BATTERY THERMAL MANAGEMENT SYSTEM CASE STUDY

COMPARISON BETWEEN QOOLERS BTMS-C AND COMPETITIVE PRODUCT

Date: November 18, 2024

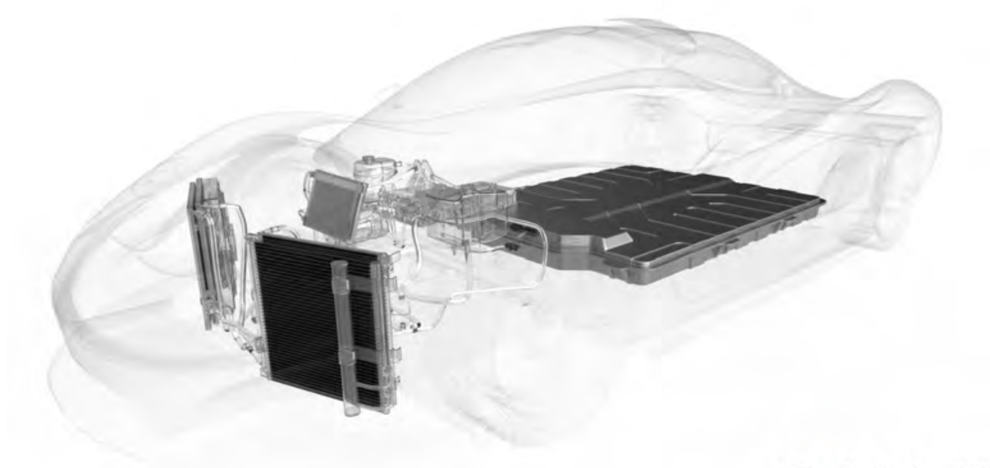
Jakub Naider MSc.

1 Introduction and Motivation

The increasing demand for high-efficiency, compact, and lightweight Battery Thermal Management Systems (BTMS) in electric mobility and stationary energy storage has accelerated the need for innovative thermal solutions beyond conventional metal-based designs. Traditional aluminum cooling plates, while effective in heat conduction, contribute substantially to overall system mass and impose geometric limitations that restrict integration flexibility. These constraints are particularly relevant in applications where every kilogram of weight reduction translates into improved efficiency, extended range, or reduced manufacturing cost.

In this context, the primary goal of the present development effort was to design and validate a thermoplastic-based cooling system capable of serving as a high-performance replacement for conventional aluminum cooling designs. Specifically, the objective was to achieve equal or superior heat-distribution characteristics while reducing system mass and enabling more flexible geometries. The BTMS-C concept reflects this intention by combining low-density polymer materials with optimized internal channel structures to enhance coolant distribution and convective performance.

This case study presents a technical comparison between Qoolers' BTMS-C (P004) and a representative aluminum-based competitive product. Through controlled testing and detailed CFD analysis, the study evaluates thermal efficiency, flow uniformity, structural thermal behavior, and hydraulic performance. The results highlight the feasibility and advantages of replacing traditional aluminum cooling plates with advanced polymer-based designs that deliver improved thermal performance at a fraction of the weight and volume.



QOOLERS
POWER OF INNOVATION

2 Description of Compared Systems

2.1 Qoolers BTMS-C

Model: BTMS-C-P004
Application: Thermal control in liquid-cooled battery systems
Design: Modular cooler with internal serpentine channels
Material: PA12 manifold with PE-MD tubes

Table 1: Technical Specifications of BTMS-C P004

Parameter	**Value**
Inlet/Outlet Diameter	Ø12 mm (quick-connect)
External Dimensions	360 × 352× 82 mm
Weight (dry)	350 g
Internal Volume	0.61 L
Flexular modulus	700 MPa (ISO 178)
Tensile modulus	650 MPa (ISO 527-1,2)
Yield stress	17 MPA (ISO 527-1,2)
Working Fluid	Water
Operating Pressure	3 bar
Flammability	Non-flammable (ISO 3795)
Surface resistivity	$10^{14} - 10^{16}$ [Ω/□]per IEC 93
Energy Storage Capacity	13 kWh
Recyclability	>90%, PA12 & PE

Figure 1: BTMS-C model preview

2.2 Competing Product (Brand X)

Model: ThermoFlow-XL
Application: Battery cooling for light-duty EVs
Design: Aluminum manifolds with Aluminum multiport tubes.

