38th International Electric Vehicle Symposium and Exhibition (EVS38) Göteborg, Sweden, June 15-18, 2025

A novel cooling approach based on partial direct liquid cooling that extends the lifespan of batteries for electric vehicles

M. Larrañaga-Ezeiza, A. Balerdi, G. Vertiz
CIDETEC, Basque Research and Technology Alliance (BRTA), Eskuzaitzeta Industrialdea, Oianguren, 5, Donostia-San Sebastián, Spain (mlarranaga@cidetec.es)

Executive Summary

This study presents an experimental comparison aimed at evaluating the influence of cooling strategies on the aging of lithium-ion batteries. A battery module was developed based on a novel partial direct liquid cooling approach, which enables direct contact between the cells and the coolant, thereby enhancing battery system temperature control. To assess its effectiveness in mitigating battery degradation, a comparative analysis was conducted against a module based on the conventional indirect liquid cooling strategy, commonly adopted in electric vehicles. Experimental results revealed that the proposed strategy increased battery durability by 62.5%, highlighting its potential to significantly extend system lifespan and cope with extreme operating situations. These findings support the technical feasibility of the proposed partial direct liquid cooling strategy as a high-performance thermal management solution for electromobility applications.

Keywords: Electric Vehicle, Batteries, Energy Storage Systems, Thermal Management, Life Cycle Analysis

1 Introduction

The electric vehicle is currently one of the key pillars being integrated into the global socioeconomic framework to reduce pollutant gas emissions in areas of high energy density. Consequently, its market has grown exponentially in recent years, fostering a state of continuous technological development aimed at meeting the increasing demands for improvement within the industry [1].

Lithium-ion batteries (LiBs) are the preferred energy storage technology for electric vehicles (EVs) due to their high energy density, low degradation, and long lifespan. However, the performance and ageing of these batteries are influenced by several operational factors, which makes the issue of battery ageing a critical concern. The aging of batteries affects not only the capacity and efficiency of the battery, but also its overall lifespan, which is of great consequence to both EV manufacturers and users [2].

The ageing mechanisms of LiBs are complex and depend on several factors including temperature or the state of charge of the cell [3], [4], [5]. These parameters influence system design and operating conditions; therefore, more and more innovative strategies are being proposed to condition these parameters in their optimal operating range.

In the context of thermal management strategies, indirect liquid cooling strategies (ILC) currently represent the most widely adopted approach within the electric vehicle market. These systems employ heat transfer fluids with high thermal absorption capacity, are integrated into compact designs and represent a cost-efficient solution [6]. However, a critical limitation lies in the fact that these fluids are electrically conductive, thereby preventing direct contact between the battery cells and the coolant. Consequently, it is necessary to implement safety mechanisms based on electrical insulation, which in turn introduce a thermal resistance network that hinders efficient heat transfer [7]. This limits the system's ability to effectively regulate battery cell temperature, posing challenges in simultaneously meeting the requirements of high-performance operating conditions and extended service life.

Given the limitations of ILC, direct liquid cooling (DLC) strategies are receiving growing interest as a more effective solution. These systems use dielectric fluids, which allow direct contact between the battery cells and the coolant. This direct contact reduces thermal resistance and improves heat transfer at the cell level, making these approaches well-suited to meet the increasing demands for performance, safety, and durability in the electric vehicle sector. Among the different types of DLC strategies, immersion cooling is currently the most widely studied. This method involves fully submerging the battery cells in a dielectric liquid, ensuring that the entire cell surface is in contact with the coolant. As a result, thermal management becomes more effective, enabling precise temperature control even under demanding operating conditions [8], [9], [10], [11], [12], [13], [14]. However, according to recent studies, the higher viscosity of some dielectric fluids increases the power consumption of the system, and the quantity of the fluid needed to develop the strategy increments the overall weight of the battery pack [15].

This work, therefore, introduces a novel cooling strategy based on partial direct liquid cooling (PDLC). By enabling direct cooling of only one surface of the battery cell, this approach significantly reduces the volume of coolant required to manage the thermal behaviour of the battery system. This reduction in coolant demand contributes positively to the overall energy density of the system, offering a promising balance between thermal performance and system-level efficiency. Previous work has been used to scale-up the PDLC strategy at the module level [16].

This study conducts an experimental comparative analysis focused on the influence of cooling strategies on battery degradation. The investigation involves two battery modules: one configured with the commercially available solution employing a conventional ILC approach, and the other representative of a proposed PDLC strategy.

