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Analytical thermal model for characterizing a Li-ion battery cell

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Presentation outline

- **Research context**
- **Background research**
- **The research approach**
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  - Electrical Analysis
- **Test Case**
  - Electrical test result
  - Thermal analysis
- **Conclusions & Future works**

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Research context

General aims:

- **Characterization of a thermal model.**
- **Determinate** the **heat generated** from a single cell at a **different working conditions.**
- Determinate the heat generated for **different single cell**
- Determinate the **cell** average **temperature.**

Scenario of investigation:

- **Custom battery packs** for automotive.
- **Small** and **medium** enterprises (SME)

Background research

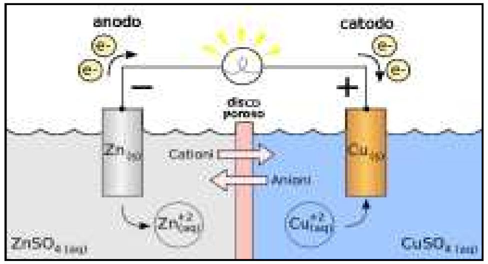
Why this study?

The performance, life, and safety of lithium-ion batteries depend on operative and storage temperatures

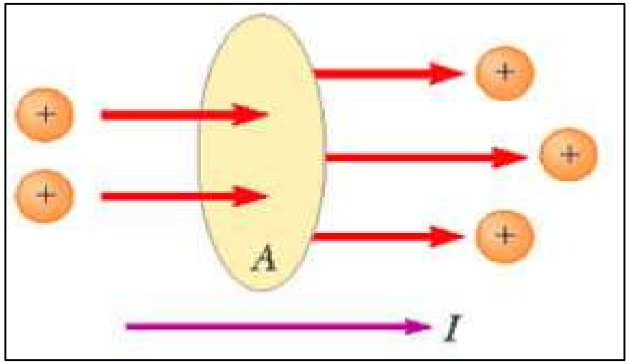
How to produce the heat in the lithium batteries?

The heat output is generated by three sources:

Activation (on Kinetics interfacial)



Concentration (transport species)



Ohmic losses (Joule heating)

Thermal Characterization

The thermal characterization is an important step to evaluate the performance, lifetime and safety.

The behavior of temperature distribution in an important aspect for definition and design the storage system.

$$\dot{Q} = I(V - E_0) - IT\frac{\partial E_0}{\partial T}$$

The thermal analysis is based on a study by Thomas and Newman which evaluates the heat produced by single cell

- $\dot{Q}$: Total Heat generated
- $I(V - E_0)$: Irreversibile Heat generated by the Joule's effect
- $IT\frac{\partial E_0}{\partial T}$: Reversible Heat generated

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$$\dot{Q}_{irr} = I(V - E_0) = I^2 R_i$$

The term $I(V-E_0)$ is the irreversible heat generated by Joule effect, its value is always positive (exothermic reaction) and depends on the internal resistance R_i.

$$\dot{Q}_r = IT\frac{\partial E_0}{\partial T} = T\Delta S\frac{I}{nF}$$

The expression $IT\partial E_0/\partial T$ indicates the reversible heat generated by the entropy change and reported. Specifying, the ratio ∂E0/∂T can be replaced as ΔS/nF , when ΔS is the entropy change of the cell reaction which can be either positive or negative (reduction reaction), n indicates the number of exchanged electrons and F is the Faraday's constant

Thermal Characterization

The cooling fluid considered in this research is air, but the same procedure can be extended to other Newtonian fluid.

For validate this method, proposes the main energy balance between the generated electrochemical reaction heat, the convective cooling and the variation of thermal capacity

$$I(V - E_0) + IT\frac{\partial E_0}{\partial T} = h_{comb}\left(T_{sup} - T_{\infty}\right)A + m_{cell}c_{p_{cell}}\frac{dT}{dt}$$

