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Performance Evaluation of a Battery Pack Assembled from Used Li-Ion Cells of Electronic Vape for Small-Scale Applications

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ABSTRACT

Lithium-ion cells are well known for their low mass and high energy density. However, improper disposal of Li-ion cells from disposable vape devices contributes significantly to battery waste, even though many of these cells still retain substantial usable capacity. This study explores the second-life potential of such cells by assembling a 3P4S battery pack using reclaimed 13300-type Li-ion cells for low-power applications. Three configurations were tested: without a Battery Management System (BMS), and with two passive BMS units (BMS-40A-4S-E and HXYP-C47-MA18). The repurposed pack exhibited a nominal voltage of 14.8 V and a rated capacity of 1.2 Ah. Constant current discharge at 0.6 A showed high remaining capacity across all setups, with measured capacities of 1.199 Ah (99.9% SOH) without BMS, 1.255 Ah (100% SOH) with BMS-40A-4S-E, and 1.241 Ah (100% SOH) with HXYP-C47-MA18. Thermal testing revealed safe operating temperatures, peaking at 35 °C during 1.5C discharge. All configurations reached full charge within 67–69 minutes and managed to power a 28 W load for up to 40 minutes. Voltage uniformity, low thermal rise, and stable discharge curves confirm the feasibility of repurposing vape cells into reliable battery packs. While all setups demonstrated acceptable short-term performance, the inclusion of a proper BMS remains essential to ensure safety, protect against overcharge/discharge, and prolong pack lifespan for long-term usage.

Keywords: Battery repurposing, Energy storage, Lithium-ion batteries, Second-life applications, Sustainability.

1. INTRODUCTION

Lithium-ion (Li-ion) batteries have become the dominant energy storage solution across a wide range of applications, including consumer electronics, electric vehicles, and renewable energy systems [1], [2], [3]. Their widespread adoption is attributed to key advantages such as high energy density, long cycle life, and low self-discharge rates, enabled by their graphite anodes and lithium-based cathodes [2], [4]. However, despite their technical benefits, lithium-ion batteries raise a critical concern about environmental sustainability due to their high production costs and improper end-of-life disposal practices [5], [6]. A growing subset of this issue involves disposable

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*Corresponding author: mohd_abdl@iium.edu.my vape pods, which are frequently discarded after short-term use. Notably, many embedded cells in these devices retain up to 80% to 95% of their original capacity, offering a valuable overlooked opportunity for reuse in low-power applications [7].

While battery lifecycle research and technology have matured, current efforts are largely focused on repurposing large batteries from electric vehicles for stationary energy storage [8], [9], [10], [11], [12], [13]. In contrast, smaller lithium-ion cells from consumer electronics remain underexplored, despite their substantial contribution to battery waste streams [14]. These cells are often excluded from recycling or reuse programs due to challenges such as inconsistent quality, collection difficulties, and perceived safety risks [8]. Thus, this issue motivates the exploration of more practical and sustainable second-life strategies for these underutilized cells, specifically by repurposing them into functional battery packs and systematically evaluating their performance, in terms of capacity retention, voltage stability, and thermal behaviour.

It is noted that effective reuse requires careful design of battery configurations and their embedded systems to ensure performance and safety. Typically, cells are connected in series to increase voltage and in parallel to increase capacity, or both, depending on the application requirements [7], [8]. A critical component in any repurposed battery pack is the Battery Management System (BMS), which safeguards against overcharging, over-discharging, and thermal hazards. While active BMS solutions offer advanced balancing and monitoring capabilities, they are often complex and costly, making them less suitable for low-budget or small-scale applications. In contrast, passive BMS systems provide a simpler and more cost-effective solution, albeit with basic protection and balancing features [15], [16], [17]. This raises an important question in second-life battery research: How significant is the BMS's role in shaping overall pack performance in repurposing scenarios for this specific application?

