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Report on the additional cooling tests on a battery dummy

Extension to the experiments performed in March 2021 in Trauen.

Reasons for carrying out the experiments

The cooling tests carried out in March 2021 showed that cooling a traction battery with water from below or from the side leads to an increase in the heat dissipated. However, the overall power level was lower than expected. This is due to the design of the experiment, in which the battery dummy has very low thermal conductivity between the inner block (which serves as a heat accumulator) and the housing (which is sprayed with water) due to air gap insulation. For this reason, another variant with a better thermal connection between the heat accumulator and the housing shall be investigated.

Test setup

The battery dummy used for these tests is the same as the one used for the tests in Trauen. However, for the tests with higher thermal conductivity, an aluminium plate was clamped between the bottom of the aluminium block and the housing. These two versions can be seen in Figure 1 and Figure 2.

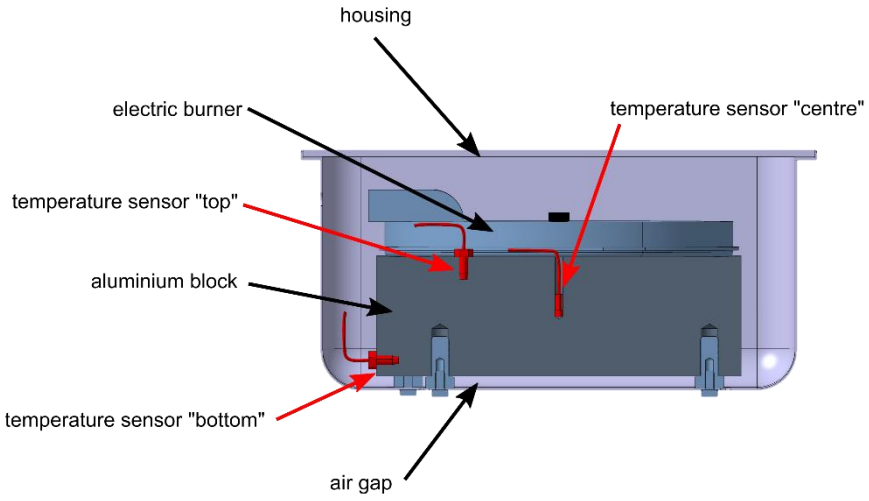

Figure 1: Sectional View of the Battery Dummy

The dimensions of the additional plate are 185 x 142 x10mm. In order to improve the heat conduction between the additional plate and the housing, fireproof burner putty was used to bond the contact surfaces.

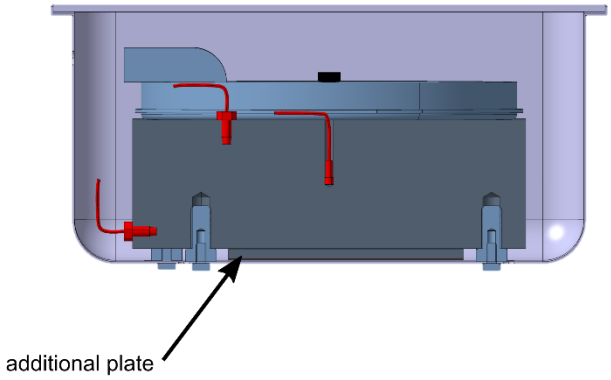

Figure 2: Sectional View of the Battery Dummy with Improved Thermal Conductivity

Since only the influence of the thermal connection is to be investigated in these tests, a simplified overall test set-up is used, which abandons the use of additional components which represent the vehicle.

This setup can be seen in Figure 3. It can be seen that only the battery dummy, which is held above the ground with spacers, is used for this setup. Furthermore, the measuring point above the body is omitted and only one external measuring point is mounted between a fastening screw of the aluminium block and the spacers.