Total Heat generated

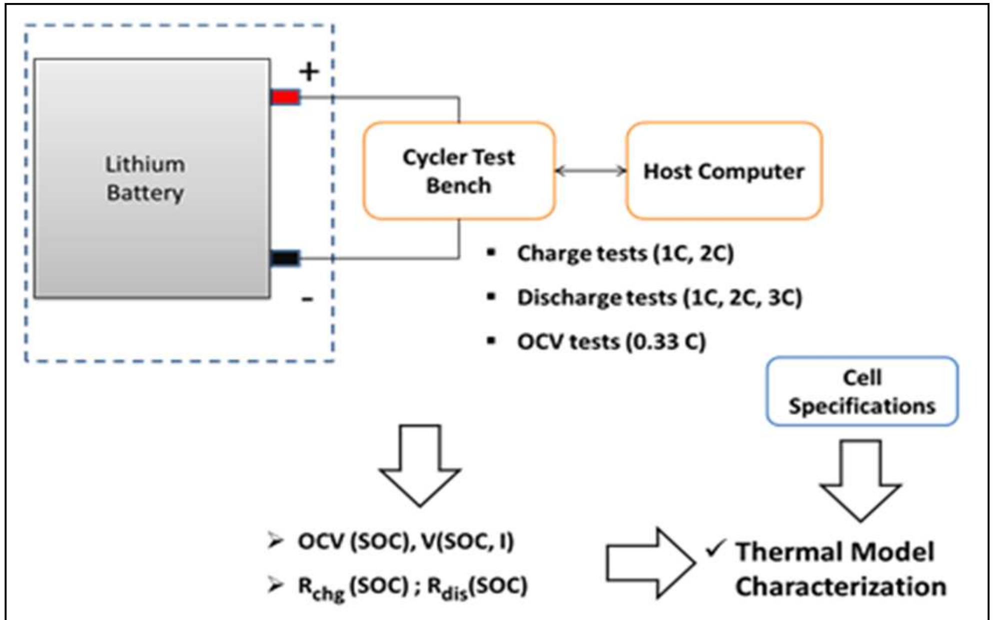
Convective cooling

Variation of thermal capacity

Electrical Analysis

The electrical analysis allows to measure parameters such as: current, voltage, OCV (open circuit voltage). These parameters are useful to determine the heat generated .

A defined protocol has been defined to measure the electrical values. Each test reproduces cycles of charge and discharge



The main tests are: charge and discharge at constant current rate, and OCV measurements to achieve the physical parameters useful for the cell thermal characterization.

The cycler can continually charge and discharge the battery, keeping a specific current profile during the test. In particular, the cycler transforms the network alternating current into the direct current which is required for the Li-ion battery to work.

An host PC is linked to cycler, in order to acquire and record experimental data in real time. Thus it is possible to monitor current rate, voltage profile, SOC and the internal resistance.

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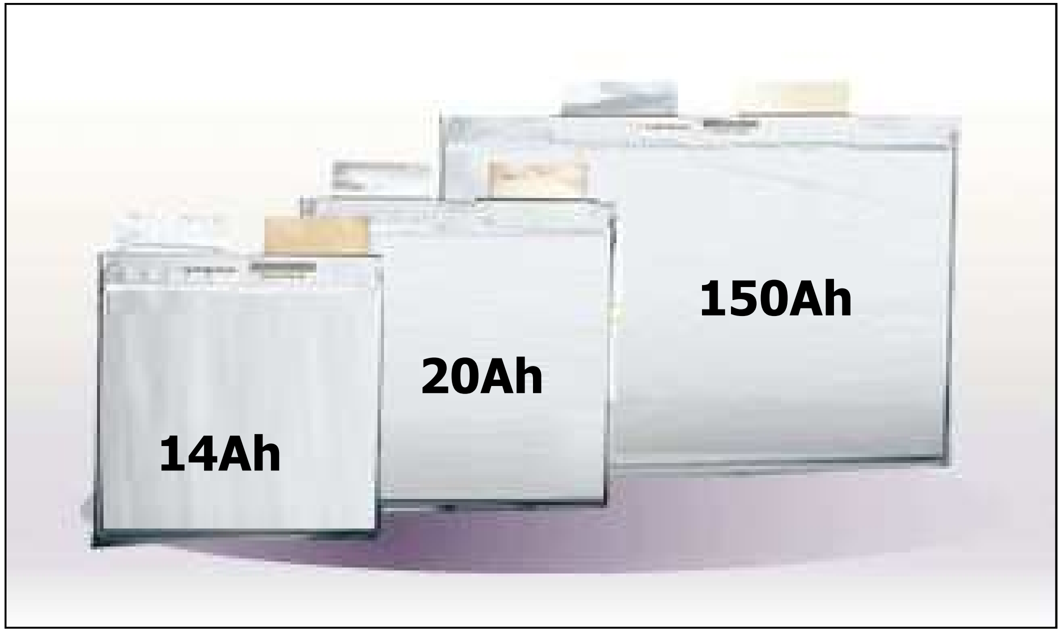
Test case

The proposed approach wants to validate the analytical model for different type of Li-Ion cell.

