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Miba FLEXcooler® – innovative thermal management for batteries

Summary:

Traditional battery cooling takes the form of a plate, usually made from aluminum, with embedded channels for the coolant. The battery cells, which are usually surrounded by a metal sleeve, and the cooling plate consist of rigid surfaces. Any direct contact – for example, due to manufacturing tolerances – always leads to an air gap and thereby to poor heat conductivity. To achieve good thermal coupling expensive thermal interface materials (gap fillers) are required. Here we describe how a flexible heat exchanger can replace the cooling plate. The flexible heat exchanger adjusts its shape to the battery cell, which leads to direct thermal contact between the heat exchanger and the battery cell, even without the use of thermally conductive paste.

The flexible heat exchanger can be used in a wide variety of cooling options for extremely different shapes of cells (cylindrical, prismatic, and pouch). A comparison of the different cooling options based on the newly defined cross-system ***cooling efficiency coefficient*** and the ***cell uniformity coefficient*** shows the superior performance of pole cooling for cylindric cells.

Cooling system with direct thermal contact: FLEXcooler®

To ensure proper functioning, the heat sink/heat exchanger must have nothing but coolant flowing through it. Moreover, to ensure efficient thermal conductivity, it must be thermally connected with the battery cell casing. This can be achieved through the use of a flexible heat exchanger, which is right next to the battery cell casing and is pressure-resistant. When connected to the coolant circuit the pressure of the coolant provided by the coolant pump inflates the flexible heat exchanger, thereby pressing it against the battery cell. The Miba FLEXcooler® adapts perfectly to the contours of the battery cells (Figure 1), thereby ensuring efficient heat transfer.

A flexible heat exchanger has the further benefit that contact between the heat exchanger and the battery is not affected by manufacturing tolerances. In particular variations in the height of battery cells and production-related variations in the installation positions of battery cells within a module are compensated for (Figure 1).

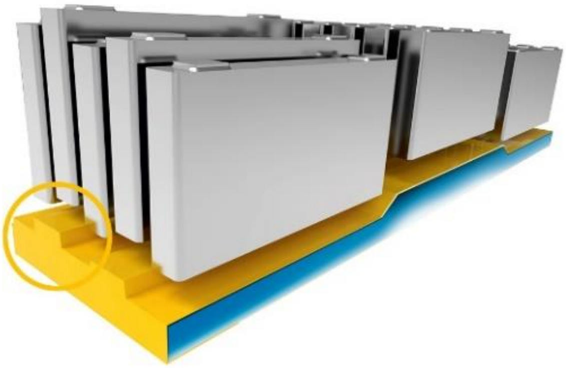

Figure 1: Tight thermal contact and compensating manufacturing tolerances with prismatic cells. A flexible heat exchanger levels out manufacturing tolerances, as shown here in a diagram of the installation of prismatic cells in a battery module.

In detail, this means that, the flexible heat exchanger is inserted below the battery cells and battery housing with prismatic cells (Figure 1) or between the battery cells, with cylindrical cells. As soon as coolant flows through the heat exchanger, a flat liquid channel is formed, which perfectly adjusts itself to the shape of the battery cells (and fills the gaps between them). The gaps between the battery cells can, therefore, be very small, thereby saving space and increasing energy density.

Comparing cooling options for battery cells

The FLEXcooler® can generally be added to modules of battery cells in three versions: single-sided surface cooling, double-sided surface cooling and cooling via the negative pole (equivalent to tab cooling in pouch cells). (A 4th option would be cooling above the positive pole. However, due to fuses between the bus bar and the positive pole, thermal contact can be poor). The impact of different cooling options on the battery cells is shown in Figure 2 for cylindrical battery cells. If we assume that the battery cell produces the same thermal loss of 2 W in all cooling options (corresponding to charging/discharging at approx. 2 C) and that the coolant has a temperature of 25°C, then – depending on the cooling option – the battery cell surface reaches a certain temperature in a stationary state.