Table 2: Technical Specifications of Competitive Product

Parameter	**Value**
Inlet/Outlet Diameter	Ø12 mm
External Dimensions	650 × 430 × 92 mm
Weight (dry)	1.8 kg
Internal Volume	0.823 L
Pressure Resistance	4.5 bar
Temperature Range	-30°C to +70°C
Working Fluid	Water
Operating Pressure	3.0 bar
Energy Storage Capacity	11 kWh
Recyclability	65%

Figure 2: Competition model preview

- Note: The competitor's model was simulated without any form of electrical insulation, as selecting one of the many available insulation types could introduce bias, and omitting it ensures full objectivity in the comparative analysis.

3 Testing Methodology

3.1 Tools and Environment

- Simulation: ANSYS Fluent 2024 R2
- Repeated cycles for consistency and objectivity

3.2 Boundary Conditions

- Fluid: Water
- Inlet Temperature: 8°C
- Flow Rates: 10 L/min
- Heat generated by charge rate of 3C & 6C

3.3 Objectivity Assurance

Measurements were repeated under identical conditions. The calibration was compliant with ISO 17025 and was verified by a third-party accredited institution.

4 Key Parameter Comparison

The comparison of key thermal parameters relevant to battery cooling performance highlights several distinctions between B BTSM - C P004 and the competitor. In terms of thermal power, BTSM - C P004 shows a clear advantage, particularly at the 6C discharge rate, where it extracts a greater amount of heat from the system. In cooling applications, higher thermal power corresponds to improved heat removal capability, enabling the battery to operate more safely and consistently under elevated electrical loads. This characteristic is crucial in maintaining temperature stability and preventing excessive thermal buildup during demanding operation.

Parameter	**Competition**	**BTSM - C P004**
P-loss (3C) [kPa]	1.312	4.519
P-loss (6C) [kPa]	1.325	4.567
t-out (3C) [°C]	12.52	8.42
t-out (6C) [°C]	17.65	9.79
W (3C) [W]	310.47	337.50
W (6C) [W]	1035.00	1125.00
twall_max (3C) [°C]	11.61	10.82
twall_max (6C) [°C]	24.25	23.45

Table 3: Comparison of competition and P004 across key thermal and hydraulic parameters.

A similar trend is observed in the results of the outlet temperature. For both 3C and 6C conditions, BTSM - C P004 produces lower outlet temperatures compared to the competitor. Lower outlet temperatures indicate more effective heat transfer, as the coolant returns to the battery pack at a reduced temperature, improving the overall thermal balance of the cooling loop. Operating the pack at reduced temperatures supports longer battery life and improves the reliability of the system by mitigating thermal stress.

The measurements of maximum wall temperature further reinforce this behavior. The lower or comparable wall temperatures achieved by BTSM - C P004 suggest improved management of local temperature peaks within the battery modules. Since hotspots can accelerate cell degradation and introduce safety concerns, keeping wall temperatures well controlled is an important indicator of robust thermal behavior across the battery structure.

Although BTSM - C P004 exhibits a higher pressure loss than the competitor, this result does not necessarily imply a performance disadvantage. Increased pressure loss is often associated with improved heat-transfer surfaces or higher turbulence levels, both of which strengthen thermal exchange efficiency. In high-performance cooling designs, modest increases in pressure loss are a common and acceptable trade-off when they accompany gains in cooling effectiveness. Furthermore, the magnitude of the pressure difference remains within a range that typical pump systems can accommodate without significant efficiency reductions.