In addition, ensuring the safety and reliability of second-life lithium-ion battery packs remains a key challenge, particularly when repurposed cells are used in new configurations without comprehensive manufacturer data. Variations in cell state of health and degradation patterns can affect performance and pose safety risks if not properly assessed. Therefore, a thorough evaluation of critical parameters such as capacity, voltage stability, and thermal behaviour is essential to validate the feasibility of reused cells in practical applications. Previous studies have employed various diagnostic methods to assess these parameters. Capacity is commonly evaluated using constant-current discharge tests, which provide a straightforward, most effective way to estimate the remaining usable charge [18]. Voltage stability can be assessed using techniques such as constant-current voltage monitoring or electrochemical impedance spectroscopy, with the former being more accessible for small-scale testing due to its simplicity [19]. Thermal behaviour is typically monitored using thermocouples, calorimetry, or thermal simulations. Among these, thermocouples offer a practical, real-time method suitable for resource-constrained projects, whereas more advanced techniques require specialized equipment and computational resources [20].

Based on the review, this work adopts a balanced, practical evaluation approach, using constant-current discharge for capacity measurement, voltage monitoring for stability assessment, and thermocouples for real-time temperature tracking. These methods are selected for their affordability, simplicity, and effectiveness, aligning to assessing second-life battery pack performance under realistic small-scale reuse conditions.

2. MATERIAL AND METHODS

This study was conducted to develop a functional battery pack using Li-ion cells and assess its performance for small-scale electronic applications. The process involved repurposing 13,300-type cells from disposable vape pods, assembling them into a 3P4S configuration and integrating passive safety and charging systems. The completed pack was then subjected to a series of tests to evaluate its electrical and thermal performance under various controlled conditions.

2.1 Battery Repurposing and Construction

Used 13,300 Li-ion cells were extracted from disposable vape pods and tested to ensure their suitability for reuse. Each cell was visually inspected for signs of damage, such as swelling, corrosion, or leakage. Cells with no physical defects and with voltages above 2.5 V were retained for further use. This initial screening was essential to ensure safe operation and consistency among the cells selected for repurposing.

The battery pack was constructed using a 3P4S configuration. Three cells were connected in parallel to increase total capacity, and four of these parallel groups were connected in series to increase voltage. Each cell had a nominal capacity of 400 mAh, resulting in an overall capacity of approximately 1.2 Ah and a nominal voltage of 14.8 V. Since the cells were already fitted with nickel strips, copper wires were soldered directly to these strips to create electrical connections between groups. Electrical insulation was applied using Kapton tape to reduce the risk of short circuits during handling and testing. Figure 1 shows the assembled battery pack configuration that will be tested in this work.

Figure 1: Assembled battery pack configuration.

In this work, two BMS modules, namely the BMS-40A-4S-E and HXYP-C47-MA18, were selected for comparison. Each BMS was integrated separately into the same battery pack to evaluate performance and safety under different protection schemes. A configuration without a BMS was also tested as a baseline to observe the battery pack's uncontrolled behaviour. The connection layout, including the BMS wiring and terminal outputs, is illustrated in Figure 2.

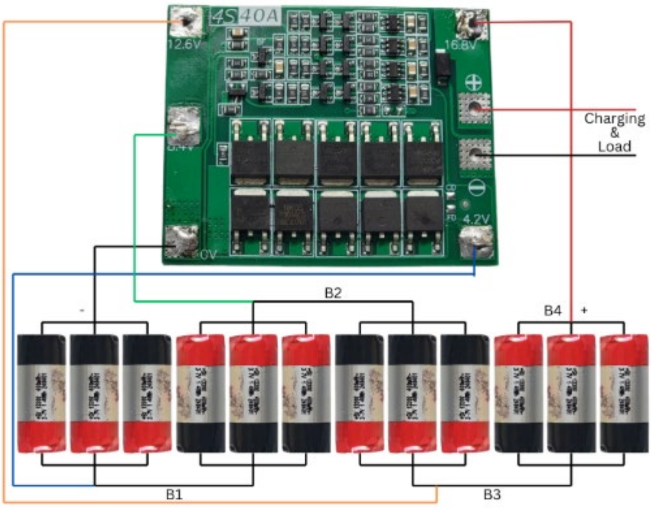


Figure 2: Connection Between Batteries and BMS-40A-4S-E.