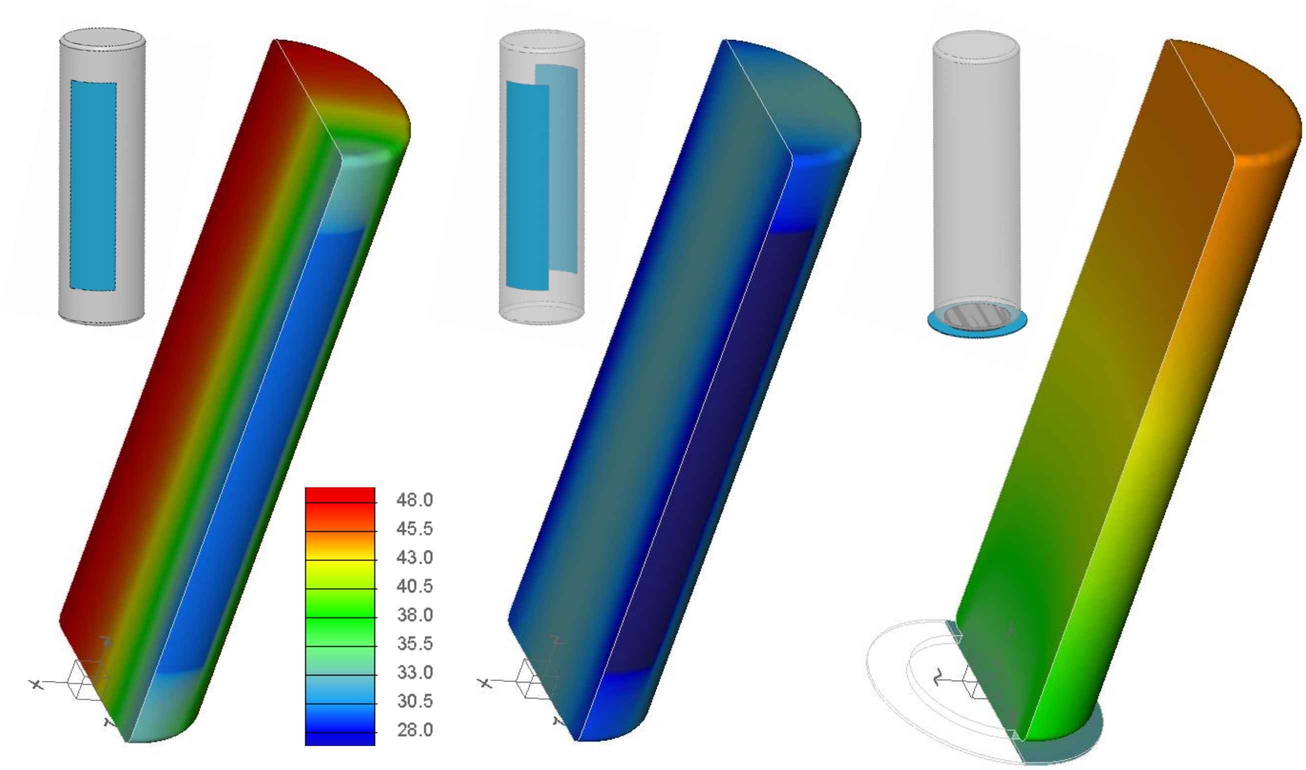

Figure 2: Temperature Profile for cooling variants of 2170 cylindrical battery cells. single-sided surface cooling (left), double-sided surface cooling (middle) and cooling via the negative pole (right).

Any direct comparison of the cooling options based on the complex temperature profiles alone (Figure 2) would be difficult. For an initial estimate, however, it would be possible to compare the cooling options based on average temperatures and surface temperatures. However, those values are always dependent on the battery performance at that time (and the resulting power dissipation (waste heat) of the battery) and the particular coolant temperature.

Given the temperature of the coolant and the given waste heat coming from the battery cell, the performance of a cooling option in relation to a cell is determined by two parameters:

- The resulting mean cell temperature, given the coolant temperature or the difference between the mean cell temperature and the coolant temperature
- The temperature spread within the cell.

If these values are standardized based on the waste heat coming from the battery cell, the standardized values are independent of the selected charging parameters and actually describe performance the cooling option and how well a cell is cooled. This results in coefficients which apply independently of specific charging scenarios:

- ***Cooling efficiency coefficient***: $k_{efficiency}^{cooling} = \frac{\text{waste heat of cell}}{\text{mean cell temperature} - \text{coolant temperature}}$
- ***Cell uniformity coefficient***: $k_{uniformity}^{cell} = \frac{\text{waste heat of cell}}{temperature\ spread}$

Interpretation of the cooling efficiency coefficient:

The materials between the cooling liquid and the inside of the battery (where the waste heat is produced) is defined for each cooling system and method (e.g. pole/side cooling). This means that the thermal resistances are also defined. These resistances are constant (assumption: no dispersion with temperature at first approximation), and independent of the specific charging status of the cell. If the waste heat increases (e.g. through faster discharge), it can only be dissipated via the same materials and surfaces. High waste heat also leads to higher temperatures and a higher temperature spread: The ratio (***cooling efficiency coefficient***), however, remains unchanged. If a cooling system uses better materials (with lower thermal resistance), then the cell is cooled more efficiently. Given a certain coolant temperature, this results in a lower average cell temperature, and the resulting ***cooling efficiency coefficient*** is higher.
versions of cooling systems can also easily be compared with regard to efficiency (e.g. due to different attachment surfaces for single-sided and double-sided cooling, which lead to different cell temperatures although the waste heat is constant per cell, resulting in different cooling efficiency coefficients).

The ***cooling efficiency coefficient*** is, therefore, a good performance indicator for the cooling system.