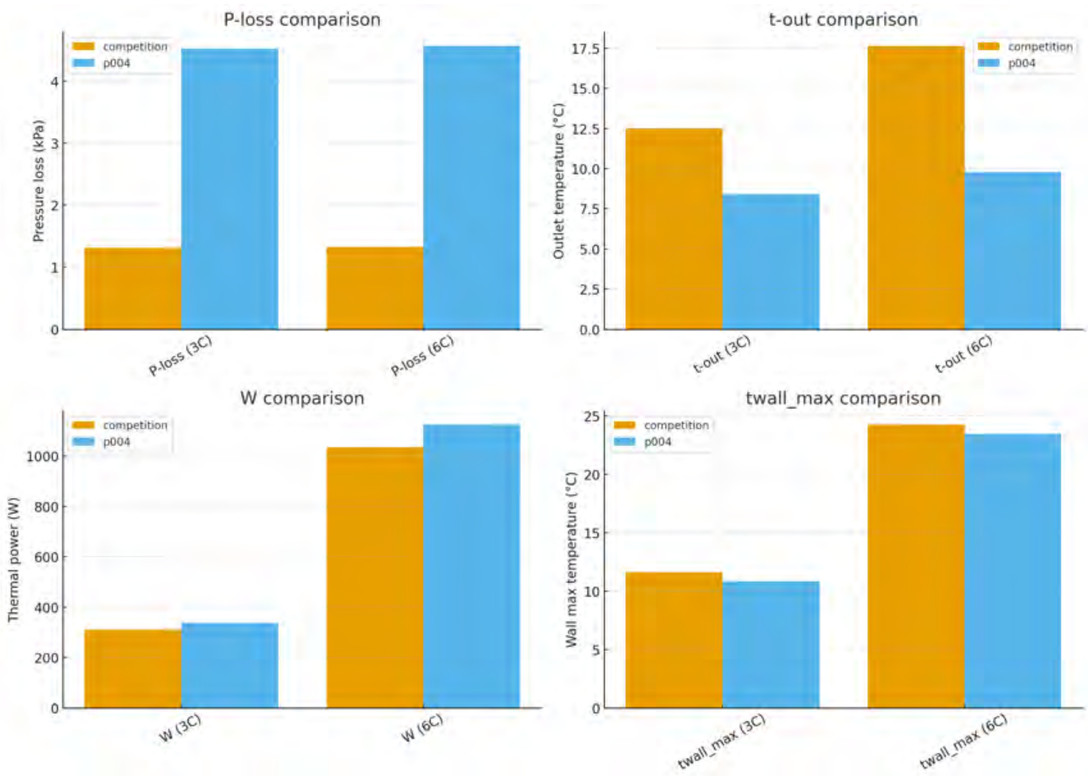


Figure 3: Temperature distribution contours at battery conduction faces

In general, the collective results show that BTSM - C P004 provides superior thermal control in the areas that matter the most for battery cooling. Provides improved heat extraction, lower operating temperatures, and better suppression of thermal hotspots. The additional pressure loss is minor in context and does not detract from the overall thermal performance benefits. Therefore, BTSM - C P004 represents a more effective solution for maintaining safe and stable thermal conditions in high-power battery applications.

5 Results Interpretation

5.1 BTMS-C P004

The wall-temperature contours of BTSM - C P004 show a very uniform thermal distribution across the cooling channels, with temperatures ranging only from about 281 K to 285 K. The smooth gradients and absence of pronounced hot spots indicate effective heat transfer and consistent coolant flow throughout the geometry. Slightly warmer regions appear near the upper portions of some cylinders, but the variations are minimal and remain well within acceptable limits. Overall, the contours confirm that BTSM - C P004 maintains stable wall temperatures and provides efficient thermal management under the evaluated operating conditions.

