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Date:
Project within FFI – Accelerate Startup Partnership

Content

Brief about FFI

FFI is a collaboration between the state and the automotive industry to jointly finance research and innovation activities with a focus on Climate & Environment and Traffic Safety. The initiative involves activities of approximately 1 billion SEK per year, of which public funds amount to over 400 million SEK.

Read more at www.vinnova.se/ffi.

1. Summary

This study evaluates the replacement of the cold plate with Uni.T™ within Volvo battery pack to eliminate direct contact between the cells and the coolant. By using Uni.T™, the risk of leaks is removed, as the cells will no longer be directly exposed to the fluid. Uni.T™ is a thermal plate able to conduct heat up to 100 times better than copper.

The study demonstrated that Uni.T™, effectively maintains the battery pack within the required temperature limits across all evaluated configurations. Both double-sided and bottom cooling configurations results in a maximum cell temperature below 27°C for all cases, and temperature difference between cells below 3°C. The results indicate that Uni.T™ provides efficient heat transfer performance, eliminating the need for leak detection systems.

Detailed mechanical designs of Uni.T™ adapted to Volvo's pack were drawn and priced to highlight a potential price of 5.46 USD/kWh for the Uni.T™. Building the component and testing it in a real-life application will allow validation of the thermal and mechanical performance. Also, design optimization is possible to further reduce weight and cost of the solution. An end-of-life analysis shows that the proposed solution is easy to recycle and can be integrated in the current Volvo factory since it only requires standard metal without any chemicals.

3. Background

The conventional liquid cooling thermal management system used currently in Volvo's energy storage systems is prone to failure which can impact the safety of the battery pack. A coolant leakage detection is currently being evaluated in our other projects and is driving cost and complexity. Consequently, Volvo is struggling with providing cost-efficient concepts to remove the risk of coolant leakage inside of the battery pack.

Calogy's Uni.T technology is a Thermal Ground Plane that takes the form of a thin, lightweight plate offering very low resistance to heat propagation, 10x to 100x better than a similar copper plate. It is installed in contact with battery cells to maintain their uniform, optimum temperature by efficiently extracting heat from the battery module. The plates embed closed chambers under vacuum, lined with a capillary structure and partially filled with water that evaporates, travels and condenses to efficiently transport heat. The working principle is represented in Figure 1. Heat generated by the cells in contact with Uni.T evaporates the water inside the Uni.T, and this vapor travels along the component to the opposite end, where it condenses to release heat through an external heat sink or a cold plate attached to the Uni.T. Water then returns to the hot zone (evaporator) by wicking in the capillary structure.

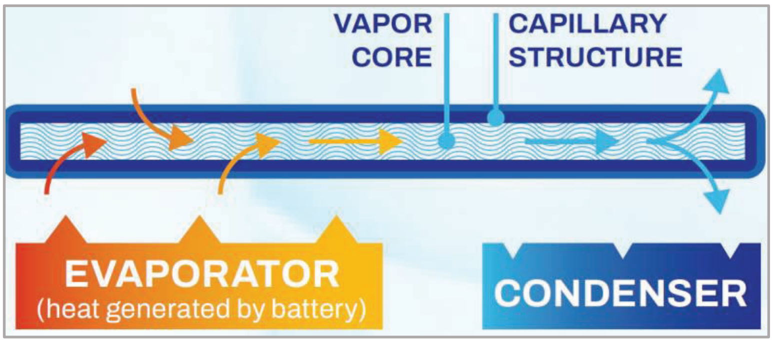


Figure 1 - Working principle of Uni.T

The whole process takes place with negligible temperature difference across the system, as all energy (heat) transfer takes place via a thermally efficient phase change and steam flow processes. The performance of Uni.T has been amply demonstrated by heat pipes and vapor chambers, using the same principle, which operates with thermal conductivities 10-100 times greater than those of equivalent solid plates made of aluminum or copper. The cells are therefore maintained at a uniform temperature, and the heat they generate is efficiently conducted to the outer surface of the battery module, where air, liquid, or refrigerant cooling systems can be used to reject the heat to the surrounding environment. Uni.T components therefore provide a highly efficient heat transfer path between the battery cells and the pack's outer casing. As a consequence, cold plates with liquid cooling lines and connectors can be avoided within the battery pack. Also, Uni.T components can be used in the reverse cycle for even heating of the battery in cold conditions.