2 System description

2.1 Reference battery cell

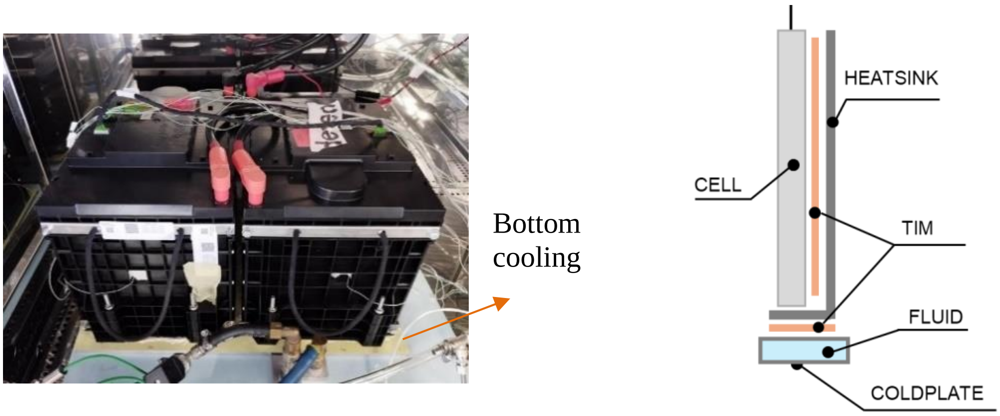
The proposed research considers the degradation analysis of two fundamental battery systems that are based on the same battery cells, a high-energy-density 60 Ah NMC pouch-type battery cell was selected. Its main specifications are summarized in Table 1. Owing to its flexible form factor, the cell can be efficiently integrated into the available space, contributing to a reduction in the total weight of the battery system. This design advantage not only facilitates a more efficient packaging process but also enhances the system's energy density, thereby contributing to improved overall performance.

Table 1: Reference battery cell general characteristics.

Parameter	**Value**
Nominal capacity	60 Ah
Charging current	120 A
Discharging current	180 A
Operational temperature range	-20 – 60 ºC
Dimensions: L x W x H	226 x 227 x 12 mm
Mass	1.14 kg

2.2 Reference battery module based on ILC strategy

A battery module based on ILC strategy was selected as a reference to develop the comparative study. This battery system was based on a 2- module sub-system and was used in electric bus applications. Each of the modules have 24 cells and the cooling strategy uses a cold plate as a cooling component to control the thermal behaviour of the battery system from the bottom. Figure 1 shows the main battery subsystem and the schematic definition of the assembly.

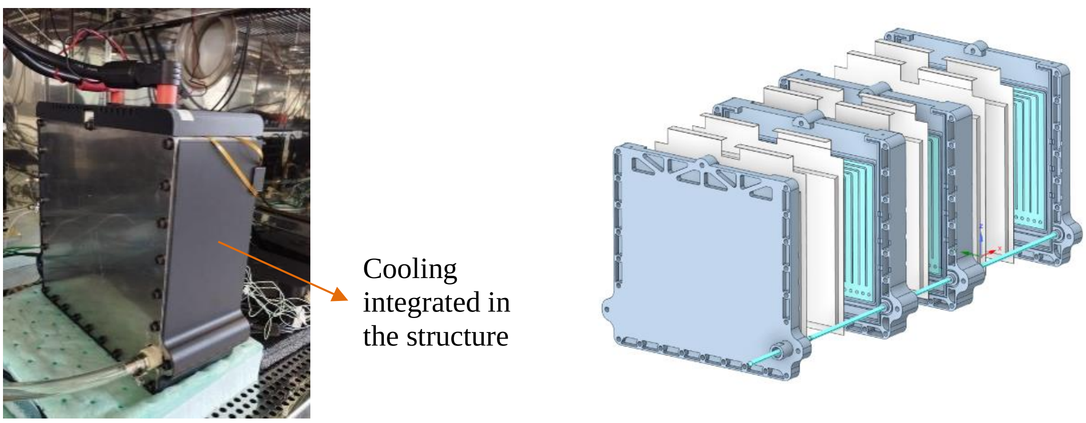


a) b)

Figure 1: Indirect liquid cooled battery system a) sub-system level assembly and b) schematic configuration of the battery module based on ILC.

2.3 Proposed PDLC strategy

In this research, a battery module of 6 battery cells was developed using as a reference the cell-level prototype presented in previous research [16]. Equipped with uniform flow distribution channels to manage the equitably the thermal conditions of all the battery cells, this arrangement effectively reduces the number of elements, weight, and dimensions of the battery module considering the preliminary configuration of the cell-level prototype (Patent pending WO2025021843A1). A module of six cells was developed experimentally to analyse the impact of the strategy in the aging of the battery cells. Considering the prototype nature of the strategy, this characteristic performance showcases the potential feasibility and competitiveness of the proposed PDLC strategy approach in practical applications for EVs. Figure 2 presents the main components of the module-level PDLC strategy.



a) b)

Figure 2: The module level a) assembly and b) scale up explode view.

3 Testing methodology

3.1 Setup

The same testing bench was designed for both cooling strategies, that includes specific equipment to test battery systems. Figure 3 presents the overall schematic overview of the testing setup.