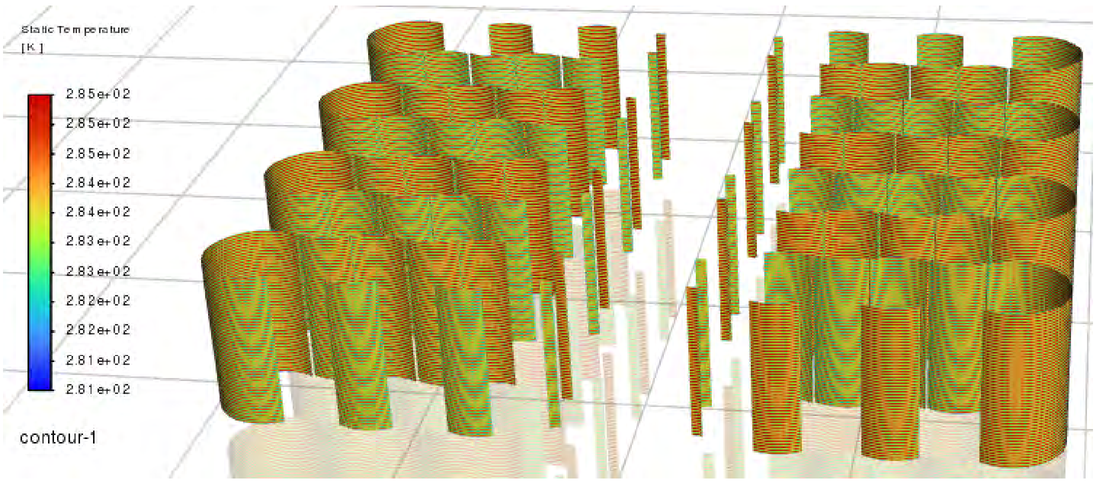


Figure 4: BTSM-C P004 temperature distribution contours at battery conduction faces

The velocity pathlines for BTSM - C P004 show a smooth and well-distributed flow through the cooling channels, with the highest velocities concentrated near the inlet region and gradually decreasing as the coolant progresses downstream. The transition from red/yellow to predominantly blue indicates controlled deceleration without signs of major recirculation zones or stagnant pockets. The flow remains attached along the curved passages, suggesting that the channel geometry effectively guides the coolant and maintains uniform velocity profiles. Overall, the pathlines confirm that BTSM - C P004 provides stable and consistent coolant transport, supporting efficient heat removal throughout the system.

