Behavioural Tests for Lithium - Ion Batteries and Selection Procedures of Secondary Life Batteries

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Abstract. - Rapid growth in electric vehicle sector has resulted in a substantial increase in the manufacturing and usage of lithium-ion batteries which create challenges that are related to battery degradation and end-of-life management. During vehicle operation, there is a fade and increased internal resistance in EVs, and when state of health (SoH) reduces to approximately 70–80%, they will be no longer suitable for traction applications despite retaining significant residual capacity. This remaining one can be effectively utilized for low-power and stationary applications through appropriate testing, grading and reconfiguration. Therefore, the secondary-life deployment of the retired EV batteries offers a technically viable and environmentally sustainable approach to extend battery life, reduce waste, and improve overall resource utilization.

Keywords: Secondary Life Batteries (SLBs), Electric Vehicles (EVs), State of Health (SoH).

1. INTRODUCTION

Electric Vehicles are considered a promising option to conventional internal combustion engine vehicles because of their high energy efficiency [3]. There is an increase in EV adoption worldwide due to its rising fuel costs, strict emission regulations and government incentives. The International Energy Agency reports a significant growth in global EV sales, and it is supported by advancements in lithium-ion battery technology and charging infrastructure.

In India, EV growth is mainly seen in two-wheelers and electric public transport systems, and it is encouraged by government initiatives such as FAME and state-level subsidies. However, there are challenges like high initial cost, limited charging stations and battery recycling concerns which remain. Recent research highlights that improvements in fast-charging systems, battery management and recycling techniques can reduce these limitations and support large-scale EV adoption. Hence, EVs are expected to play a vital role to achieve sustainable and eco-friendly transportation in the future.

Types of batteries used in EV’s:

Electric vehicles primarily use lithium-ion batteries due to their higher energy density, longer lifespan and good efficiency when compared with old ones. Within lithium-ion batteries, different chemistries are used based on various EV requirements such as safety, cost, driving range and performance. The most used lithium-ion chemistries in EVs are Lithium Iron Phosphate (LFP), Lithium Nickel Manganese Cobalt Oxide (NMC) and Lithium Nickel Cobalt Aluminum Oxide (NCA). Each of these has distinct characteristics that influence vehicle range, durability and safety.

Lithium Iron Phosphate

LFP batteries have a lifespan of 8–12 years and can withstand 3000–5000 charge cycles, offering moderate driving ranges of about 250–400 km per charge, and have excellent thermal stability and high safety that make them resistant to overheating and ideal for EVs.

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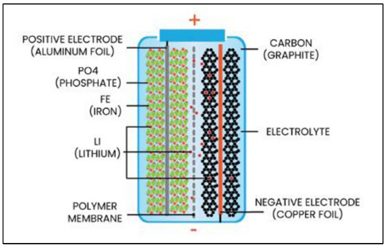


Fig. 1. Lithium Iron Phosphate Battery

Lithium Nickel Manganese Cobalt Oxide
NMC batteries generally last 8–10 years and can withstand 1500-3000 charge cycles, offering a higher driving range of about 400-600 km, approximately balancing energy density, performance and cost, and this makes them widely used in passenger Evs.

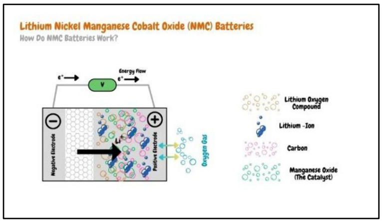


Fig. 2. Lithium Nickel Manganese Cobalt Oxide Battery

Lithium Nickel Cobalt Aluminum
NCA batteries provide the highest energy density among them, and they provide longer ranges of 500–700 km, but they have a slightly shorter lifespan of 7–9 years and require advanced battery management systems because of lower thermal stability. Comparatively, LFP batteries offer a longer lifespan and higher safety than NMC and NCA with a lifespan of 8–12 years and excellent thermal stability. They are more cost-effective, cobalt-free, and environmentally friendly. Hence, LFP is preferred for durability, safety, and daily use EVs.