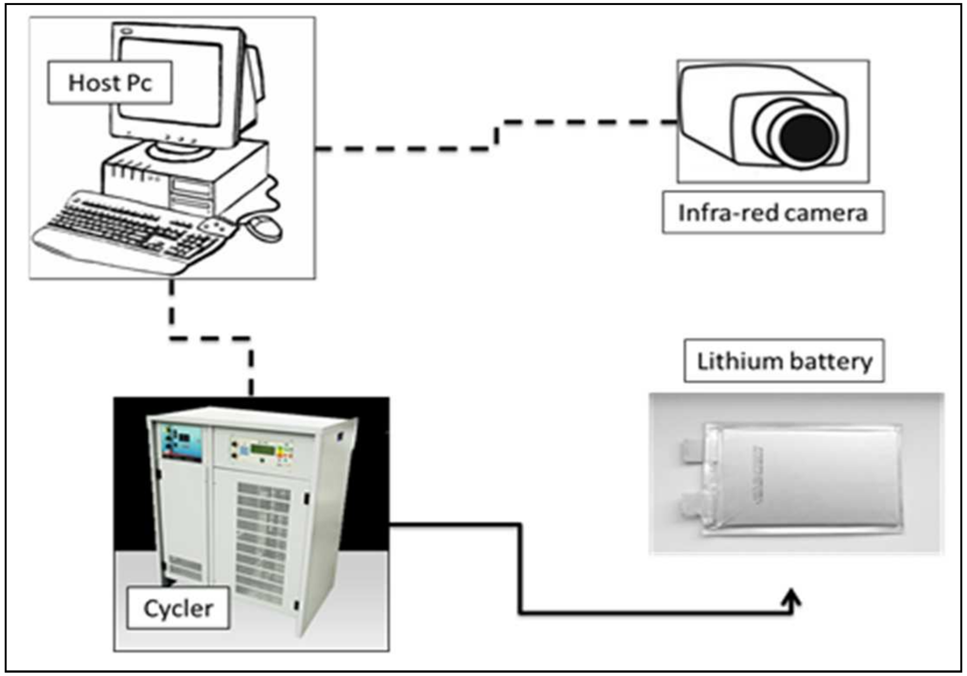


The table shows the main characteristic of the three cells analyzed

Type		1	2	3
Chemical		$LiFePO_4$	$LiNiCoMnO_2$	$LiFePO_4$
Geometry		Soft Pouch	Soft Pouch	Soft Pouch
Dim	Length	222 mm	216 mm	327 mm
	Width	129 mm	129 mm	453 mm
	Thick	7.2	7.2	10.7
Nom. Voltage		3.25 V	3.65V	3.7 V
Nom. Capacity		14 Ah	20 Ah	150Ah
Max Discharge		140 A	100 A	300 A
Max charge		14 A	20 A	150 A
Weight		380 g	425 g	3300 g

Test case

To acquire the experimental variables was used the following test bench



The main components are:

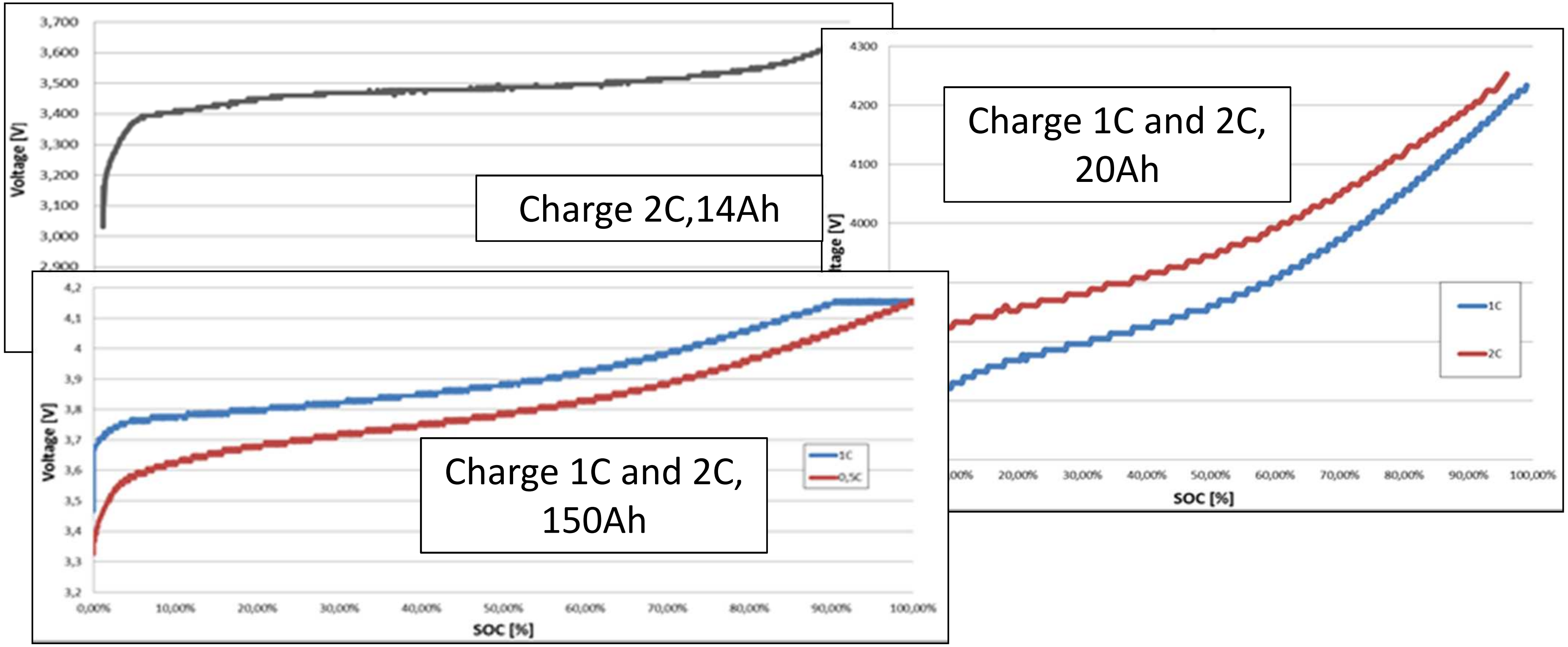
- **The cycler**, is a device which can continually charge and discharge the battery, keeping a specific current profile during the test. In particular, the cycler transforms the network alternating current into the direct current which is required for the Li-ion battery to work.
- **Host Pc ,** is linked to cycler, in order to acquire and record experimental data in real time. Thus it is possible to monitor current rate, voltage profile, SOC and the internal resistance.
- **Infra red camera**, monitoring the temperature distribution during each test

The instrumentation allows to acquire the main electrical quantities such as: voltage (V), current (A), energy (W), capacity (Ah) power (W), SOC (%), and internal resistance (ohm).

This component makes an interaction bridge between the cycler and the IR camera, where the IR camera measures the battery thermal profile. Then, an advanced software allows the temperature values to be elaborated and reported in tables and graphs.

Electrical test result

In order to validate the proposed methodology, the different cells have been tested at several current rates in charge and discharge mode