The use of Uni.T results in a much lighter, less complex, and less costly overall battery thermal management system while offering unrivaled thermal performance. Uni.T also improves the safety of battery systems by reducing the risk of thermal runaway and allowing closed and sealed battery modules. Compared to traditional liquid cooling, flammable glycol does not need to circulate throughout the battery pack. Uni.T itself does not leak if punctured, since the few milliliters of water is trapped in the wicking structure. Furthermore, the ultra-high thermal conductivity of Uni.T balances efficiently the heat between cells, thus reducing the temperature gradient below 5°C which will increase the lifetime of the pack, and prevents cells surrounding a faulty one from overheating and igniting, preventing thermal runaway. Calogy's Uni.T concept can be integrated into the casing of the battery pack (see Figure 2), thus replacing existing parts for a limited impact on cost and reduced assembling complexity. Uni.T is a promising alternative solution for thermal management where a conventional battery thermal management system struggles with design, assembly or safety.

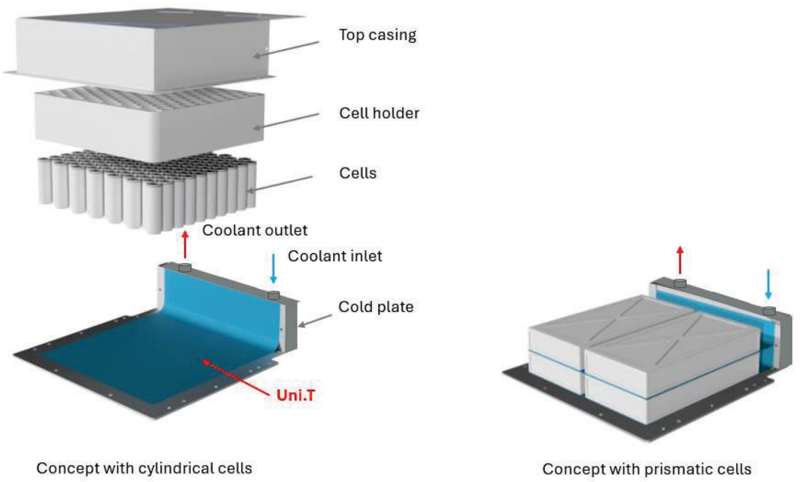


Figure 2: General battery pack concept with Uni.T as bottom casing (illustrated for cylindrical cells).

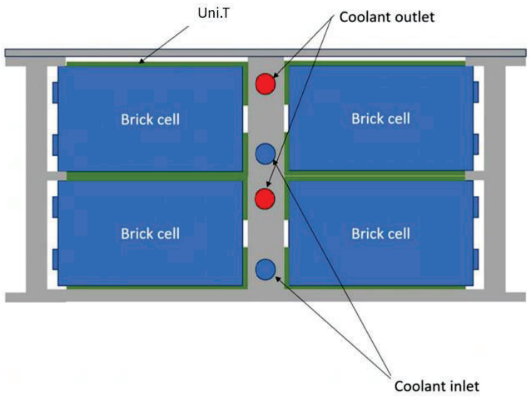
4. Purpose, Research Questions and Method

Uni.T technology presents great potential to cool and heat the Volvo battery pack. For this integration to be successful, the following questions should be addressed:

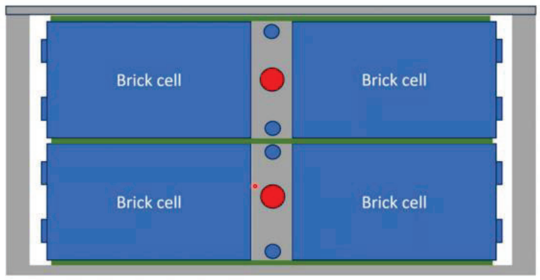
1. What is the best way to integrate Uni.T within the Volvo battery pack for an effective cooling solution?
2. How does the integration of Uni.T within battery cells impact their thermal performance (in term of maximum temperature and temperature gradient)?
3. What are the structural requirements of Uni.T to act as a load-bearing structure for the battery cells?
4. How much a potential Uni.T configuration would cost for large volume production and integration inside the Volvo battery pack?