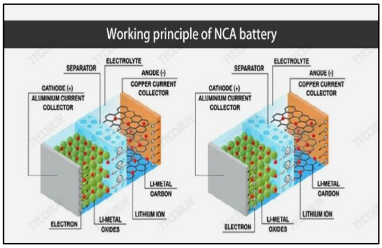


Fig. 3. Lithium Nickel Cobalt Aluminium Battery

2. LITERATURE SURVEY

IEEE Recommended Practice for Energy Storage System Design using Second-Life Electric Vehicle Batteries by the IEEE Power and Energy Society has been reviewed. The Energy Storage and Battery Committee developed this paper under the IEEE Std 2993-2025. Selection criteria along with the test procedures for the repurpose of second-life batteries [2] were extracted from this paper.

3. SCOPE OF PAPER

This paper has two main phases. The first phase consists of a chain of tests, examinations, procedures, and their results for used lithium-ion cells. Although those cells were not degraded to the level of secondary life, to learn the behaviours and characteristics of those cells, they were exposed to basic tests. The second phase consists of a basic flowchart of how the selection of cells takes place and the selection criteria, along with the test procedures extracted from the standards for the used EV cells that can be utilized for packing secondary life batteries.

4. METHODOLOGY

4.1 IR Grading

14 lithium-ion cells were collected. They were already discharged to a particular level. Grading was done based on internal resistance. Cells with internal resistance less than or equal to 50 milliohms were categorized under grade A, and cells exceeding the resistance value of 50 milliohms were categorized under grade B. The cells were numbered from 1 to 14. Cells 1 to 10 fell under grade A, and cells 11 to 14 fell under grade B. Internal resistance of each cell is measured using the RC3563 battery tester. It is a type of battery internal resistance tester. It is designed to measure the internal resistance and voltage of various types of batteries, such as lithium-ion, lead acid, and NiMH batteries.

Fig. 4. RC3563 Battery Tester

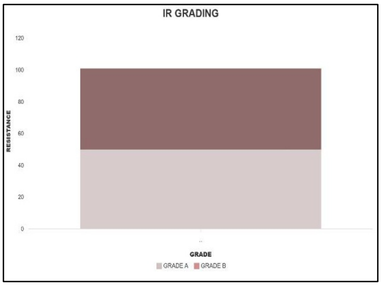


Fig. 5. IR Grading Range

4.2 Charging and Discharging Cycles

Four cycles of charging and discharging took place with the help of SEMCO INFRATECH SI-BCDS 5V-10A. This is a battery charge-discharge system used for testing batteries. Cylindrical Lithium Battery Testing [6]. A bracket is an accessory that holds cylindrical batteries for testing. The bracket has screws to adjust the probe height. Constant voltage and constant current charging are performed. Then, constant current discharge is performed [7]. These four cycles are performed to degrade them much more to learn about their performances.

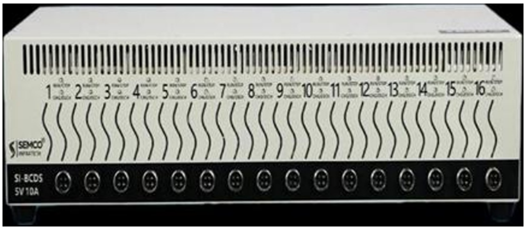


Fig. 6. SEMCO INFRATECH SI-BCDS 5V-10A

4.3 Thermal Test

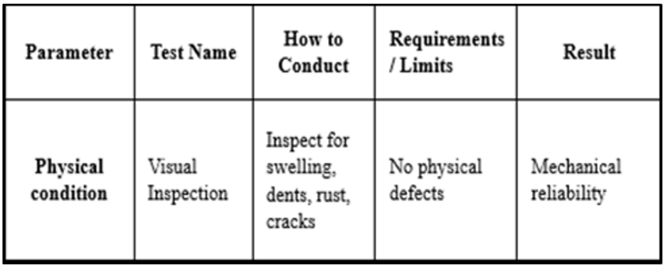
Thermal testing is a laboratory method that is used to evaluate the safety and performance of secondary life batteries [5]. Since SLBs are reused after their initial electric vehicle operation [4], to monitor their temperature and behavior that helps identify degradation, internal resistance variation, and potential thermal risks.

FLIR TG165-X thermal camera helped us capture and compare values. A FLIR thermal imaging camera with `FLIR analysis software was used for non-contact thermal measurement and that camera captured infrared radiation from the battery surface and generated thermal image which allows real-time visualization of temperature distribution across individual cells. Multiple spot points were selected to measure localized temperatures accurately.