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Electrical test result

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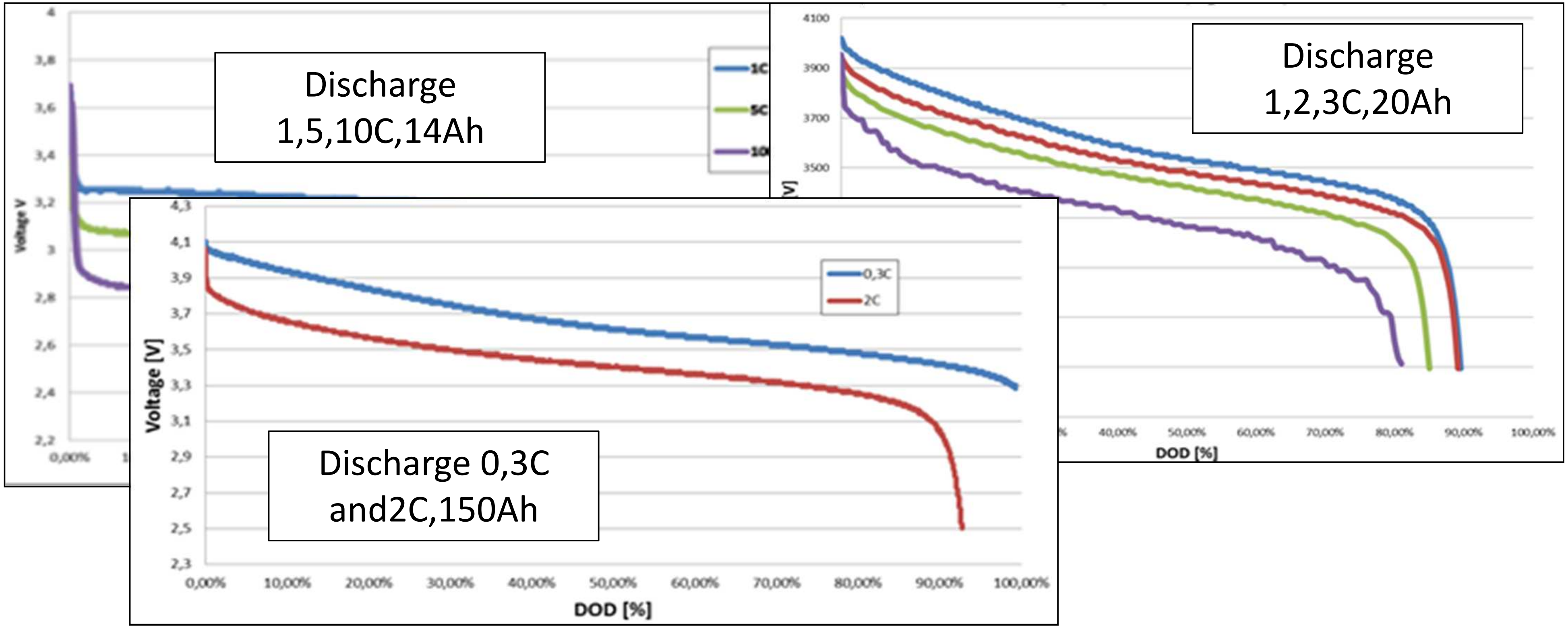

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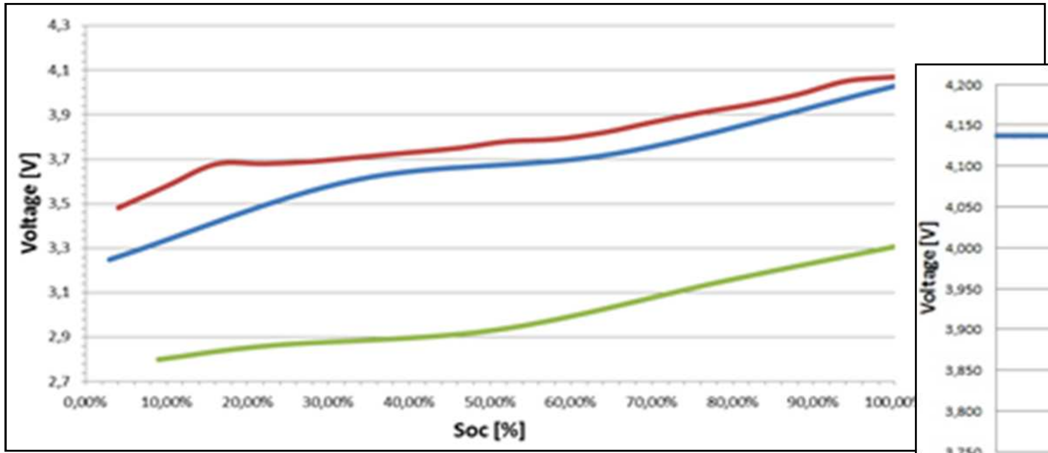
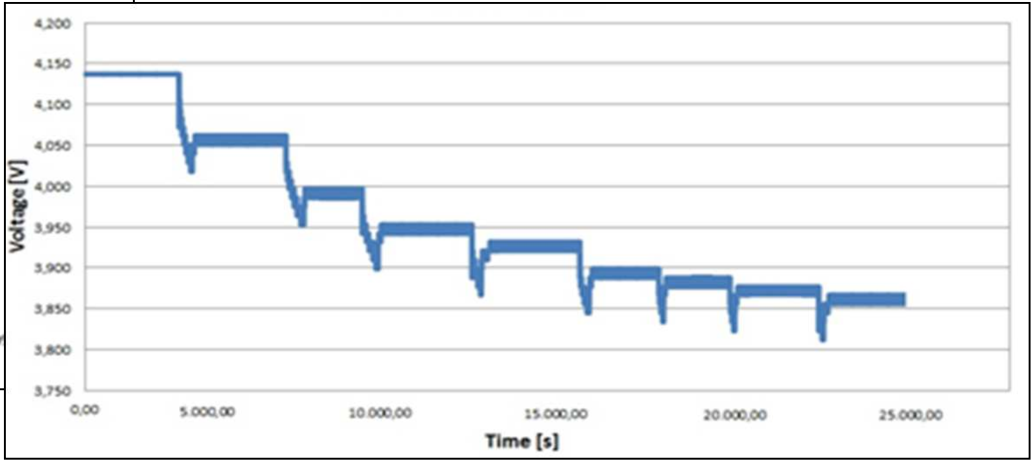
Electrical test result

