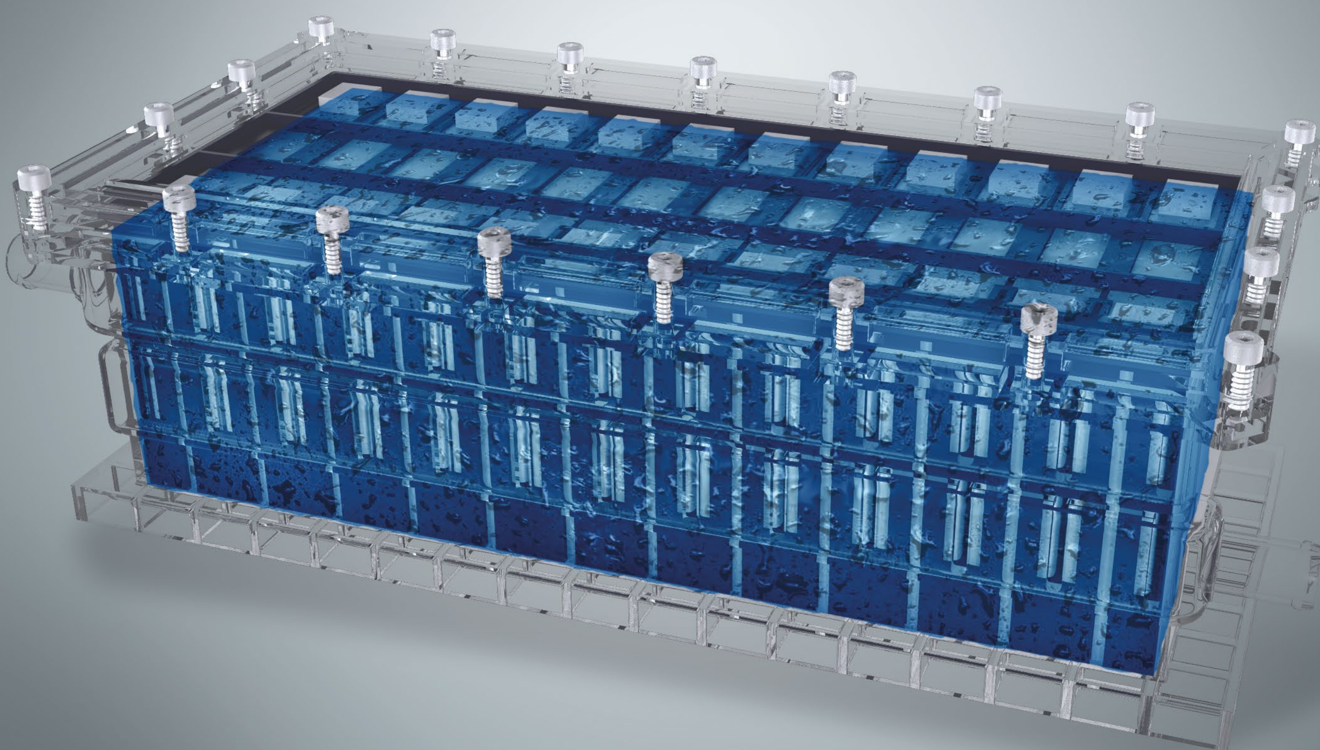

© Valeo SA

Immersive Battery Cooling Using a Dielectric Fluid

Immersive cooling has several advantages compared to traditional thermal management systems with aluminum coolers and cooling plates, This results from the direct contact of the coolant with the cells. Valeo is currently developing such a cooling solution for passenger car traction batteries with a dielectric fluid from TotalEnergies. The solution aims to enhance fast charging while minimizing power derating at the same time.

WRITTEN BY

Pascale Herman
is Product Marketing, Research & Innovation Director in the Thermal Systems Business Group at Valeo in Paris (France).

Prof. Kamel Azzouz
is Head of Research & Innovation at Valeo in Paris (France) as well as Associate Professor at Arts et Métiers ParisTech in Paris (France).

Lithium-ion battery cells need to be operated in a range of temperature between 5 and 35 °C to deliver the electric energy safely and avoid aging acceleration. This requires warm up in winter and cool down in summer. Today the electric vehicle market is using mainly aluminum coolers They can consist of cooling plates at the bottom and/or the top for prismatic cells, wavy coolers for cylindrical cells, and vertical coolers for pouch cells. The gap between the real power to recharge (nominal) and the power to recharge announced (depicted) can be up to 40 %, which is limited mainly by the cells' temperature rise, forcing a power derating.