To answer those questions, a structured approach is developped in which multiple integration concepts are evaluated in term of thermal performance, mechanical integration requirement and cost. Figure 3 presents various preliminary concept solutions provided by Volvo and Calogy including Calogy Uni.T technology and cold plate systems. In some of these configurations, Uni.T would be in contact with the bottom or with the side of each cells. Coolant flow can be located as described above or in the outer walls, cooling plates, lid or floor of the battery pack.

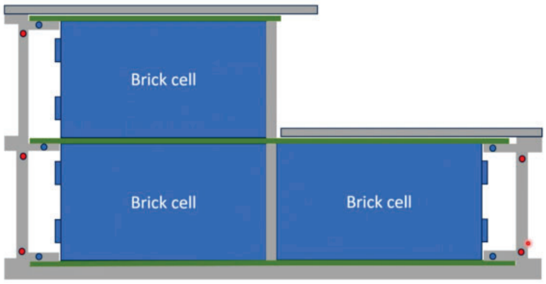
Since Uni.T can also act as part of the battery pack structure, the various configurations not only be considered for thermal aspects but also for the structural and assembly aspects. Indeed, Uni.T can be fabricated with structural metallic layers, making the component load bearing. This can allow Uni.T to replace existing structural parts in the pack design, contributing to a reduction in number of parts, in weight and potentially in cost. It can also be designed to act as a support for the cells, which can also facilitate the assembly process, reducing assembly complexity, time and cost. Through its joint thermal-structural roles, Uni.T allows the thermal management to be directly integrated and embedded within the pack structure. This can reduce the need for intermediate module subassemblies, allowing performant and compact cell-to-pack configurations.



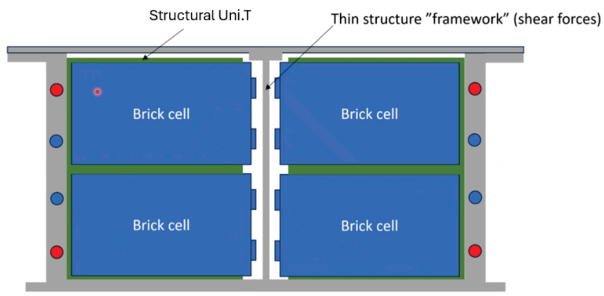
(a) Side cooling configuration #1



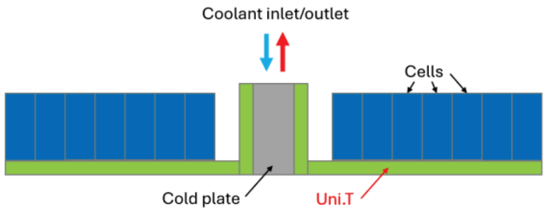
(b) Side cooling configuration #2



(c) Side cooling configuration #3



(d) Side cooling configuration #4



(e) Bottom cooling configuration #1

Figure 3: Various battery pack concepts using brick cells with Uni.T.

The following “**Deliverables**” shall be provided by Calogy to Volvo Group:

- WP1
    - <u>Deliverable 1 – Technical report</u>:
        - Simulated performance results: cells temperature against various parameters (time, C-rate, coolant temperature and flow) and in different configurations.

- Milestone 1*:*
  - Demonstrate that the thermal performance of Uni.T technology meets the requirement of the envisioned applications.
  - Success metrics:
    - Temperature gradient between cells $\leq 5°C$,
    - Meet cooling/heating requirement of 0,0214 kW/kWh*,*
    - Respect cell temperature below target for most stringent charge/discharge cycles.