The detection of OCV is more complex. During OCV tests, the cells are gradually discharged with step 5% of SOC at constant 0.3C current rate. Between each discharge step there is a cutoff of voltage and a waiting phase to measure the final OCV value for the related SOC.

Usually the waiting phase lasts 8h, but in this case it has been considered 3h of waiting to acquire the OCV values.

After a complete discharge, the same cell has been recharged again at 0.3C in 5% step of SOC, in order to obtain two profile of OCV in charge and discharge.

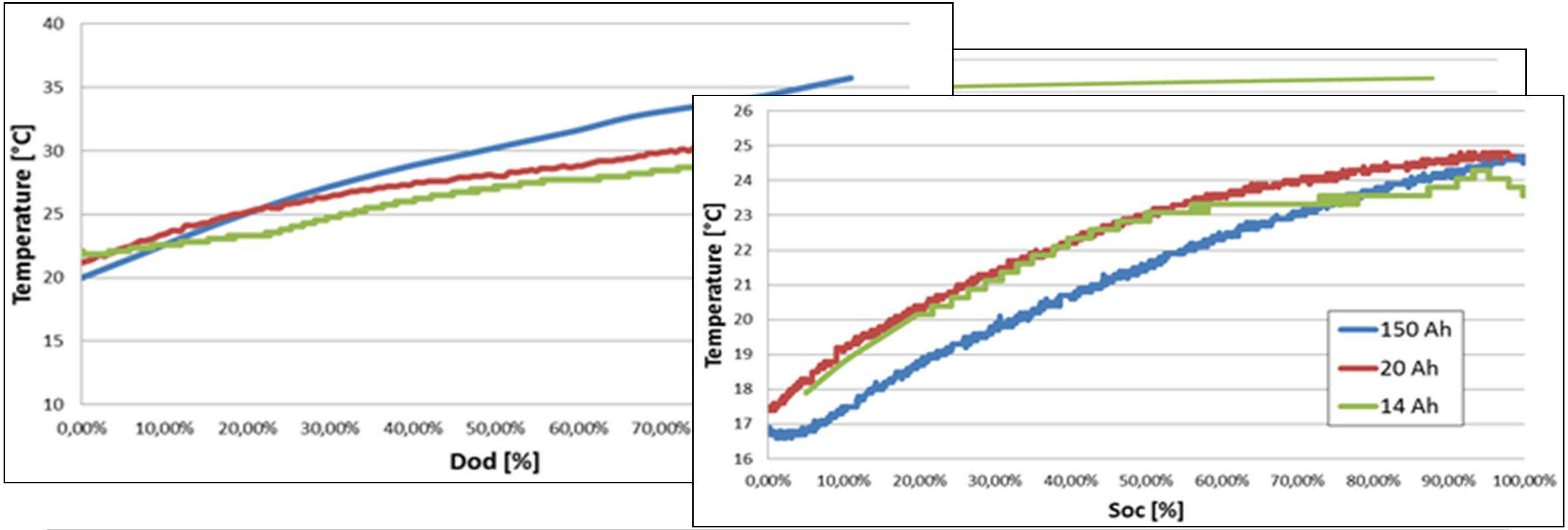




Thermal analysis

The electrochemical heat source has been evaluated using the parameters previously discussed. The reached temperature has been analyzed by:

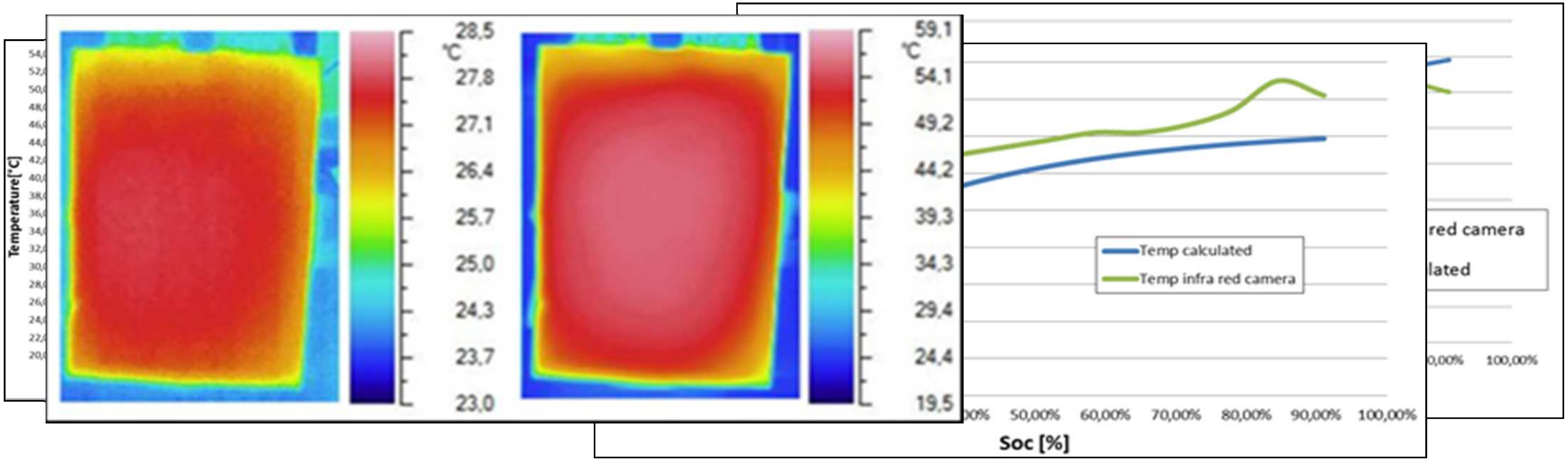
$$I(V - E_0) + IT\frac{\partial E_0}{\partial T} = h_{comb}(T_{sup} - T_{\infty})A + m_{cell}c_{p_{cell}}\frac{dT}{dt}$$



Thermal behaviour of cell 14 Ah

The cell type 1 with 14 Ah of capacity is the battery with a smaller size than the other analyzed

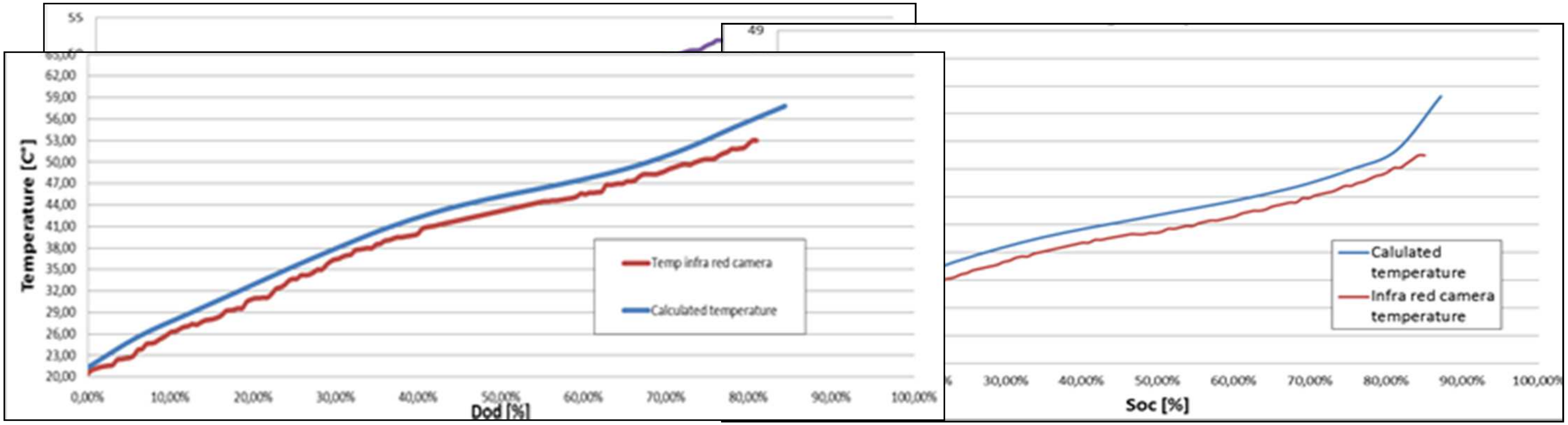
Despite low capacity, this type of LiFePO4 cell allows to provide high power density. In fact, this cell can be discharged at 10C in continuous. However a current of 140 A (10C mode) in discharge causes a strong increase in temperature, and the designer have to take into account this issue.