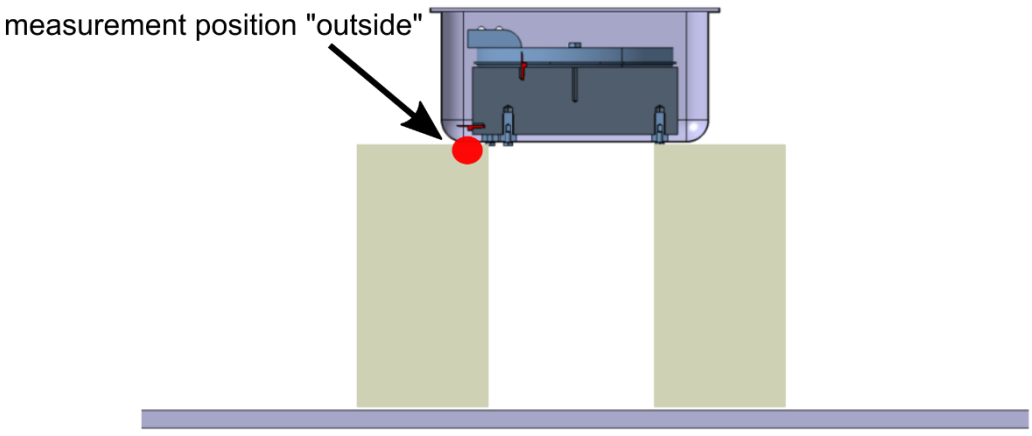

Figure 3: Test Setup

This setup is used for all measurements carried out.

Examined Variants

A distinction can be made between the following 3 different types of setups:

- Setup as in March 2021 (w/o plate)
- Increased thermal conductivity (w/ plate)
- Increased thermal conductivity (w/ plate) + opened lid

The two setups "w/o plate" and "w/ plate" are each examined twice without additional cooling as well as with water from below. The setup "w/ plate and open lid" is examined only once without additional cooling and once with water filled into the housing up to the position of the lower sensor.

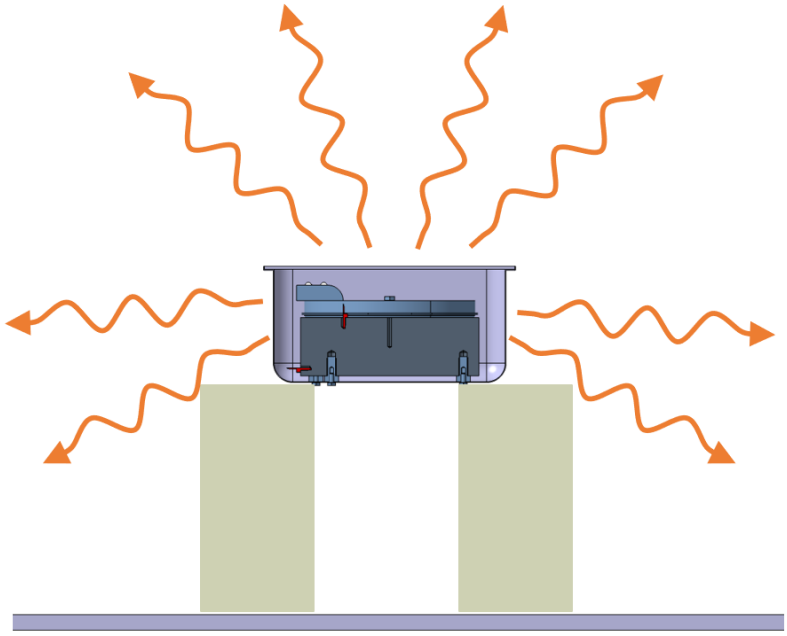

Figure 4: Setup "Air"

Figure 4, Figure 5 and Figure 6 each show the basic structure of the different variants of the setups examined. In the "air" experiments, there is no additional cooling of the experimental setup and the heat is dissipated purely by convection.

The "water" experiments were carried out by spraying the bottom of the enclosure with water. The amount of water used during these experiments was decreased significantly compared to the experiments conducted in March 2021, which means that these results cannot be directly compared with each other.