Market trends are evolving to meet the demands of increasingly rapid charging rates, with a growing preference for 3C and 4C charging. However, it is essential to note that higher charging rates, particularly 4C charging, quadruples the heat production compared to traditional 2C charging.

FIGURE 1 illustrates the temperature of battery cells with fluid at 15 °C at the inlet of the pack for various cooling technologies (simple bottom cooler, double top and bottom cooler, immersive technology) and under different charging rates. It is evident that the relationship between C-rate and heat dissipation for battery cells exhibits nonlinear behavior. At the highest C-rate capabilities, only immersive cooling technology can maintain cell temperatures within the permissible limit of 45 °C.

Moreover, there is a growing focus of battery development on enhancing safety by controlling thermal events and preventing thermal propagation. This additional market trend highlights the need for advanced thermal management strategies in order not to only dissipate heat but also to mitigate the risks associated with thermal events, ensuring the safety and integrity of battery systems. Additional to these trends, there is also a need to improve the cooling efficiency of critical components such as busbars, which are essential for electrical current transmission within battery systems.

By addressing these market trends through immersive cooling technology, like the one proposed by Valeo, the industry can effectively support faster charging rates while prioritizing safety, efficiency, and reliability in electric vehicles. In this article, the convergence of these trends is explored, and the immersive cooling solution [2] is presented as a robust answer to the changing dynamics of battery thermal management in electric vehicles.

TECHNOLOGY ILLUSTRATION WITH PATENTED THERMAL HYDRAULIC ARCHITECTURE

The immersive cooling of the so-called Valeo Smart Battery incorporates a dielectric fluid [3], which is integrated into a structural module casing. This fluid, along with an optimized and patented thermal hydraulic architecture, minimizes the fluid volume while maximizing heat transfer efficiency between the cells and the fluid. Additionally, the hydraulic pump power demand is reduced significantly. The combination of a specific dielectric thermal hydraulic module, high-performance pump and dielectric cooler designed permits to respect the same electrical consumption as a battery pack with standard coolers, **FIGURE 2**.

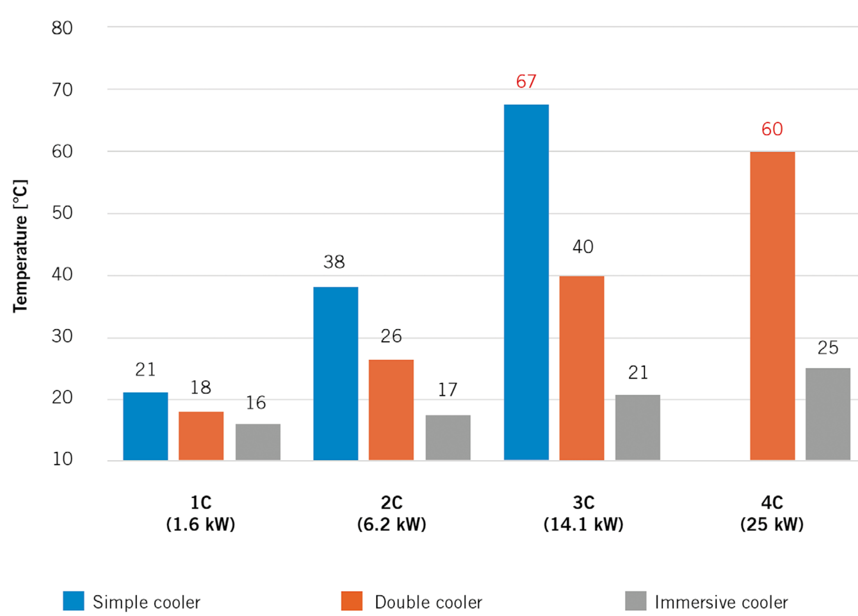

FIGURE 1 Temperature comparison for different cooler types at charging rates from 1C to 4C and charging power from 1.6 to 25 kW (fluid at 15 °C at the inlet piece of the pack, cell shape prismatic, pack energy content 103 kWh, pack flow rate 1200 l/h) (© Valeo SA)