Charging was carried out using an XL4015 buck converter configured in constant current and constant voltage (CC-CV) mode. The output was set to 16.8 V with a charging current of 1.2 A, which corresponds to a 1C charging rate for the battery pack. The charger used is shown in Figure 3.

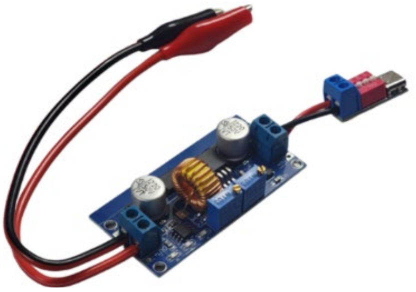


Figure 3: XL4015 Buck converter module with PD trigger.

2.2 Performance Evaluation and Testing

After the battery pack was constructed, a series of tests was conducted to evaluate its suitability for low-power applications. These tests were designed to assess three key parameters: capacity, voltage stability, and thermal performance. Additional assessments were also conducted to observe charging time and duration under load. All tests were performed on the same 3P4S battery pack, using three different setups: without a BMS, with BMS-40A-4S-E, and with HXYP-C47-MA18. This approach enabled performance comparison under varying levels of protection and control.

Capacity testing was performed using a constant current discharge method at a rate of 0.6 A, which corresponds to 0.5C of the pack's rated capacity. The XY-FZ35 electronic load, as shown in Figure 4, was used to discharge the pack from full charge down to the cut-off voltage. The total discharge time was recorded and used to calculate the actual capacity and estimate the remaining state of health (SOH) of the reused cells.

Figure 4: XY-FZ35 Electronic load.

Voltage stability was monitored throughout the discharge test using the voltage-time curve generated by the XY-FZ35. Irregular voltage drops, imbalance among cell groups, or early voltage dips were observed as indicators of internal resistance or degraded cells. The comparison across the three setups highlighted the impact of passive BMS on voltage control and stability during operation. Figure 5 shows an example of a voltage-time curve.

Thermal performance was assessed by measuring the surface temperature of the battery pack during both charging and discharging cycles. A UNI-T UT890C thermocouple was used to record temperature at multiple points on the pack's surface. Tests were conducted at discharge rates of 0.6 A, 1.2 A, and 1.8 A. Charging was done at 1.2 A. The temperatures were recorded to identify any thermal hotspots and evaluate the pack's ability to dissipate heat safely. Figure 6 shows the thermal monitoring setup.