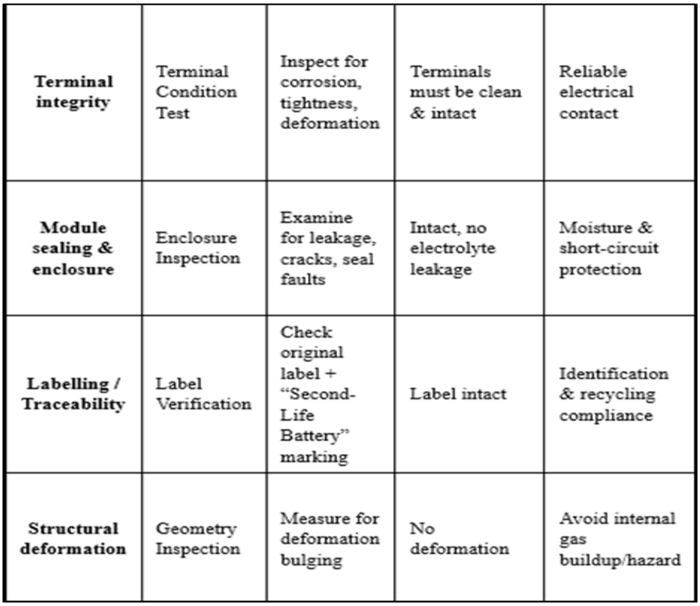
Fig. 7. FLIR TG165-X Thermal Camera

5. SELECTION CRITERIA

5.1 Mechanical parameters[1]



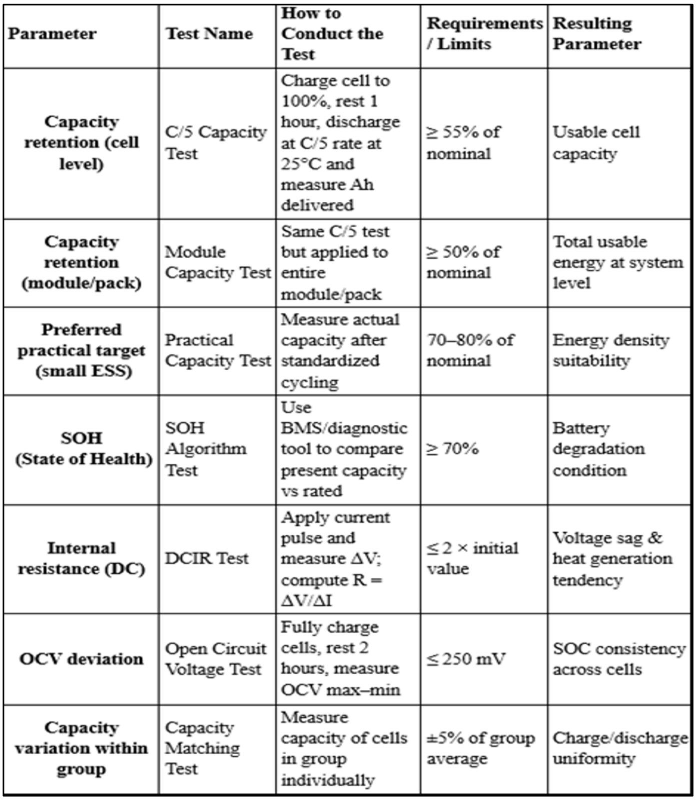
Parameter	Test Name	How to Conduct	Requirements / Limits	Result
Physical condition	Visual Inspection	Inspect for swelling, dents, rust, cracks	No physical defects	Mechanical reliability