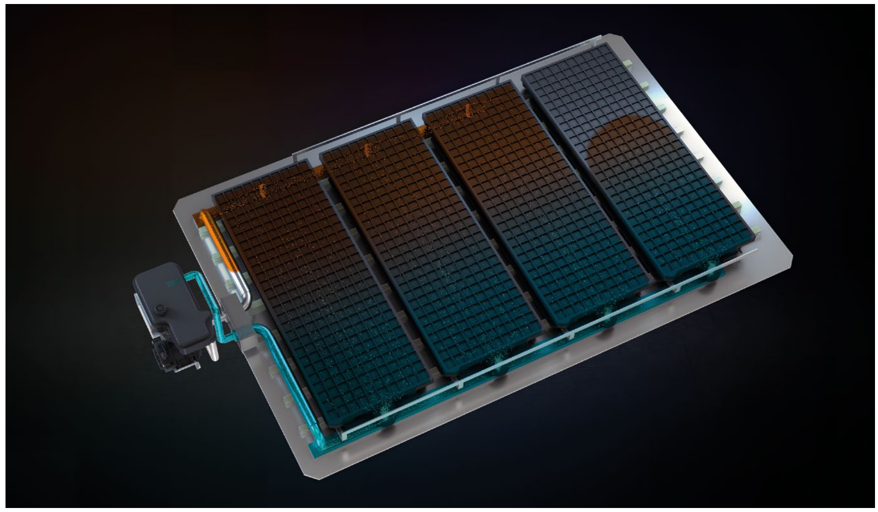

FIGURE 2 Immersive cooling system for cylindrical battery cells: integrated dielectric fluid connection and structural module casing made from organo sheet (© Valeo SA)

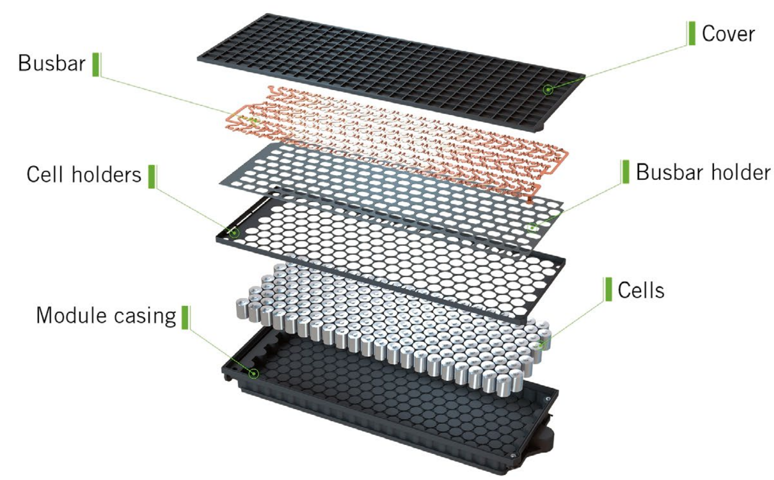

FIGURE 3 Set-up of the immersive cooling system with the structural module casings and the internal subcomponents (© Valeo SA)

The internal hydraulic architecture is coupled with an adapted venting network, facilitates a unique passive fluid circulation. This natural circulation process ensures that the fluid flows around each cell, mitigating the risk of a thermal runaway even when the pump is not in operation.

Another characteristic of the immersive technology is the usage of structural modules made from organo sheet (a fiber/matrix semi-finished product). This provides robust mechanical protection against crashes and significantly reduces the CO_2 footprint (50 % less CO_2 equivalent emissions compared to aluminum) while keeping aspects of light weight design, **FIGURE 3**.

Material compatibility with dielectric fluids has been tested and confirmed through aging tests (> 1000 h at 80 °C) and mechanical test comparisons with the initial state. In addition, organo sheet material meets all battery requirements, such as EMC shielding thanks to the ability to integrate thin metal layers or fire resistance as it can withstand high temperatures (> 1000 °C during 5 min), **FIGURE 4**.