Thermal behaviour of cell 20 Ah

The battery with a capacity of 20 Ah is different from the other type for the chemistry of which is constituted.

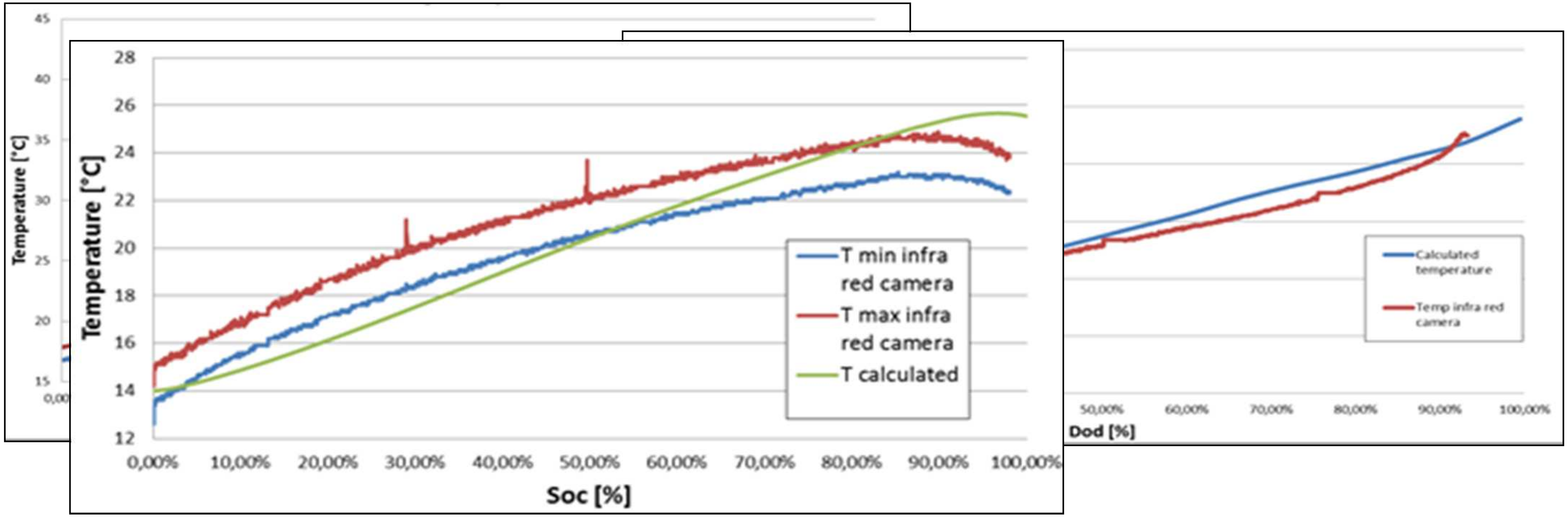
In particular the battery chemistry $LiNiCoMnO_2$ allows to achieve higher voltage peaks than the $LiFePO_4$ cells. However the trends of voltage curves are not constant during charge and discharge phase. The presence of cobalt makes these battery cells very expensive to produce, but also more profitable to recycle.



Thermal behaviour of cell 150 Ah

This type of cell is particularly used in automotive applications due to its high capacity and power density.

The chemistry LiFePO4 allows to have an constant voltage during an important part of charge and discharge cycles .



Conclusion & future Works

The methodology has been proposed to guarantee high flexibility, good quality and reduced time to market in the design process of customized battery packs

An electrical and thermal analysis have been applied to calculate the heat generated by the electrochemical reactions of Li-ion battery cells

This analysis allows not only to evaluate the maximum temperature achieved during operative condition, but also to simulate the thermal behavior of one Li-ion cell using a 3D virtual model.

The proposed methodology can be extended to the design of a complete battery pack. The calculated values of heat generated, both reversible and irreversible, can be used as input for a FEM analysis

Study the difference temperature distribution between adjacent battery elements using virtual tool, in order to optimize security and cooling

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THANKS FOR YOUR ATTENTION

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