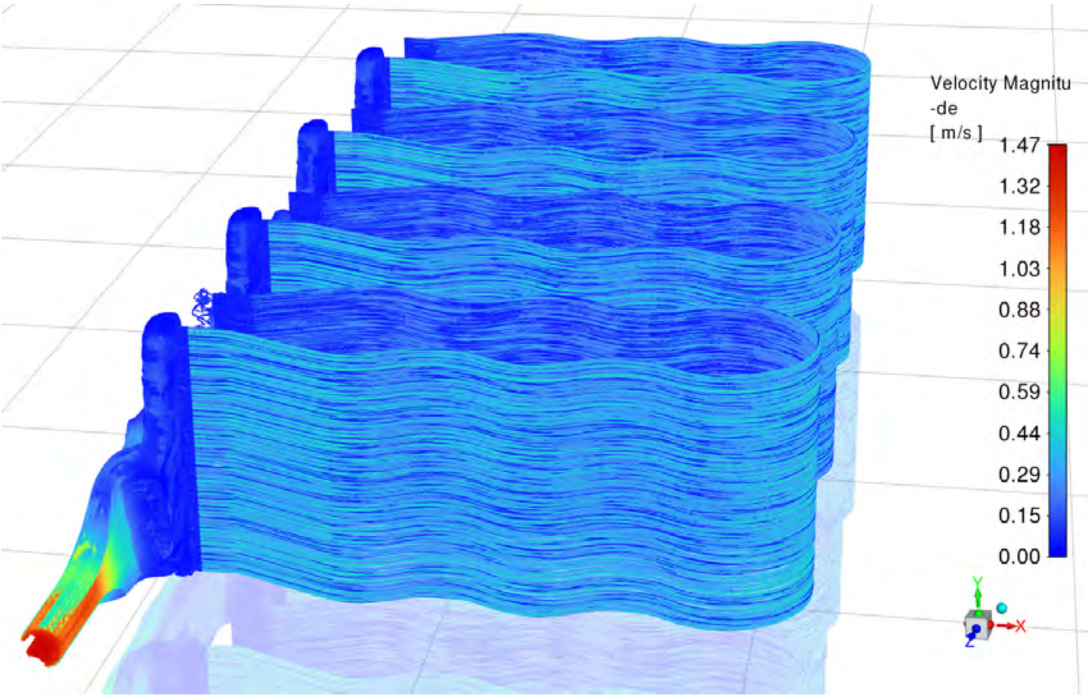


Figure 5: BTSM-C P004 velocity pathlines from simulation

5.2 Competitor's BTMS

The temperature contours of the competitor's cooling system indicate a broad and uneven thermal distribution, with extended regions experiencing elevated temperatures relative to the surrounding areas. This pattern reflects a lack of uniform heat removal across the channel length, suggesting that the coolant does not maintain consistent thermal contact with all surfaces. The presence of steep temperature gradients and localized hot zones points to insufficient coolant penetration, especially in downstream regions where effective heat transfer is critical. Such behavior is indicative of geometric inefficiencies that limit thermal spreading and promote areas of thermal stagnation. Relative to the more uniform and lower-temperature profiles observed in P004, the competitor's design demonstrates reduced thermal control and diminished capability to maintain stable operating temperatures under load.

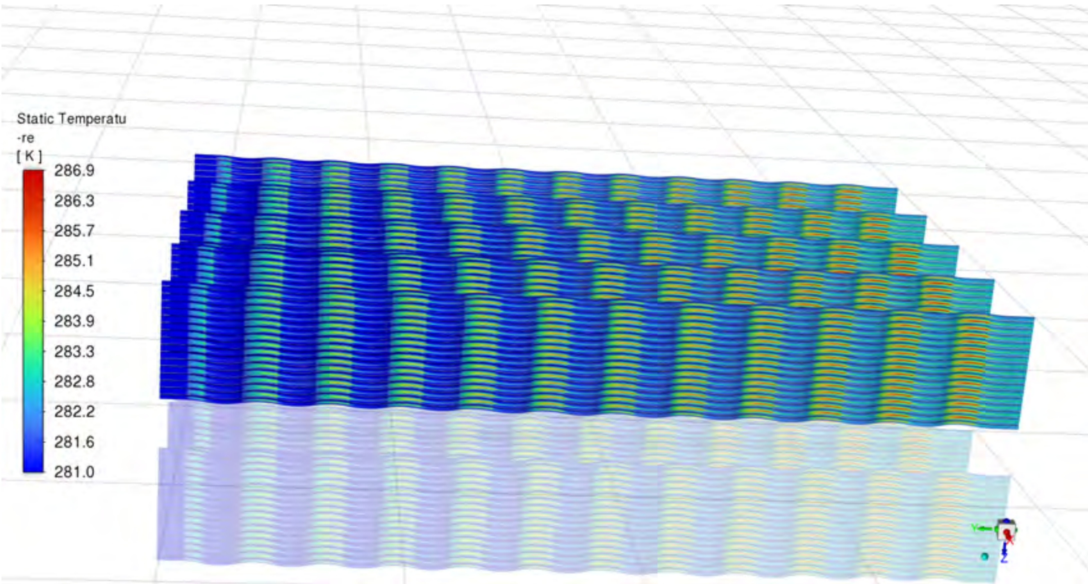


Figure 6: Competitor's BTMS temperature distribution contours at battery conduction faces

The velocity field for the competitor's design reveals substantial non-uniformity in coolant distribution, characterized by high-velocity concentrations near the inlet followed by progressively weaker flow throughout the majority of the channel network. This imbalance results in insufficient coolant transport to downstream regions, where effective convective heat transfer is essential. The presence of recirculation pockets and areas of flow separation further reduces mass flow utilization and contributes to stagnation zones that impair thermal performance. These features illustrate a hydraulic design that fails to maintain coherent flow paths, thereby limiting overall cooling efficiency. When compared to the more uniform and stable flow behavior exhibited by P004, the competitor's configuration shows clear weaknesses in coolant delivery and flow management.