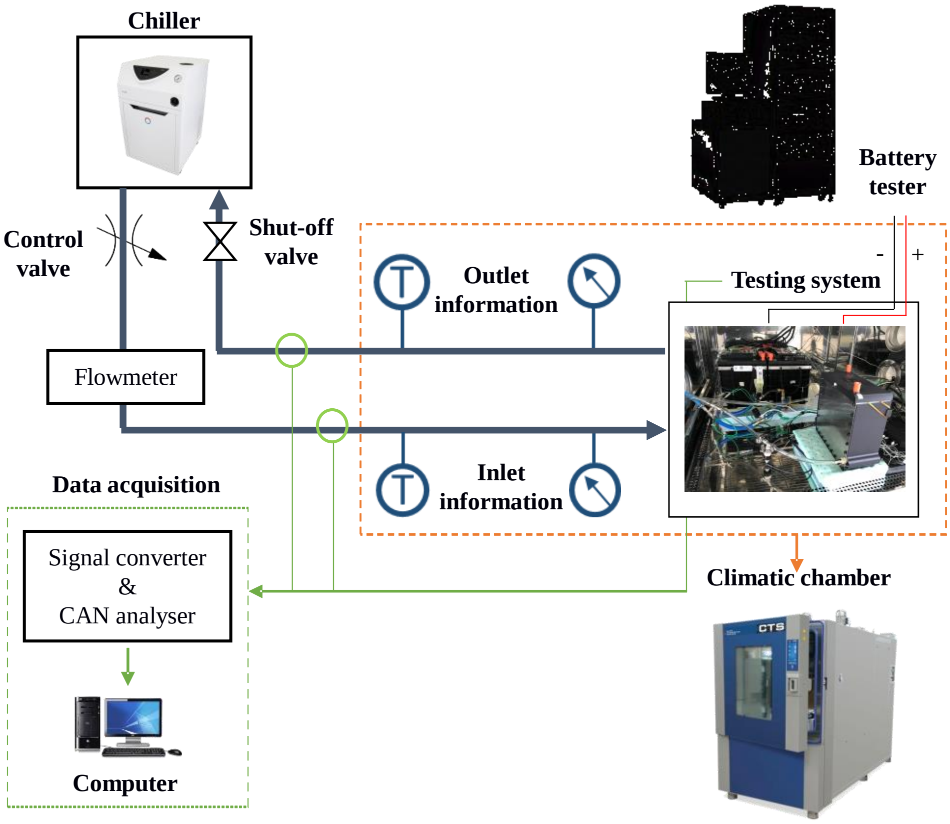


Figure 3: Schematic overview of the experimental setup.

The equipment used in each case is presented in Table 2. Both, PDLC and ILC battery systems were introduced in the same climatic chamber to define the same thermal boundary conditions of the test and to ensure the safety of the testing process. A Chroma 17020 battery tester was used to implement the testing profiles for both subsystems with a temperature cut-off controller for safety. Finally, two LAUDA VC5000 chillers with same characteristics were used for each hydraulic circuit to control the fluid temperature and flow rate.

Table 2: PDLC and ILC test bench reference equipment technical data.

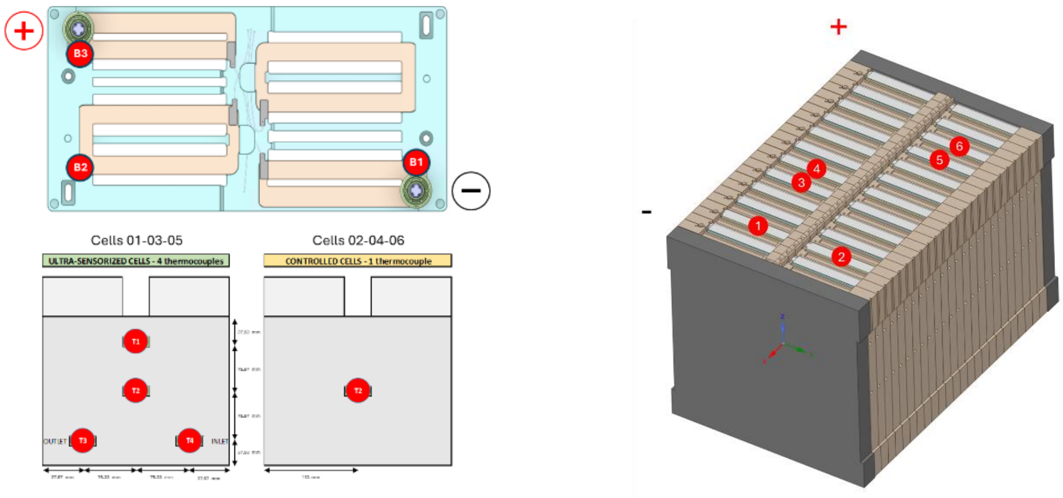
Equipment	**Model**	**Parameter**	**Specification**
Climatic chamber	CTS CS-40	Temperature range	-40/180 ºC
Battery tester	Chroma 17020	Power range	±50 A // 100 V // 2.5 kW
Chiller	Lauda VC5000	Maximum flow rate and temperature range	60 L/min// -20/40 ºC
Signal converter	Ipetronik	M-sense 8	Current and voltage range
Flowmeter	CODA K-Series	Flow rate range	0-300 kg/h
Pressure transmitter	WIKA A-10	Pressure range	0-1 bar
Thermocouple	K-type	Temperature range	-30/1100 °C

Regarding the instrumentation employed during the testing phase, identical data acquisition systems were utilized for both cooling strategies. The setup included K-type thermocouples for monitoring cell temperature, a WIKA A-10 pressure transmitter to measure pressure drop within the hydraulic circuit, and a CODA flowmeter for evaluating fluid flow rate. An Ipetronik signal converter was used to condition sensor outputs, while a DC power supply provided electrical input. Data acquisition was managed via a computer system equipped with a Controller Area Network (CAN) protocol, ensuring synchronized and accurate data collection throughout the experiments.