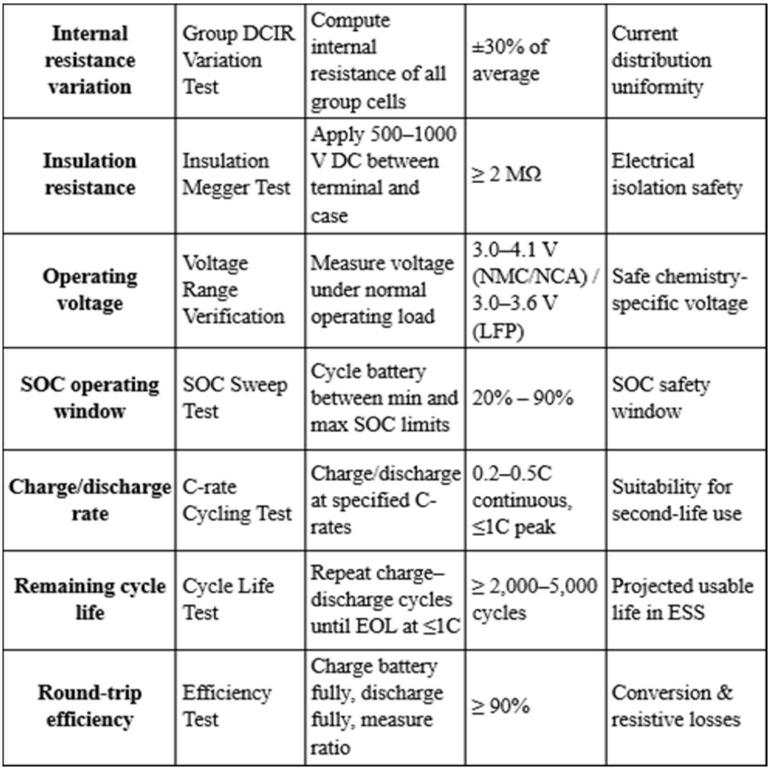
Terminal integrity	Terminal Condition Test	Inspect for corrosion, tightness, deformation	Terminals must be clean & intact	Reliable electrical contact
Module sealing & enclosure	Enclosure Inspection	Examine for leakage, cracks, seal faults	Intact, no electrolyte leakage	Moisture & short-circuit protection
Labelling / Traceability	Label Verification	Check original label + "Second-Life Battery" marking	Label intact	Identification & recycling compliance
Structural deformation	Geometry Inspection	Measure for deformation bulging	No deformation	Avoid internal gas buildup/hazard

Fig. 8. Mechanical Parameter

***Electrical Parameters*[1]**



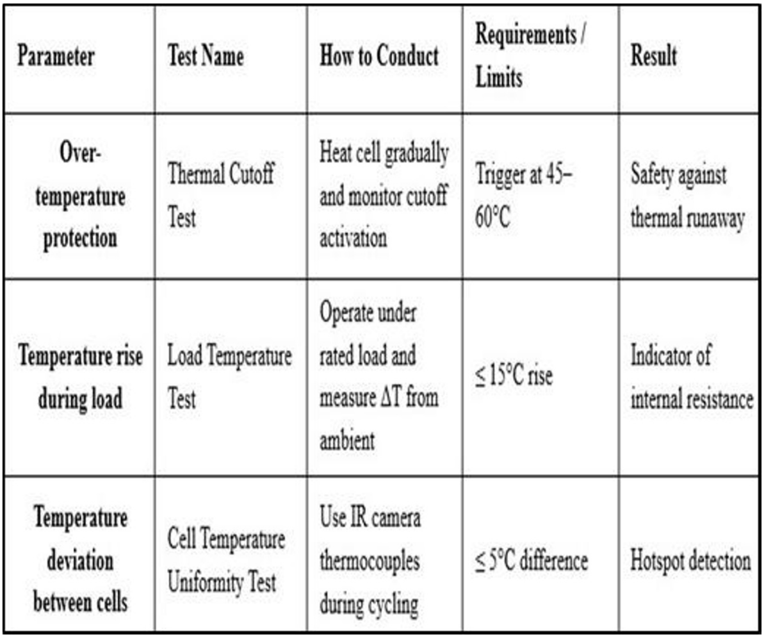
Parameter	**Test Name**	**How to Conduct the Test**	**Requirements / Limits**	**Resulting Parameter**
Capacity retention (cell level)	C/5 Capacity Test	Charge cell to 100%, rest 1 hour, discharge at C/5 rate at 25°C and measure Ah delivered	≥ 55% of nominal	Usable cell capacity
Capacity retention (module/pack)	Module Capacity Test	Same C/5 test but applied to entire module/pack	≥ 50% of nominal	Total usable energy at system level
Preferred practical target (small ESS)	Practical Capacity Test	Measure actual capacity after standardized cycling	70–80% of nominal	Energy density suitability
SOH (State of Health)	SOH Algorithm Test	Use BMS/diagnostic tool to compare present capacity vs rated	≥ 70%	Battery degradation condition
Internal resistance (DC)	DCIR Test	Apply current pulse and measure ΔV; compute $R = \Delta V/\Delta I$	≤ 2 × initial value	Voltage sag & heat generation tendency
OCV deviation	Open Circuit Voltage Test	Fully charge cells, rest 2 hours, measure OCV max–min	≤ 250 mV	SOC consistency across cells
Capacity variation within group	Capacity Matching Test	Measure capacity of cells in group individually	±5% of group average	Charge/discharge uniformity