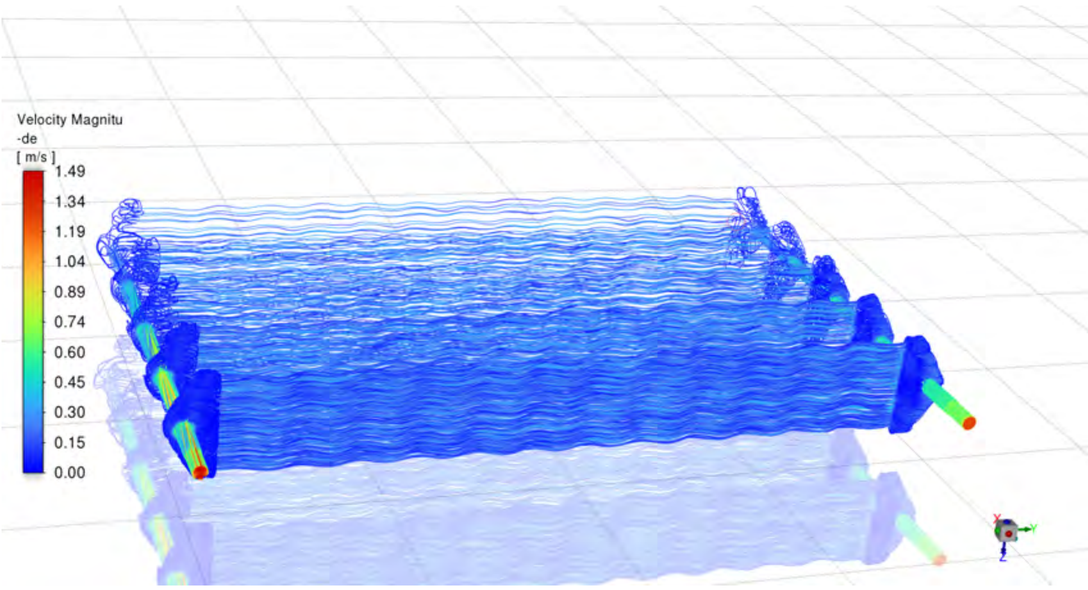


Figure 7: Competitor's BTSM velocity pathlines from simulation

5.3 BTMS-C Advantages

- Demonstrated higher thermal extraction capacity at both 3C and 6C discharge rates, reflected by consistently higher thermal power values (337.5 W vs. 310.47 W at 3C and 1125 W vs. 1035 W at 6C).
- Lower outlet temperatures across all operating conditions, confirming more effective heat removal and improved cooling-loop thermal balance.
- Reduced maximum wall temperatures at both load levels, indicating superior suppression of localized thermal peaks and improved structural thermal stability.
- More uniform coolant flow distribution, as verified by simulation pathlines showing stable velocities with minimal recirculation regions.
- Overall improved thermal robustness, making the system better suited for high-current, high-load battery operation where thermal consistency is critical.

5.4 Competitor Advantages

- Lower pressure loss through the cooling channels, which corresponds to reduced pumping energy for the same flow rate.

6 Conclusion

Summary: The combined experimental and simulation results demonstrate that the BTMS-C (P004) delivers higher thermal efficiency than the competing solution. It achieves lower outlet temperatures, reduced wall temperatures, and higher thermal power at both 3C and 6C discharge rates, resulting in improved thermal stability and enhanced battery module safety. These performance gains are particularly significant considering that the BTMS-C operates with approximately half the internal volume of the competitor's device and less than a quarter of its dry weight.

It should also be noted that the competitive cooler used in this study does not incorporate any electrical insulation between the multi-port tubes and the battery cells, which results in reduced electrical safety and does not satisfy the insulation requirements expected in modern battery thermal management systems. Moreover electrical insulation would decrease thermal transfer efficiency due to additional conduction layer. Despite exhibiting a higher pressure drop, this remains a predictable and acceptable trade-off associated with increased heat-transfer effectiveness and does not hinder system integration. Overall, P004 provides superior cooling capability in a substantially more compact and lightweight package, making it the more efficient and technically advanced solution for high-performance battery thermal management.

Outlook:

- Targeted geometric refinements to reduce pressure loss without compromising thermal efficiency.
- Integration of embedded temperature, pressure, and flow sensors for advanced monitoring and diagnostics.
- Development of physics-informed digital twin models to evaluate long-term thermal ageing and optimize future BTMS designs.