3.2 Battery system monitoring

To enable a reliable analysis of the temperature distribution within the battery modules, a tailored thermocouple configuration was implemented for each cooling strategy. In the case of the PDLC strategy, 15 thermocouples were installed on the uncooled surfaces of the cells. As shown in Figure 4a, cells 1, 3, and 5 were instrumented to assess thermal homogeneity at the cell level, while cells 2, 4, and 6 were used to monitor the internal thermal behaviour of the module. Additionally, three thermocouples were positioned on the busbar to capture the temperature of both lateral and internal cell tabs, enabling a comprehensive evaluation of cell- and module-level thermal uniformity.

For the ILC strategy, commercial modules imposed limitations on internal instrumentation. Each module was equipped with six pre-defined temperature sensing points along the busbar, strategically distributed to monitor module-level thermal behaviour (Figure 4b). According to manufacturer specifications, these measurements represent the cells' thermal conditions. To ensure consistency and reduce uncertainty, the present study focuses on the comparative analysis of busbar temperatures across both cooling strategies.



a) b)

Figure 4: Schematic representation of the thermocouple disposition of a) PDLC strategy and b) ILC strategy.

3.3 Testing process

To fully analyse the thermal behaviour of the two cooling strategies and to compare their degradation evolution, the same thermal demanding working conditions were defined for both battery systems. These testing conditions have been established to induce accelerated aging of the battery system; consequently, they simulate extreme operational scenarios. With the objective of avoiding temperatures above safety limits, the current rate defined for the test was 1.5/1.5C, where the temperature reached in the ILC module was on the scale of 50 ºC. Considering the Depth of Discharge (DOD) of the cycles, to minimize the effect of this factor in the obtained aging, an 80% of the DOD was defined [17]. The charging process was done using a constant current – constant voltage condition (CC-CV), and the discharge process using only a constant current condition (CC). After each process, a 20 min of rest was defined to stabilize the cells and provide also some break for the cooling effect (Figure 5).

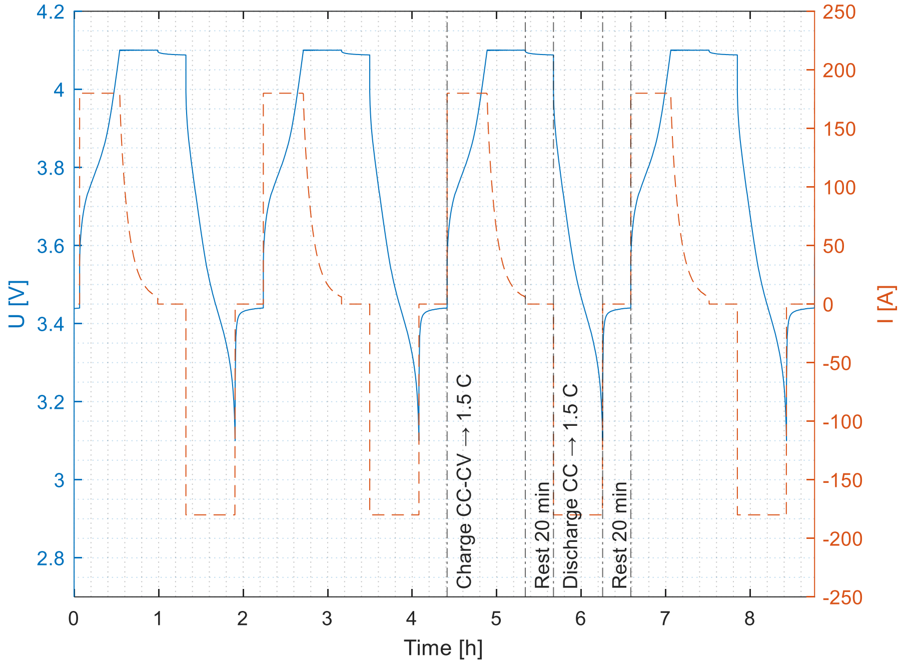


Figure 5: Current profile of cycling aging test

It was also necessary to determine the number of measurement points to be taken during the aging process. In consideration of the datasheet for the selected battery cell, it was determined that approximately 1,000 cycles of the proposed aging profile would be performed. Consequently, the SOH of the battery cells was measured at 140-cycle intervals (approximately two weeks) to ascertain the degradation tendency of the two strategies. The check-up test comprises 3 charging and discharging cycles at a 1C rate, which were conducted to stabilize the performance of the cells and measure the last cycle capacity discharged. After each process, a 1 hour of rest was defined to stabilize the cells and provide also some break for the cooling effect. This method enabled the capacity value of each battery module to be measured under identical electro-thermal conditions, thereby only detecting variations in capacity while minimising the influence of other factors.

3.4 Terms of comparison

To ensure a fair comparison between the two cooling strategies, the boundary conditions, such as ambient temperature, fluid temperature and flow rate were defined in advance. It was decided that the ambient and fluid temperatures would be 20 ºC for both cooling strategies. This ensured or at least minimised the absence of heat transfer between the fluid and the surrounding environment given that the two temperatures were equal.