- WP2
  - Deliverable 2 – Technical report:
    - Mechanical design (outer dimensions, mechanical stiffness and thermal performance) of Uni.T and pack integration (CAD),
    - Costing of the thermal management solution for target volume of units,
    - Secondary cost reduction values (due to simplified design of the battery pack and to lifetime increase),
  - Milestone 2:
    - Propose a viable mechanical integration configuration for the Uni.T technology in the battery pack for the most promising configuration that meets the target cost.
    - Success metrics:
      - Overall cost lower than the actual solution,
      - Proposed integration easier than the current solution.

5. Objectives

The main objective of the project is to determine if Uni.T™ is the appropriate thermal management technology for the next Volvo battery platform from both technical and cost perspective. Specific objectives are as follow :

1. Develop a thermal model of Uni.T integrated in a battery pack to evaluate its impact on the maximum temperature and the temperature uniformity of the cells.

2. Evaluate the thermal performance of various configurations of battery pack integrating Uni.T with multiple charge and discharge profile.
3. Perform a mechanical design of Uni.T that will allow easy integration in the battery pack while respecting the specifications.
4. Evaluate the cost of the proposed solution for large volume production.

6. Result and Goal Achievement

1. A thermal model using resistance nodes was developed to evaluate the importance of each thermal resistance along the heat flow from the cells to the liquid coolant.
    a. Results showed that more than 70% of the thermal resistance comes from the cell itself.
    b. The remaining thermal resistance is approximately evenly spread between the resistance of the Uni.T, the cold plate and the contact resistance.
2. During charging, the cell temperature increases between 5°C and 7°C for all studied configurations.
    a. In bottom cooling, the temperature gradient between cells remains below 3°C for all configurations.
    b. In side cooling, the temperature gradient between cells remains below 2°C for all configurations.
3. During discharge, the heat generated is low and allows the battery pack to go go back to within 1°C of the coolant temperature enabling mutlipling charge and discharge cycles without interuption.
4. A mechanical model was developped to size the required stifness of Uni.T.
    a. A thickness of 6 mm was chosen to hold the weight of the cells at an acceleration of up to 10G.
5. Multiple seam designs were evaluated to assemble different Uni.T together. The chosen design was based on the lowest number of fasteners or weld seam.
6. Two detailed designs were completed. One with a flat configuration and a second one with a L-shaped configuration. The L-shaped designs allows a longer surface of Uni.T in contact with the cooling channels. However, the main drawbacks are higher cost and lower compacity for the solution.

7. A pricing analysis was completed to assess the manufacturing cost of the 2 mechanical designs for different volume.
    a. In volume, the CAPEX price of the Uni.T solution could be 1880 USD to thermally manage a 350 kWh battery pack.
8. Cost savings opportunities were identified to reduce the cost of the proposed solution by up to 35%.

7. Dissemination and Publication

7.1 Knowledge and Result dissemination

How is/planned the project result to be used and disseminated?	Mark with X	Comment
Increase knowledge within the area	X	
Carry forward to other advanced technical development projects	X	
Carry forward to product development projects	X	
Introduced to the market		
Used in investigations/regulations/permit cases/political decisions		

7.2 Publications

None

8. Conclusions and Further Research

This project enabled Volvo Truck and Calogy Solutions to investigate in depth the potential of the Uni.T technology to completely remove liquid coolant from the inside of a battery module. The proposed solution brings the following benefits :

- Drastically reduce the possibility of coolant leakage inside the battery pack
- Uniformize the temperature of each battery cell even with a small flow of coolant
- Reduce the requirements related to detection and control of a potential coolant leak
- Enables a passive temperature control of the cell even in the event of a pump or valve failure
- Reduce the safety requirements of the coolant since it is located further away from the battery cells.

- Unlock new design possibilities with the multiple shapes of Uni.T. For example, the side of the cell could be cooled with an additional Uni.T for enhanced performance.

A complete mechanical design and costing analysis was also performed to validate integration in the battery pack as well as costing for large volume production. Further research is required to validate the following points:

- Reduce weight of the solution by up to 40%
- Reduce cost of the solution by up to 35%
- Experimentally validate the performance of the solution in laboratory for various heat load, ambient temperature and orientation.

9. Participating Parties

Calogy Solutions and Volvo Truck