Increased EV-Range through Improved Battery Thermal Management with Cooling Plates
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Abstract
Lithium-Ion cells are temperature sensitive: operation outside the optimal operating range causes premature aging and correspondingly reduces vehicle range and battery system lifetime. Consumer demands for high-performance electric and hybrid-electric vehicles result in higher cell heat loss. Thus, especially in adverse climates, a battery thermal management system (BTMS) is often required. However, the production complexity and cost of a BTMS can result in an unfavorable cost-benefit ratio, resulting in the elimination or simplification of the BTMS.

In this work, the suitability of various cooling plate layouts for battery thermal management is analyzed. The cooling plate designs were optimized for alternative production techniques within the research project eProduction. Thermal performance and energy savings through reduced pressure drop are analyzed experimentally utilizing a novel hardware-based cell model (Smart Battery Cell, or SBC). It is shown that certain cooling plate designs are more suitable as a BTMS, allowing for ideal production techniques to be identified.

Cooling Plate Designs
Friction Stir Welding (FSW), Electron Beam Welding (EBW), and Adhesion were analyzed for their suitability for joining multiple-piece 5 mm-thick cooling plates. Two cooling plates (Figure 1) were designed and assembled within the project eProduction. These cooling plates (1 and 2) allow for functional integration, providing both thermal management and mechanical structure in the battery system and/or vehicle.

The state of the art (cooling plate 3) is made from thin, soldered aluminum extrusions and plates. Cooling plate 3 is designed to minimize weight, but cannot act as a structural element in the battery system.

Procedure and Results
A hardware-based cell model (SBC) is utilized in place of an actual Lithium-Ion cell for the experimental trials. The SBC eliminates safety risks and costly specialized equipment required for experiments with actual Lithium-Ion cells and guarantees that initial conditions are quickly and reproducibly reached. Please see the submitted paper for more detail. Eight SBC are combined to form a so-called battery module (Figure 1) and attached to the cooling plates. Trials are performed at three ambient temperatures (Tₐ).

- The cell heat loss profile used as the input for the SBC (Figure 2, top) represents an aggressive driving and charging profile for a high-performance plug-in electric vehicle (PHEV). The separate profiles show the temperature dependence of cell heat loss.
- The average module temperature (Tmod avg) within the eight SBCs is plotted in Figure 2, middle. The results are shown at a constant coolant flow rate and inlet temperature for each cooling plate. The average temperature of the same eight-SBC module without thermal management is shown as a reference.
- The temperature differences over each individual cell (ΔT) are compared to one another via the quantity ΔΔT, which is the difference between the individual cell temperature gradients. As ΔΔT goes to 0, the temperature-induced aging of all cells occurs more similarly.

The pressure drop (not shown) is also critical and is discussed in detail in the submitted paper. The coupling of thermal performance and cooling plate design for production suitability help identify a cost-effective cooling plate that is suitable for mechanical integration in the battery system and/or vehicle and economically viable.

Conclusions
The experimental trials show that heat transfer to the coolant is more dominant than conduction within the solid aluminum portion of the cooling plate. Thus, a balance between the solid material required for the joining technique used, the required mechanical stability of the cooling plate, and the maximal fluid area must be found. The pressure drop resulting from geometrical changes is far more sensitive than the thermal behavior (see submitted paper). This work has shown that thin cooling plates produced via alternative techniques provide sufficient thermal performance versus the state of the art with the added benefit of potential mechanical integration. As a result, cell aging is inhibited while optimizing the vehicle integration of the BTMS, thereby contributing to greater vehicle range.