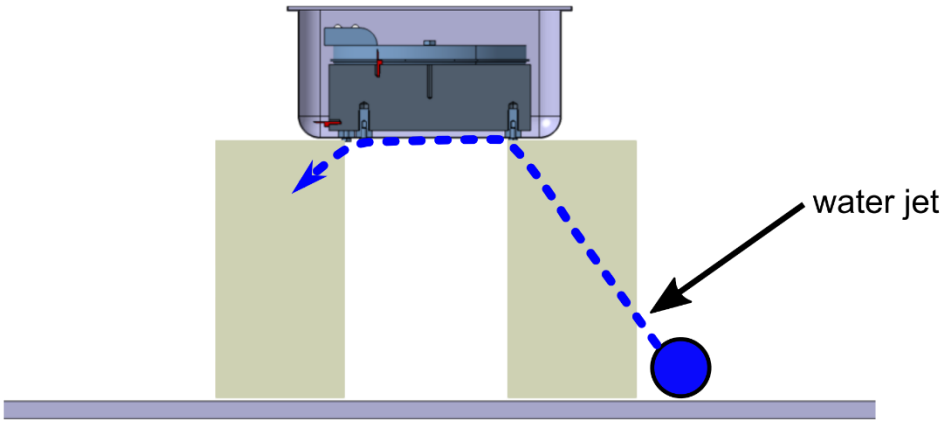

Figure 5: Setup "Water"

Figure 6 shows the setup of the last experiment, in which the opened housing of the battery dummy was filled with water up to the lower temperature sensor.

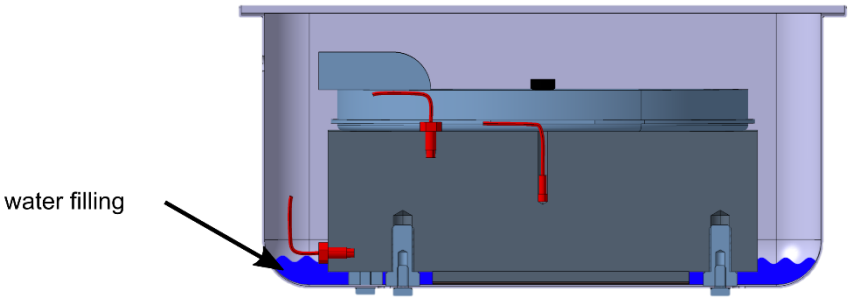

Figure 6: Setup "Water Filling"

This level was kept constant over the measurement period.

Experimental Procedure and Measurement Results

Experimental Procedure

The test procedure corresponds to that of the experiments conducted in March 2021. Except for the measurement duration which was shortened to 10 minutes during the tests in which the setup was cooled with water.

Measurement Results

To graphically illustrate the results, the temperature curves over the time are shown. Therefore, the temperature curves of all measurement variations carried out are plotted in individual graphs for the specific measurement positions. The solid line corresponds to the first measurement, while the second is shown as a dashed line. Figure 7 shows the temperature curves for the measurement position in the middle of the aluminium block.