FASTER CHARGING WITHOUT THERMAL RUNAWAY

The immersive cooling solution is currently undergoing experimental validation by Valeo. Preliminary results

Charging forward

to the next generation
of efficient transportation

BORGWARNER

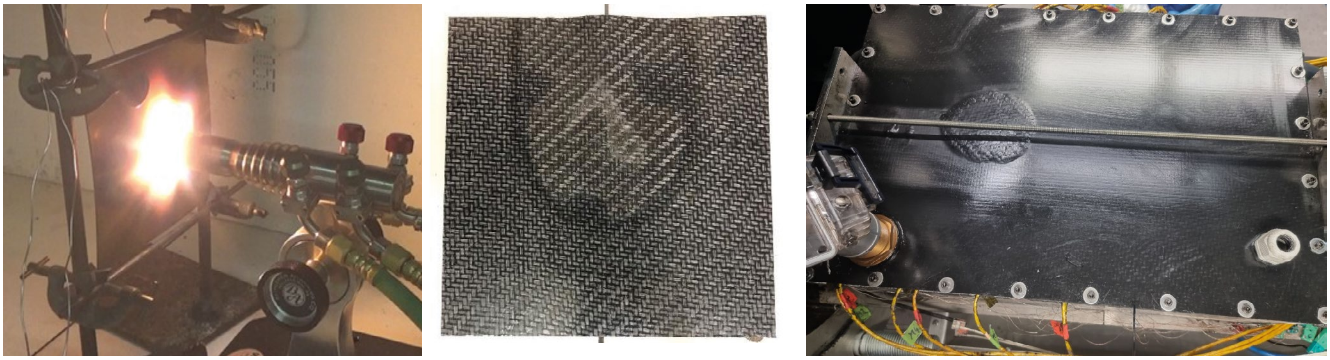

FIGURE 4 Illustration of several typical organo sheet fire resistance tests on material samples and on battery packs (© Valeo SA)

confirm its thermal hydraulic behavior and also demonstrate the capability to extend fast charging operations by 30 %, enabling the battery to recharge from 10 to 80 % state of charge in less than 12 min – compared to the previous longer duration of 18 min, **FIGURE 5**.

These enhancements in charging operation are attributed to the immersive solution's increased cooling capacity (+36 %), achieved with the same hydraulic power of the pump. The consistent performance at iso hydraulic power is attained through a specific design of the dielectric cooler with low pressure drop, the internal architecture of the immersive module, and the associated flow distribution with adapted piping and connections.

The thermal runaway test results confirm the effectiveness of the immersive technology in controlling this event. **FIGURE 6** illustrates the results of the test which was conducted during a battery overcharge. It could be shown that the maximum temperature of the overcharged cell reached 220 °C, while the adjacent cell remained at a safe temperature of 110 °C, without a propagation of thermal runaway being observed.

Furthermore, this test was conducted without the circulation of the dielectric fluid (the pump was not operational). This demonstrated the efficiency of passive fluid circulation by natural flow around each cell in mitigating the thermal runaway.

CONCLUSIONS

Through the patented thermal hydraulic architecture combined with an adapted venting network, allowing a passive fluid

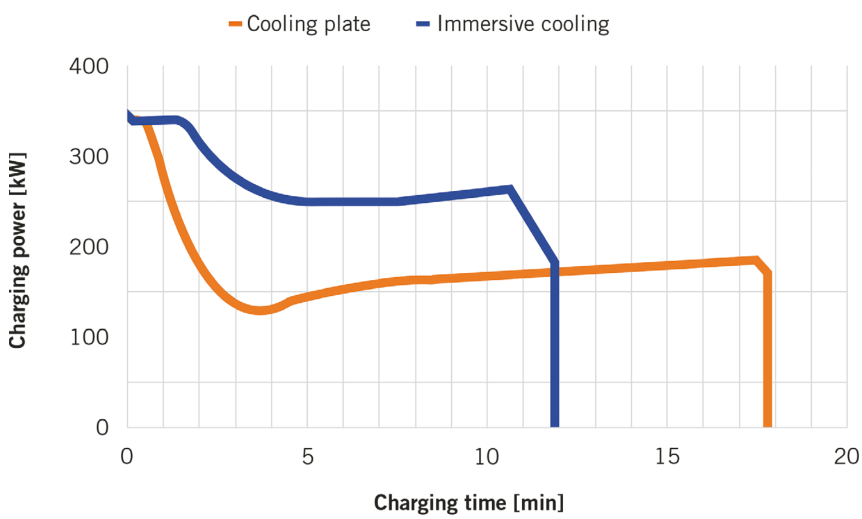

FIGURE 5 Shorter charging times for immersive cooling compared to conventional cooling plate from state of charge 10 to 80 % (at constant current and constant voltage (CC-CV), AC system, ambient temperature 35 °C) (© Valeo SA)