To define equivalent flowrate for both strategies, pumping power consumption criteria was defined. A reference initial operating condition was considered, in which the ILC battery subsystem operates at a flow rate of 1.3 L/min. The pump power loss associated with the cold plate was calculated by multiplying the flow rate by the pressure drop of the component. From this analysis, a pump power consumption of 0.50 W was measured for the ILC system at a reference flow rate of 1.3 L/min (Figure 6a). The cold plate was designed to manage the thermal behaviour of a subsystem composed of 2 battery modules (48 battery cells). Therefore, to compare both cooling strategies, it was necessary to scale down to the cell level. To determine the equivalent power consumption, the previously calculated value of 0.50 W was divided by the total number of cells (48 battery cells) resulting in 0.01 W per cell.

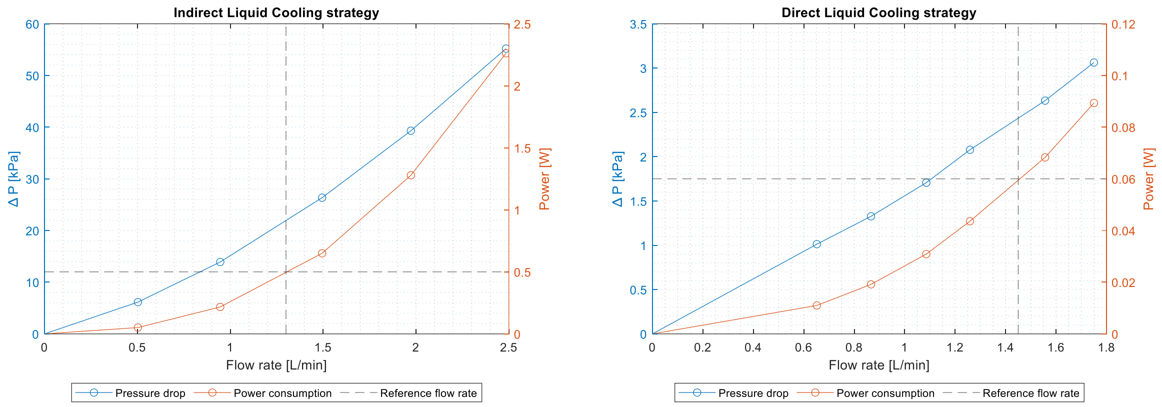


Figure 6: Experimental pressure drop variation for: a) ILC strategy and b) PDLC strategy at different flow rate values and the reference power consumption of each strategy.

Based on this reference value, the equivalent power for the six-cell module under the proposed PDLC strategy was computed. It was determined that, to equalize the flow conditions between both strategies, the proposed strategy had to operate at a flow rate of 1.45 L/min (Figure 6b).

Considering the fluid used for this experimental comparative study, a commercial water glycol 50-50%v was used for the ILC strategy and for the proposed PDLC strategy, a specific sustainable hydrocarbon was implemented. The main technical characteristics of the dielectric fluid are presented in Table 3.

Table 3: Procedure definition main characteristics.

Property	**Dielectric fluid**
Resistivity (MΩm)	$> 5 \cdot 10^6$
Density (kg/m^3)	774
Kinematic viscosity (mm^2/s)	4.3
Specific heat capacity (J/kgK)	2130
Thermal conductivity (W/mK)	0.135

4 Results

This study examined the impact of cooling strategies on the degradation behaviour of battery modules. The evaluation focused on the evolution of two critical parameters: thermal performance and capacity fade. The analysis included the temporal progression of maximum cell temperatures and thermal uniformity under thermally demanding operating conditions. In addition, periodic experimental check-up tests were performed to quantify capacity loss over time. The comprehensive assessment of these parameters enabled a comparative evaluation of the degradation associated with each cooling strategy, thereby facilitating the identification of the most effective approach for mitigating battery deterioration and extending the operational lifespan of the modules.

4.1 Thermal performance evolution

Considering the temperature response of the battery systems, Figure 7 illustrates a comparison of the temperature profiles recorded at the initial and final cycles of the degradation process, referred to as the aging test. Under identical thermally demanding operating conditions the evolution of temperature and cooling capacity was evaluated after 1,000 cycles.