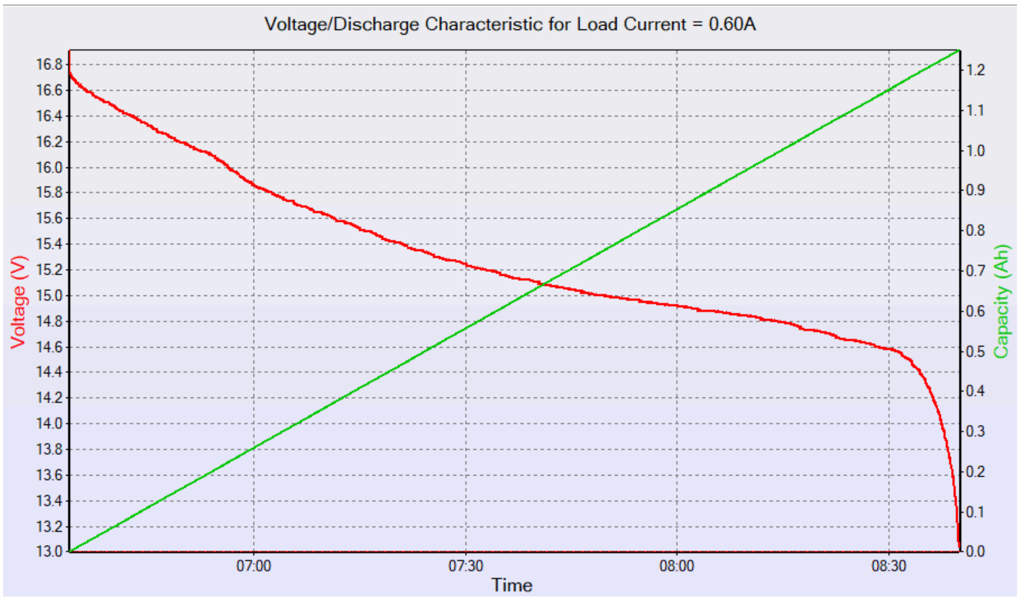


Figure 5: Voltage-Time curve example.

Figure 6: Thermal performance test setup.

Charging time testing was conducted by measuring the time required to charge the battery from its cut-off voltage to 16.8 V at 1.2 A using the CC-CV method. A stopwatch was used to measure the duration for each setup. This test allowed observation of how BMS integration affects charging efficiency and protection response.

Lastly, the duration under load was tested by connecting a 28 W incandescent lamp through a DC-DC converter set to output 12 V. The battery pack was fully charged before each trial, and the duration under load was recorded. Figure 7 shows the experimental load setup.

Figure 7: Duration under load test.

3. RESULTS AND DISCUSSION

Initially, the open-loop voltage of each parallel group in the battery pack setup is measured and compared with the theoretical value. The groups were connected in series to form the 4S configuration, and voltages were measured between the negative terminal and the intermediate terminals of Groups 1, 2, 3, and 4, including the positive terminal. Table 1 shows that the measured voltage is uniform, indicating that no single group is overburdened during operation. The repurposed 3P4S lithium-ion battery pack exhibited consistent voltages across all parallel groups after an overnight rest. The slight variations from the nominal 4.20 V indicate well-balanced cells, with negligible self-discharge or imbalance.

Table 1: Parallel group voltages after overnight settling.

Group	Measured voltage (V)	Designed voltage (V)
Group 1	4.18	4.20
Group 2	4.16	4.20
Group 3	4.19	4.20
Group 4	4.17	4.20

The tap voltage measurements between the main negative terminal and each interconnection point along the series showed very close alignment with theoretical values. This confirms the correct configuration of the 3P4S setup and indicates minimal voltage drop across connections, as shown in Table 2 (refer to Figure 2 for the circuit configuration).

Table 2: Voltages between the negative terminal and intermediate terminals.

Group	Measured voltage (V)	Designed voltage (V)
B1	4.18	4.20
B2	8.34	8.40
B3	12.53	12.60
B4	16.70	16.80

3.1 Capacity Retention and SOH

The constant-current discharge tests at 1.2 A revealed that all three battery pack configurations exhibited high SOH, with all packs achieving over 99% SOH. The slightly higher discharge capacities observed in BMS-equipped packs suggest that their cut-off voltages were lower, allowing a bit more usable energy to be extracted without compromising safety. These results are summarised in Table 3.

Table 3: Capacity and SOH results for battery pack.

Setup	Run 1 (Ah)	Run 2 (Ah)	Run 3 (Ah)	Average capacity (Ah)	SOH (%)
No BMS	1.222	1.186	1.190	1.199	99.9
BMS-40A-4S-E	1.264	1.257	1.245	1.255	100
HXYP-C47-MA18	1.240	1.234	1.250	1.241	100