Interpretation of the cell uniformity coefficient[1]:

For a selected battery cell its materials are given and its thermal resistances are therefore defined. For a given cooling option, the heat is dissipated from the cell, e.g. via a particular surface area. Due to the thermal resistance of the materials within the cell, there is a certain temperature difference (temperature spread) within the cell. If the waste heat increases (e.g. through faster charging), the temperature spread also increases. The ***cell uniformity coefficient*** remains constant in the same way as the *cooling efficiency coefficient* and remains unchanged for a given cooling system or cooling option. If the cooling system is improved by increasing the cooled surface or through attachment to the

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[1] This coefficient is similar to the coefficient defined for pouch cells by Hales et al, (Hales et al, The cell cooling coefficient. Journal of The Electrochemical Society 166 (12) (2019) 2383-2395.)

poles, thus making use of the better longitudinal thermal conductivity, then this cooling option has a higher ***cell uniformity coefficient***.

The cooling efficiency coefficient and the cell uniformity coefficient have both been defined for a combination of cooling system and battery cells (here: FLEXcooler® and 2170 cylindrical battery cell). Alternatively, by comparison with a standardized cooling system, the coefficients make it possible to assess the cooling capacity of different battery cell variants (Figure 3).

For the three cooling configurations of the FLEXcooler® cooling system this means highest coefficients for double-sided cooling, average coefficients for pole cooling, and the lowest coefficients for single-sided cooling.

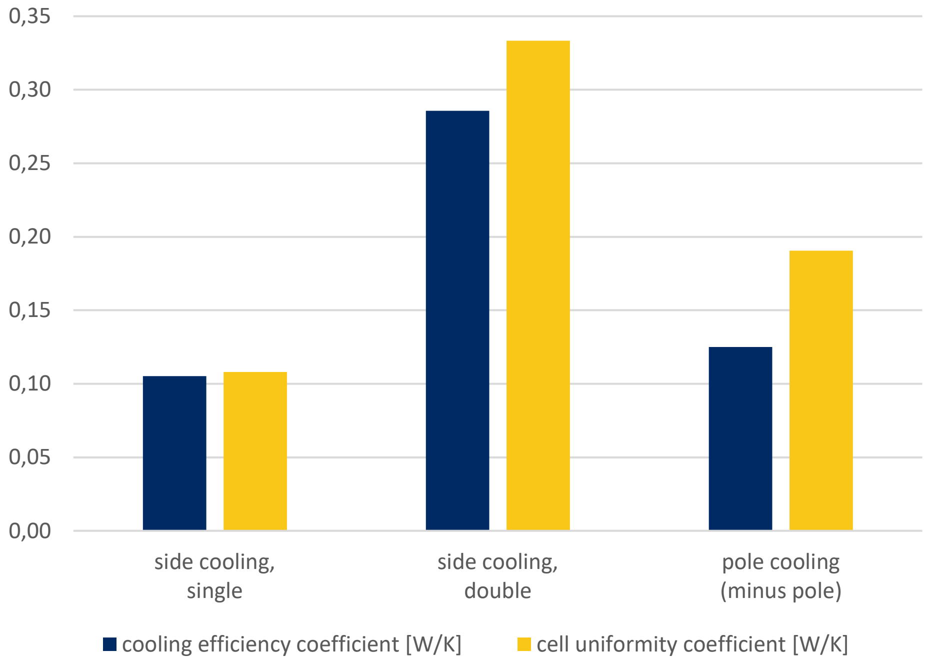

Figure 3: cooling efficiency coefficient and cell uniformity coefficient for 3 different cooling variants of 2170 cylindrical battery cells (single-sided surface cooling (left), double-sided surface cooling (middle) and cooling via the negative pole (right)).

What is surprising, however, is the relatively high cell uniformity coefficient for the pole cooling option, even though the contact surface with the heat exchanger is only one third and the distance involved is quite long. This can be explained by the exploitation of thermal conductivity, which is about 20 times higher in a longitudinal direction than in the radial direction (22 W/mK vs. 1 W/mK) for the pole cooling version. In pouch cells an effect of accelerated degradation occurs for surface cooling when compared to tab cooling.[2] Due

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[2] Hales et al., Surface Cooling Causes Accelerated Degradation Compared to Tab Cooling for Lithium-Ion Pouch Cells. Journal of The Electrochemical Society 163 (9) (2016) 1846-1852; DOI: https://dx.doi.org/10.1149/2.0361609jes

to analogous layered structure of cylindrical cells, temperature gradients appear particularly critical in a radial direction with respect to accelerated degradation. Such an effect is not considered in the cell uniformity coefficient. Compared with pole cooling, which is highly uniform in a radial direction, double-sided surface cooling only has a small additional benefit within the normal performance range considered here. The more complex double-sided surface cooling option allows to remove more access heat if highest performance is required.