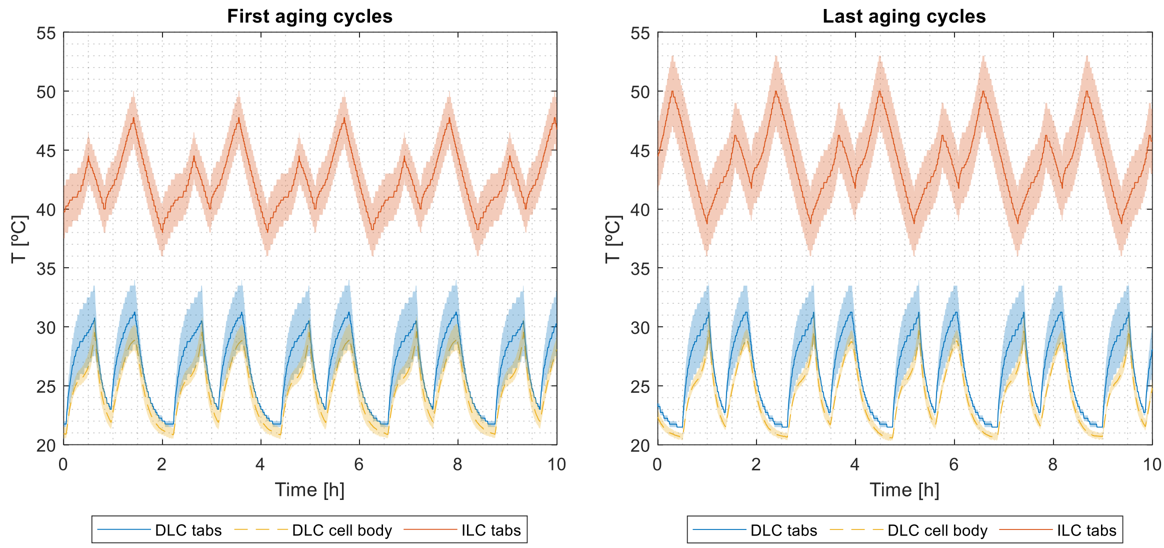


Figure 7: Temperature profiles observed under identical thermally demanding working conditions during a) the initial and b) final cycles of the aging test.

A comprehensive analysis of temperature data collected during experimental aging cycling tests revealed a consistent upward trend in cell temperature on ILC battery subsystem (see Table 4). The mean temperature increased from 44 ºC to 46 ºC after 1,000 cycles was approximately 2 ºC, and the maximum temperature was increased by 3 ºC, from 50 ºC to 53 ºC. These results also indicated that the thermal heterogeneity of the battery module exhibited an increase over the course of the cycles. At the beginning of the life, the temperature differential between battery cells was 4.5 ºC, whereas at the conclusion of the experimental test, it had increased to 6 ºC. This demonstrates that cell degradation is heterogeneous, indicating that the cooling strategy is not uniformly regulating the thermal conditions across all cells.

Table 4: Battery cell tab (T_t) and body (T_b) temperature evolution comparison.

Cooling strategy	$T_{t,max}$ (ºC)		$T_{t,mean}$ (ºC)		$\Delta T_{t,mod}$ (ºC)		$T_{b,max}$ (ºC)		$T_{b,mean}$ (ºC)		$\Delta T_{b,mod}$ (ºC)	
	Value	*Diff.*	*Value*	*Diff.*	*Value*	*Diff.*	*Value*	*Diff.*	*Value*	*Diff.*	*Value*	*Diff.*
PDLC	34 ºC	0	27.5 ºC	0	6 ºC	0	31 ºC	+0.8	25.7 ºC	0	2.5 ºC	+0.5
ILC	53 ºC	+3	46 ºC	+2	6 ºC	+1.5	-	-	-	-	-	-

Regarding the PDLC battery module, the advanced cooling system implemented successfully maintained average and maximum tab temperatures at 27.5 °C and 34 °C, respectively, with no temperature variation observed during the degradation tests. Additionally, thermocouples positioned within the battery cell bodies confirmed consistent thermal behavior from the beginning of the service life to the end of the aging test, with a maximum variation of only 0.8 °C in peak temperature. Throughout the testing period, the temperature remained within the optimal range for battery operation. These results highlight the effectiveness of the proposed strategy in uniformly controlling the thermal response of the battery system.

4.2 Battery module capacity evolution

The capacity of the battery modules was measured through the experimental check-up tests. Thereby the energy that the modules can deliver at the third discharge stage is analysed. This enabled an analysis of the capacity loss of the battery modules for each cooling strategy. Figure 8 illustrates the relative capacity evolution of the battery modules.

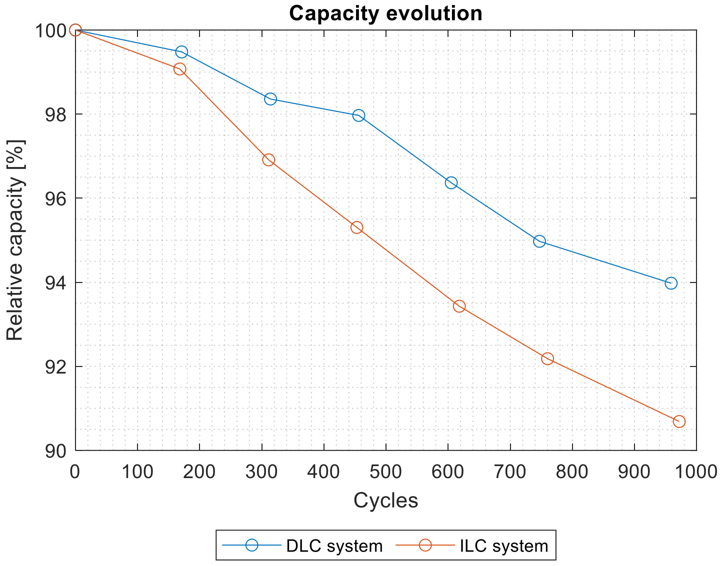


Figure 8: Evolution of the capacity of PDLC and ILC battery modules with aging.