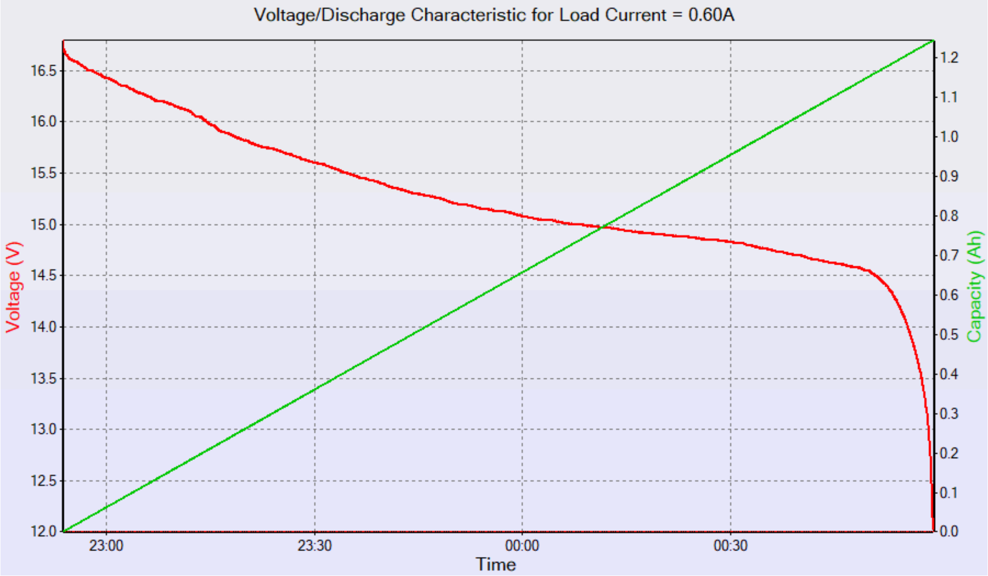
In all three configurations, including those with and without a BMS, SOH exceeded 99%, with BMS-equipped setups slightly exceeding the nominal rated capacity. However, values exceeding the limit are rounded to 100% for clarity of comparison. The no-BMS configuration averaged 1.199 Ah (99.9% SOH), while BMS-40A-4S-E and HXYP-C47-MA18 yielded 1.255 Ah (100 %) and 1.241 Ah (100 %), respectively. The higher capacity readings in BMS-equipped setups suggest better depth-of-discharge management, allowing more usable energy without reaching unsafe voltage levels. This highlights the capability of well-selected passive BMS units to marginally enhance energy extraction while providing added protection.

3.2 Voltage stability

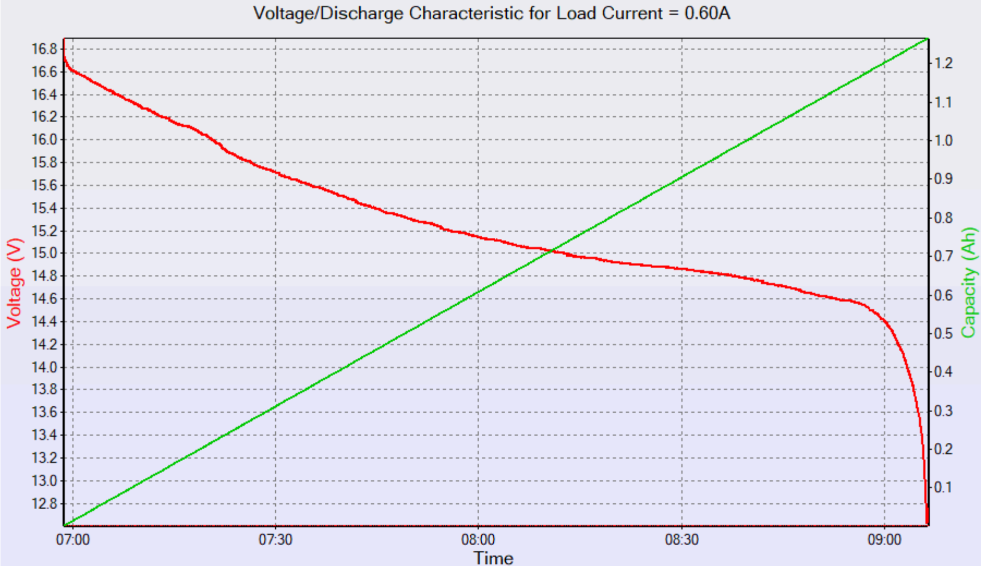
The discharge voltage–time curves exhibit stable, predictable behaviour across all tests. All three configurations demonstrated smooth and gradual voltage decline, indicating minimal internal resistance and good cell consistency. These profiles are shown in Figure 8 for those 3 setups, and the detailed results are tabulated in Table 4.