Internal resistance variation	Group DCIR Variation Test	Compute internal resistance of all group cells	±30% of average	Current distribution uniformity
Insulation resistance	Insulation Megger Test	Apply 500–1000 V DC between terminal and case	≥ 2 MΩ	Electrical isolation safety
Operating voltage	Voltage Range Verification	Measure voltage under normal operating load	3.0–4.1 V (NMC/NCA) / 3.0–3.6 V (LFP)	Safe chemistry-specific voltage
SOC operating window	SOC Sweep Test	Cycle battery between min and max SOC limits	20% – 90%	SOC safety window
Charge/discharge rate	C-rate Cycling Test	Charge/discharge at specified C-rates	0.2–0.5C continuous, ≤1C peak	Suitability for second-life use
Remaining cycle life	Cycle Life Test	Repeat charge–discharge cycles until EOL at ≤1C	≥ 2,000–5,000 cycles	Projected usable life in ESS
Round-trip efficiency	Efficiency Test	Charge battery fully, discharge fully, measure ratio	≥ 90%	Conversion & resistive losses

Fig. 9. Electrical Paramter

5.3 Thermal parameters[1]



Parameter	Test Name	How to Conduct	Requirements / Limits	Result
Over-temperature protection	Thermal Cutoff Test	Heat cell gradually and monitor cutoff activation	Trigger at 45–60°C	Safety against thermal runaway
Temperature rise during load	Load Temperature Test	Operate under rated load and measure ΔT from ambient	≤ 15°C rise	Indicator of internal resistance
Temperature deviation between cells	Cell Temperature Uniformity Test	Use IR camera thermocouples during cycling	≤ 5°C difference	Hotspot detection

Fig. 10.Thermal parameters

6. FLOWCHART

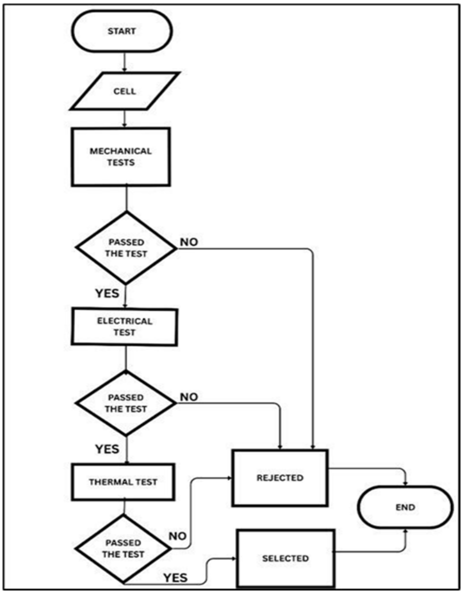


Fig. 11. Flowchart

7. RESULT

7.1 Charging and discharging cycles First cycle (Charging)

Cells	Resistance(milliohms)	Voltage
1	23.8	3.912
2	24	3.9
3	23.8	3.9
4	24	3.91
5	37.5	3.9
6	24	3.91
7	24	3.912
8	24.15	3.915
9	24	3.9
10	24	3.88

Table 1: Charging and discharging cycles First cycle (Charging)

The above table consists of values of resistance and voltage of 10 cells during the charging condition of the first cycle. The Voltage of all cells range around 3.9 with minor differences. Except the 5th cell, the internal resistance of all cells ranges around 23-24milliohms. The 5th cell has a voltage range of 3.9 and an internal resistance value of 37.5 milliohms.

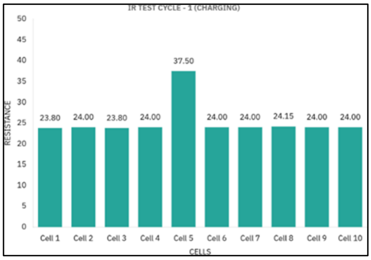


Fig. 12. IR Test Cycle -1 Charging

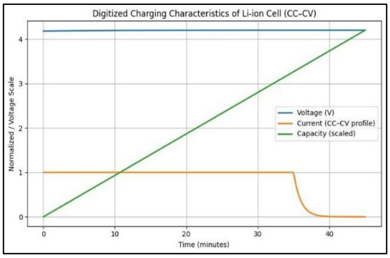


Fig. 13. IR Test Cycle -1 Charging Characteristics

7.2 *Fourth cycle charging and disharging*

Cells	Resistance(milliohms)	Voltage
1	25.06	3.218
2	25	3.213
3	24.64	3.225
4	25.29	3.213
5	40.10	3.234
6	25.06	3.238
7	25.42	3.227
8	25.20	3.227
9	25	3.245
10	25.20	3.247