The relative capacity of the battery module can be calculated following Eq.1, where C_n represents the current capacity of the module, C_0 represents the initial capacity of the module before aging test, and $C_{relative,n}$ represents the current relative capacity of the module.

$$C_{relative,n}\ [\%] = \frac{C_n}{C_0} \qquad \text{(Eq. 1)}$$

From Fig.7 it can be observed that after approximately 1,000 cycles subjected to the specified thermally demanding conditions, the capacity reduction of the ILC system was higher than that of the PDLC system. To be precise, the capacity diminished to 91 % to its original capacity, whereas the PDLC system exhibited a capacity reduction to 94 %. This indicates that the proposed cooling strategy has a positive impact on battery lifespan, highlighting that the choice of cooling strategy plays a critical role in the aging behavior of the battery system.

4.2.1 Analysis of End of Life (EOL)

In general, the battery is considered to have reached the end of its useful life (EOL) when the battery capacity has decreased to 80% of its initial value [18]. Consequently, the capacity loss curves were extended in a linear fashion in accordance with the pattern exhibited by each cooling strategy up to the EOL limit. Figure 9 illustrates the progression of both cooling strategy systems towards their EOL. As can be observed, the ILC system is estimated to have a service life of 2,000 cycles when subjected to the before specified thermally demanding conditions. In contrast, the PDLC system appears to be capable of offering a service life of 3,250 cycles under the identical defined conditions, thereby enhancing the durability of the same battery by 62.5 %.

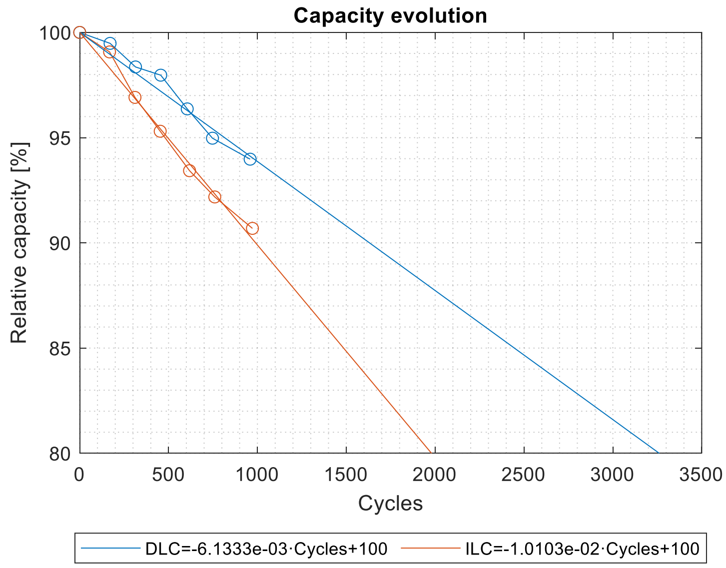


Figure 9: Estimation of the relative capacity loss of the battery modules until the end of their lifetime.

5 Conclusions

This study introduces an innovative partial direct liquid cooling strategy for the thermal management of large-scale pouch-type lithium-ion batteries. A prototype with a modular design was developed at the module level, and its performance was evaluated through experimental testing. The evaluation focused on the strategy's effectiveness in maintaining thermal control under high-performance operating conditions, as well as its capacity to mitigate the aging effects on the battery module. The results lead to the following conclusions:

- Based on the initial results of the study, it can be observed that under equivalent operating conditions and facing the same high performance working profiles, the proposed strategy provides faster and more accurate temperature control, maintaining the system at a mean temperature of 27.5℃ with a maximum of 34℃. In contrast, the mean and maximum temperatures of the battery module based on ILC reach 44℃ and 50℃, respectively. This significant difference highlights the superior thermal management capacity presented by the proposed PDLC strategy.

- The proposed strategy based on PDLC can maintain the battery system temperature within a variation of +0.8 °C after 1,000 cycles under high-demand operating conditions. In contrast, the module based on ILC strategy shows a temperature increase of up to 3°C in the cells. This result highlights the enhanced effectiveness of the proposed strategy in achieving homogeneous thermal management of the cells throughout their operational lifecycle, as compared to a conventional approach based on the ILC strategy.

- With the ability to extend the battery system's lifespan by 62.5%, the proposed PDLC strategy has proven its effectiveness in reducing the effects of battery system aging by maintaining battery temperatures within the optimal working range, even under demanding operating conditions.

By delivering superior thermal management control without increasing pumping power consumption, and with the ability to reduce cell degradation, this approach represents a compelling alternative to conventional strategies, with significant promise for applications in the electric vehicle market.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] I. Energy Agency, “Global EV Outlook 2024 Moving towards increased affordability,” 2024. [Online]. Available: www.iea.org

[2] A. Väyrynen and J. Salminen, “Lithium ion battery production,” *Journal of Chemical Thermodynamics*, vol. 46, pp. 80–85, 2012, doi: 10.1016/j.jct.2011.09.005.