Table 4: Discharge characteristics for three setups.

Setup	Initial Voltage (V)	Steady Decline Duration (h)	Total Duration (h)	Cut-Off Voltage (V)
No BMS	16.70	1.9	2.06	12.0
BMS-40A-4S-E	16.70	1.9	2.1	12.6
HXYP-C47-MA18	16.70	1.9	2.08	13.0

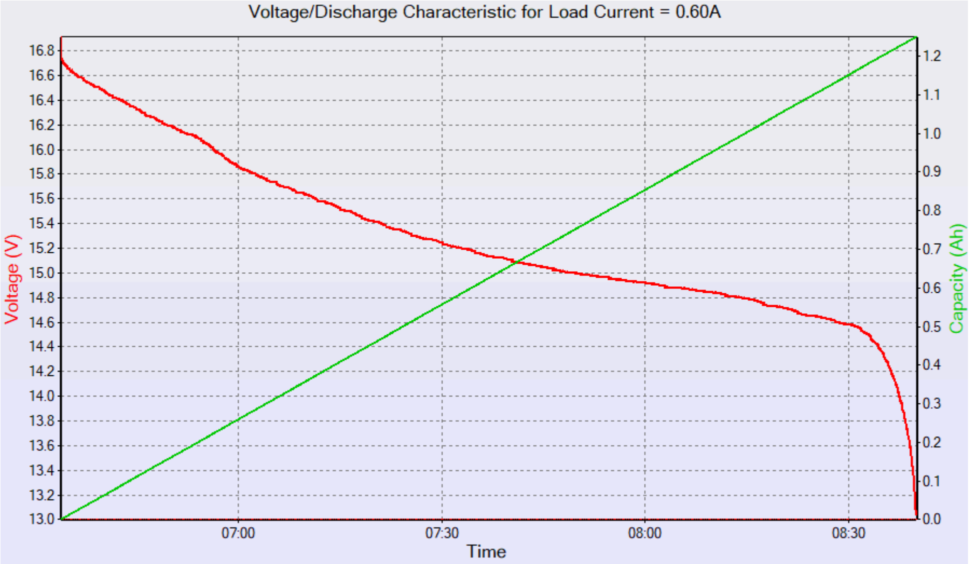


(a)



(b)

Figure 8: Time-Voltage Curves for battery with (a) No BMS, (b) BMS-40A-4S-E, and (c) HXYP-C47-MA18.



(c)

Figure 9: Continued.

Based on the results, voltage-time profiles across all setups showed smooth, gradual declines, with minimal fluctuations or voltage sags during discharge. Tap voltage measurements closely aligned with theoretical expectations, indicating uniformity and balance among series-connected groups. These results confirm the consistency and acceptable internal resistance of the repurposed cells. Voltage balancing observed after an overnight rest further supports the health of the selected cells and the effectiveness of the 3P4S configuration.

3.3 Thermal Performance

The thermal measurements during charging showed a modest increase in temperature, with the highest surface temperature reaching only 29 °C (Table 5). This suggests low heat generation and high charging efficiency. During discharging, even at elevated current loads of up to 1.5 times the rated capacity (1.5 C), the temperature rise remained within safe limits, peaking at 35 °C. These outcomes indicate good thermal stability, especially given that the cells are second-use, as summarised in Table 6.

Table 5: Maximum temperatures during charging at 1.2A.

Setup	Maximum Temperature (°C)
No BMS	29
BMS-40A-4S-E	29
HXYP-C47-MA18	29

Table 6: Maximum temperature during discharge at different current rates.

