Capacity retention was expressed as:

$$Capacity\ retention = \frac{C_{measured}}{C_{no\min al}} \cdot 100$$

Based on the calculated values, the cells were classified into five categories:

- Very good / new: 95-100%
- Good: 85-94%
- Moderate: 70-84%
- Poor: 50-69%
- Failed: <50%

All measurement results were recorded and stored in a dataset for further statistical analysis.

IV. Results and discussion

Out of the total 115 collected lithium-ion cells, 102 cells (88.7%) were successfully tested, while 13 cells (11.3%) were excluded due to low initial voltage (below 3.2 V). These excluded cells were classified as untested for safety reasons. The fact that only 11.3% of collected cells were excluded due to low voltage further supports the observation that most batteries are discarded before reaching end-of-life conditions.

The tested cells exhibited a consistently high level of capacity retention. The majority of cells-87.3% (89 cells)-retained at least 85% of their nominal capacity. Only 8.8% (9 cells) showed moderate capacity (70-84%), and 3.9% (4 cells) were classified as poor (50-69%). No cells with capacity below 50% were observed. The average remaining capacity was 89.8%, with a median of 91.4%, indicating that most discarded cells remain in good electrochemical condition.

A comparison of battery formats revealed relatively consistent performance across different cell types. The most common format, 13300, showed an average capacity retention of 90.6%, with 89.1% of cells classified as good. The 14500-format demonstrated similarly stable performance, with 90% of cells in good condition and an average capacity of 89.1%. The 13350-format exhibited slightly greater variability, with 77.8% of cells classified as good and an average capacity of 86.8%.

Other battery formats also showed generally good performance, with no cells falling into the lowest capacity category. Across all formats, the average capacity retention ranged between 86.8% and 90.6%, confirming that most batteries are discarded while still retaining a substantial portion of their usable capacity.

These results highlight a mismatch between the functional lifetime of disposable e-cigarettes and the electrochemical lifetime of their batteries. While the devices are discarded after the e-liquid is depleted, the batteries often remain in good condition. This suggests significant potential for second-life applications, particularly in low-power systems such as IoT devices or small-scale distributed energy storage.

From a sustainability perspective, the premature disposal of functional lithium-ion batteries represents a loss of valuable materials. Improved collection, testing, and reuse strategies could support more efficient resource utilization and contribute to circular economy principles.

V. Conclusions

This study evaluated the condition and reuse potential of lithium-ion cells recovered from disposable e-cigarettes. Out of 115 collected cells, 102 were successfully tested, and the results showed consistently high-capacity retention. A total of 87.3% of tested cells retained more than 85% of their nominal capacity, with an average remaining capacity of 89.8%, indicating that most cells remain in good electrochemical condition at the time of disposal.

The results confirm a clear mismatch between the functional lifetime of disposable devices and the electrochemical lifetime of their batteries. Despite being discarded, the majority of cells still retain a substantial fraction of their usable capacity.

The findings suggest that these cells have potential for second-life applications, particularly in low-power and distributed micro-energy systems. While individual cells provide limited energy, their large-scale aggregation may represent a novel resource for experimental and niche energy applications.

From a sustainability perspective, the premature disposal of functional lithium-ion batteries represents a loss of valuable materials. Improved collection, classification, and reuse strategies could support more efficient resource utilization and contribute to circular economy principles.

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