[3] E. Redondo-Iglesias, P. Venet, and S. Pelissier, “Modelling lithium-ion battery ageing in electric vehicle applications—calendar and cycling ageing combination effects,” *Batteries*, vol. 6, no. 1, pp. 1–18, 2020, doi: 10.3390/batteries6010014.

[4] X. Han *et al.*, “A review on the key issues of the lithium ion battery degradation among the whole life cycle,” *eTransportation*, vol. 1, p. 100005, 2019, doi: 10.1016/j.etran.2019.100005.

[5] S. Barcellona and L. Piegari, “Effect of current on cycle aging of lithium ion batteries,” *J Energy Storage*, vol. 29, no. March, p. 101310, 2020, doi: 10.1016/j.est.2020.101310.

[6] C. Rouaud, “Automotive Thermal Management - Online conference,” in *xEV thermal management - Model Based Development to reduce time, cost and optimise energy management (Ricardo)*, 2020.

[7] Y. Chung and M. S. Kim, “Thermal analysis and pack level design of battery thermal management system with liquid cooling for electric vehicles,” *Energy Convers Manag*, vol. 196, no. May, pp. 105–116, 2019, doi: 10.1016/j.enconman.2019.05.083.

[8] Z. Lu *et al.*, “A comprehensive experimental study on temperature-dependent performance of lithium-ion battery,” *Appl Therm Eng*, vol. 158, Jul. 2019, doi: 10.1016/j.applthermaleng.2019.113800.

[9] H. Wang, Z. Wang, D. Huang, and R. Zhao, “Analysis of dynamic characteristics of single-phase/two-phase immersion cooling battery module under sloshing excitations,” *Int J Heat Mass Transf*, vol. 242, p. 126824, Jun. 2025, doi: 10.1016/J.IJHEATMASSTRANSFER.2025.126824.

[10] C. Suresh, A. Awasthi, B. Kumar, S. kyun Im, and Y. Jeon, “Advances in battery thermal management for electric vehicles: A comprehensive review of hybrid PCM-metal foam and immersion cooling technologies,” *Renewable and Sustainable Energy Reviews*, vol. 208, p. 115021, Feb. 2025, doi: 10.1016/J.RSER.2024.115021.

[11] S. Wu, L. Lao, L. Wu, L. Liu, C. Lin, and Q. Zhang, “Effect analysis on integration efficiency and safety performance of a battery thermal management system based on direct contact liquid cooling,” *Appl Therm Eng*, vol. 201, Jan. 2022, doi: 10.1016/j.applthermaleng.2021.117788.

[12] H. Choi, H. Lee, J. Kim, and H. Lee, “Hybrid single-phase immersion cooling structure for battery thermal management under fast-charging conditions,” *Energy Convers Manag*, vol. 287, Jul. 2023, doi: 10.1016/j.enconman.2023.117053.

[13] P. Dubey, G. Pulugundla, and A. K. Srouji, “Direct comparison of immersion and cold-plate based cooling for automotive li-ion battery modules,” *Energies (Basel)*, vol. 14, no. 5, Mar. 2021, doi: 10.3390/en14051259.

[14] M. Suresh Patil, J. H. Seo, and M. Y. Lee, “A novel dielectric fluid immersion cooling technology for Li-ion battery thermal management,” *Energy Convers Manag*, vol. 229, Feb. 2021, doi: 10.1016/j.enconman.2020.113715.

[15] C. Roe *et al.*, “Immersion cooling for lithium-ion batteries – A review,” Mar. 30, 2022, *Elsevier B.V.* doi: 10.1016/j.jpowsour.2022.231094.

[16] M. Larrañaga-Ezeiza, G. Vertiz, P. F. Arroiabe, M. Martinez-Agirre, and J. Berasategi, “A novel direct liquid cooling strategy for electric vehicles focused on pouch type battery cells,” *Appl Therm Eng*, vol. 216, Nov. 2022, doi: 10.1016/j.applthermaleng.2022.118869.

[17] M. Alipour, C. Ziebert, F. V. Conte, and R. Kizilel, “A review on temperature-dependent electrochemical properties, aging, and performance of lithium-ion cells,” Sep. 01, 2020, *MDPI*. doi: 10.3390/batteries6030035.

[18] X. Han, M. Ouyang, L. Lu, and J. Li, “A comparative study of commercial lithium ion battery cycle life in electric vehicle: Capacity loss estimation,” *J Power Sources*, vol. 268, pp. 658–669, Dec. 2014, doi: 10.1016/J.JPOWSOUR.2014.06.111.

Presenter Biography

Manex Larrañaga Ezeiza received a B.S. in Energy Engineering in 2017, an M.S. in Industrial Engineering in 2019, and a Ph.D. in Applied Engineering in 2023, all from Mondragon Unibertsitatea, located in the Basque Country, Spain. He works at CIDETEC Energy Storage, a leading research centre specializing in the entire battery value chain, from chemistry to final applications. They design and develop cells, modules, and battery packs tailored to customer needs, with a strong focus on transferring technology to industry. Specialising in the thermal management of lithium-ion batteries, he has conducted several scientific studies, holds a patent and is actively involved in national and international projects in this field.