Setup	0.5C (0.6 A) (°C)	1C (1.2 A) (°C)	1.5C (1.8 A) (°C)
No BMS	29	31	35
BMS-40A-4S-E	29	31	35
HXYP-C47-MA18	29	31	35

The low thermal rise observed during both charging (up to 29 °C) and 1.5C discharging (up to 35 °C) can be attributed to several key factors: the selection of healthy cells with low internal resistance, the 3P4S configuration that distributes current across parallel cells, and the use of moderate charge/discharge rates within safe limits. Additionally, the short duration of each test cycle limited cumulative heat buildup, while effective pack assembly and thermal dissipation helped prevent hotspots. The exclusion of degraded or damaged cells further contributed to uniform temperature behaviour, confirming that repurposed vape cells can operate safely with minimal thermal risk under properly controlled small-scale applications.

3.4 Charging and Discharging Duration

Charging time tests using the XL4015 buck converter showed that all battery packs reached full charge within a consistent range of 67 to 69 minutes. This consistency demonstrates the restored cells' ability to accept charge efficiently and the converter's compatibility with the repurposed configuration, as shown in Table 6.

Table 6: Charging times from cut-off to 16.8 V.

Setup	Charging Time (minutes)
No BMS	67
BMS-40A-4S-E	69
HXYP-C47-MA18	68

In real use, the battery packs were able to power a 28 W incandescent bulb continuously for more than 38 minutes. The slightly longer runtimes observed with BMS-equipped packs again confirm more complete energy utilization, thanks to better-managed discharge endpoints. These results are shown in Table 7.

Table 7: Duration under load with a 28 W incandescent lamp.

Setup	Duration (minutes)
No BMS	38
BMS-40A-4S-E	40
HXYP-C47-MA18	39

Overall, the repurposed 3P4S battery pack built from used 13,300 lithium-ion cells demonstrates consistent voltage balancing, high energy retention, efficient charge and discharge behaviour, minimal thermal risk, and reliable performance under both simulated and real-world loads. These findings support the feasibility of reusing discarded vape batteries for low-power energy storage applications.

The consistent charging time of 67–69 minutes across all configurations indicates that passive BMS integration does not significantly affect charging efficiency, as these systems primarily act as protective cutoffs rather than active controllers during the constant-current/constant-voltage (CC-CV) charging process. Since the charging current was set to 1.2 A, aligned with the pack's 1C rate, and all cells were healthy and balanced, the packs charged efficiently regardless of the BMS's presence. In discharge testing, the slightly longer runtimes observed with BMS-equipped setups (up to 40 minutes) suggest that the BMS allowed the pack to safely discharge closer to the lower voltage limit, thereby extracting slightly more usable energy. This highlights the BMS's role in optimizing energy utilization without compromising cell safety, particularly during the end-of-discharge phase. This function becomes increasingly significant given that field observations indicate SOH degradation progresses 15–20% faster under real-world operating conditions compared to controlled laboratory environments [12].

4. CONCLUSION

In summary, this study confirms that properly screened and integrated lithium-ion cells reclaimed from disposable vape devices can deliver stable and consistent performance in small-scale energy applications. The repurposed 3P4S battery pack, assembled using second-life 13,300 cells, demonstrated reliable operation across all evaluations, including consistent voltage balancing, efficient energy discharge under both electronic load and real-use conditions, and safe thermal behaviour throughout charging and discharging cycles. The battery pack also demonstrated strong performance in terms of voltage stability, capacity retention, and runtime. While the presence of a passive BMS did not significantly enhance core performance metrics, it remains essential for ensuring long-term safety and protecting against overcharge, overdischarge, and thermal risks. These findings suggest that discarded vape batteries can be feasibly reused in low-power applications such as portable lighting, IoT devices, and educational tools, supporting both environmental sustainability and the principles of a circular economy. Given the growing volume of vape-related battery waste, systematic repurposing offers a practical, cost-effective solution with tangible ecological and economic benefits.

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