Table 2: Fourth cycle charging and disharging

The above table consists of values of resistance and voltage of 10 cells during the discharging condition of the fourth cycle. The Voltage of all cells range around 3.2 with minor differences. Except the 5th cell, the internal resistance of all cells ranges around 25 milliohms. The 5th cell has a voltage range of 3.234 and an internal resistance of 40.10 milliohms.

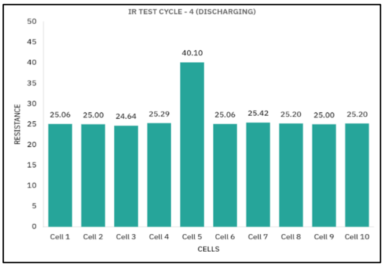


Fig. 14. IR Test Cycle -4 Discharging

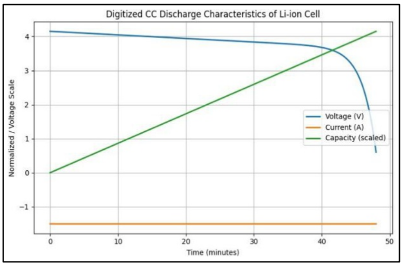


Fig. 15. IR Test Cycle -4 Discharging Characteristics

7.3 *Thermal Test*

The recorded temperature ranges between 26°C and 29°C under laboratory conditions with an emissivity setting of 0.95 and a reference temperature of 20°C. The narrow temperature variation indicates uniform heat distribution and stable operation of the SLB.

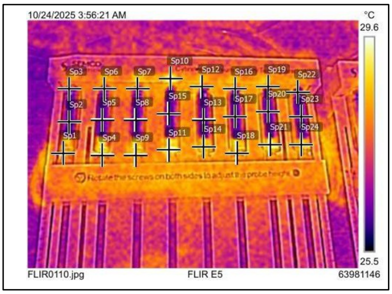
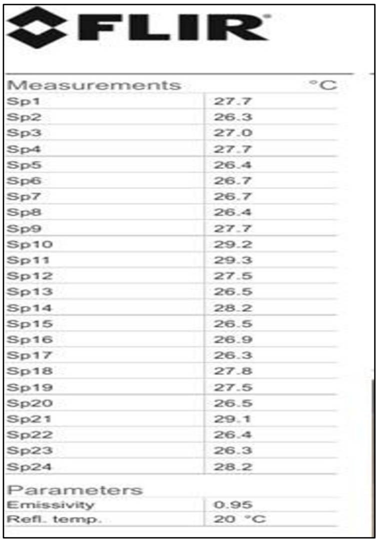


Fig. 16. FLIR Software Thermal Image



Measurements	°C
Sp1	27.7
Sp2	26.3
Sp3	27.0
Sp4	27.7
Sp5	26.4
Sp6	26.7
Sp7	26.7
Sp8	26.4
Sp9	27.7
Sp10	29.2
Sp11	29.3
Sp12	27.5
Sp13	26.5
Sp14	28.2
Sp15	26.5
Sp16	26.9
Sp17	26.3
Sp18	27.8
Sp19	27.5
Sp20	26.5
Sp21	29.1
Sp22	26.4
Sp23	26.3
Sp24	28.2
Parameters	
Emissivity	0.95
Refl. temp.	20 °C

Fig. 17. Thermal image temperature values

CONCLUSION

Thus, the paper concludes that Internal resistance was used as the criterion for grading the cells. Cells with internal resistance of ⩽ 50 milli Ohms were graded as Grade A for re-use and higher resistance cells graded as Grade B. Thermal data from the above test using infrared imaging showed that the temperature rise was within safe limits. The results show that these retired batteries can be safely utilised for re-including them in secondary energy storage systems. A multi-stage process for cell selection involving mechanical verification, electrical verification and thermal verification has been established. This method of recovery and re-utilisation of retired batteries will go a long way in reducing battery waste.

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