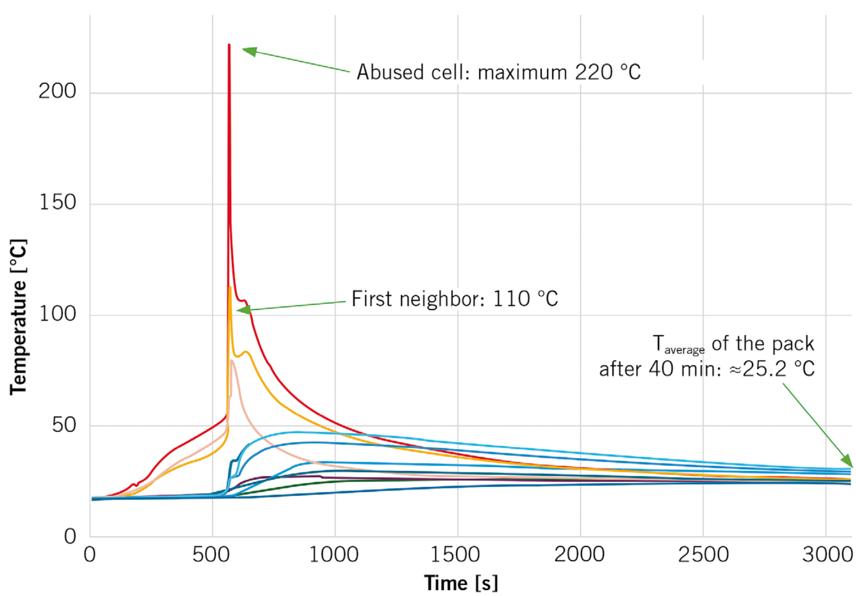

FIGURE 6 Thermal runaway test during an overcharge (© Valeo SA)

circulation, Valeo has developed a solution that enhances fast charging capabilities while minimizing power derating compared to traditional cooling systems. The experimental and numerical validation has confirmed the solution's performance, demonstrating a 30-% extension in fast charging operations and effective control of thermal runaway events, even when the pump is not in operation. It can be said that the Smart Battery immersive cooling solution represents a significant advancement in battery thermal management for electric vehicles.

PROJECT PARTICIPATIONS

Furthermore, Valeo's commitment to the development and industrialization of the immersive technology is evident through its involvement in various projects aimed at defining optimal battery cooling solutions. Since 2021, the company has actively participated in the Liberty European-funded initiative, in collaboration with Mercedes-Benz, and the Battery Spray Cooling Project funded by the French BPI/PIA4 program in partnership with Stellantis. Otherwise, the cooling solution is being advanced through an advanced development project funded by a major EU automaker, with objectives including thermal stability, lightweight design, affordability, CO_2 emissions reduction, and enhanced fast charging capability.

SUMMARY AND OUTLOOK

The immersive cooling solution from Valeo for passenger car traction batteries incorporates a special dielectric fluid provided by TotalEnergies, which is integrated into a lightweight and structural module casing. This dielectric liquid, along with the optimized and patented thermal hydraulic architecture, minimizes the fluid volume while maximizing heat transfer efficiency between cells and fluid. Additionally, it significantly reduces hydraulic pump power demand.

The architecture, coupled with an adapted venting network, facilitates a unique passive fluid circulation. This natural circulation process ensures that fluid flows around each cell, mitigating thermal runaway risks, even when the pump is not operational. Moreover, the solution meets crash-relevant standards and reduces the CO_2 footprint by 50 % compared to conventional aluminum alternatives. It also accelerates charging and warm-up speeds by 30 % in both summer and winter conditions, consequently extending the lifespan of the battery.

This solution is also an answer to the European regulation requiring from 2024 ecological design, dismantling of the battery pack, repairing and recyclability of battery cells. By utilizing this technology, the efficiency of battery cooling is improved, ensuring optimal performance and durability under various operating conditions. Final stake is to recharge faster, to downsize the battery pack and to improve affordability of electric vehicles without degrading user experience.

REFERENCES

[1] Bordes, F.: Combination of Battery Cooling and Passenger Comfort. In: ATZworldwide 10/2021, pp. 16-20

[2] Valeo (ed.): Immersive EV Battery Cooling System. Online: https://www.valeo.com/en/catalogue/ths/immersive-ev-battery-cooling-system/, access: April 17, 2024

[3] Spektrum Akademischer Verlag (ed.): Dielektrikum. Online: https://www.spektrum.de/lexikon/physik/dielektrikum/3025, access: April 23, 2024