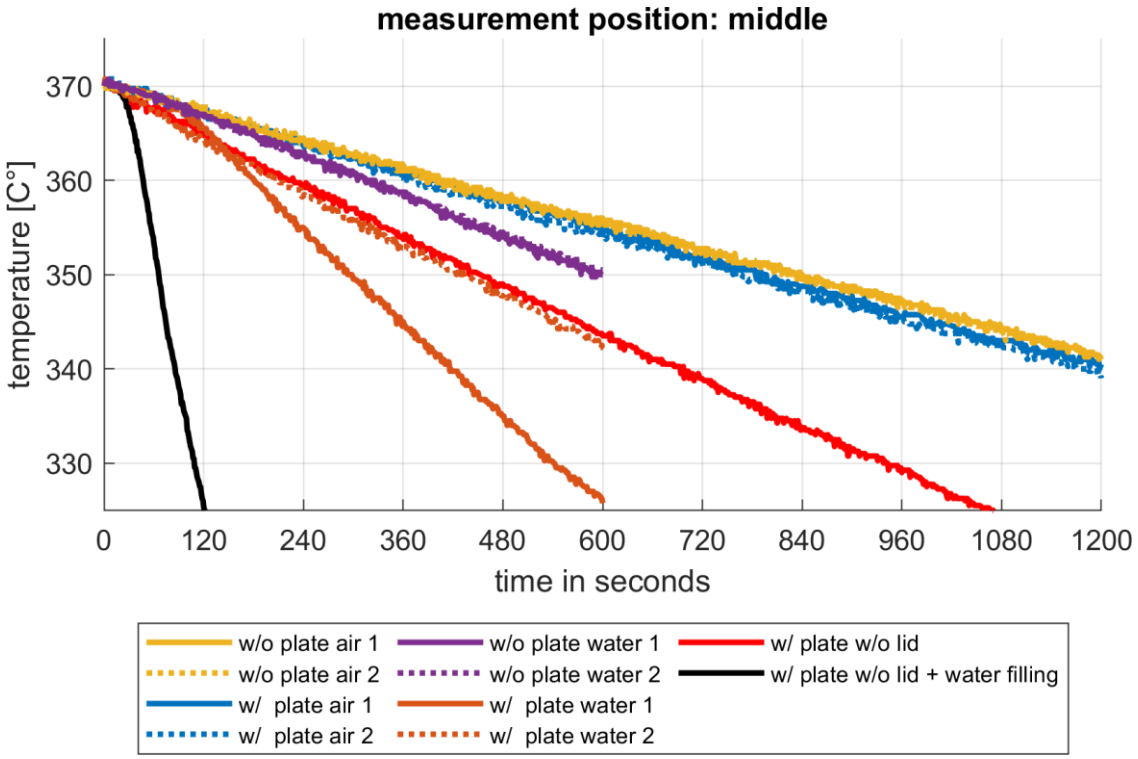

Figure 7: Temperatures Over the Different Setups at the Measurement Position "middle"

Here it can be seen that the measurements "w/o plate air", "w/ plate air" and "w/o plate water" show only slight deviations between the first and the second measurement. The difference between the measurements "w/ plate water 1" and "w/ plate water 2" was caused

by a denting of the housing during the second heating process and a resulting reduced thermal conductivity between the aluminium block and the housing. If the six measured variants are compared, it can be determined that the installation of the additional plate has only a very small influence on the tests without additional cooling (air). If we look at the tests in which the underside of the housing was sprayed with water, it becomes clear that the use of water causes the temperature to drop more quickly than in the tests without intervention. In addition, the temperature drops significantly faster in the tests with a plate (especially when the connection between the plate and the housing is intact) than in the tests without a plate. The temperature curve of the setup with an open lid shows that more heat can be dissipated through better convection than in the experiments with an air gap insulation and the housing being sprayed with water from underneath. From the experiment with the housing filled with water up to the bottom temperature sensor, the maximum possible cooling capacity over the lower surface of the aluminium block can be estimated.

To evaluate the dissipated power, an average dissipated power is calculated by using the temperature change of this measuring point over the measurement duration. Table 1 shows the average power dissipated for the six different setups. In order to clarify the change in dissipated power between the tests, the percentage change in relation to the measurement with air gap insulation (w/o plate) and without additional cooling (air) is determined.

Table 1: Dissipated Power of the Experimental Setups

Setup	Dissipated Power	Change Based on Reference
w/o plate + air (mean)	504 W	-
w/o plate + water (mean)	697 W	+ 38%
w/ plate + air (mean)	530 W	+ 5%
w/ plate + water (single measurement)	1598 W	+ 217%
w/ plate + lid opened	885 W	+ 76%
w/ plate + lid opened + water filling	6566 W	+ 1203%

The power dissipated corresponds to the expectations. By abandoning the additional metal plates (vehicle dummy) that were used in the tests carried out in March 2021, more power is dissipated in the tests without additional cooling (air). In addition, by reducing the amount

of water used, a reduced power dissipation was achieved in the experiments in which water was sprayed on to the underside of the housing. For the evaluation of the dissipated power of the assembly with the plate and water, only the measurement with an intact connection between the aluminium block and the housing is used. When the housing was filled to the lower temperature measuring position, an average of 6.5 kW was dissipated.

In addition to the data obtained from the middle temperature measuring position, the temperature curves of the upper measuring position (“top”) can also be found in Figure 8.

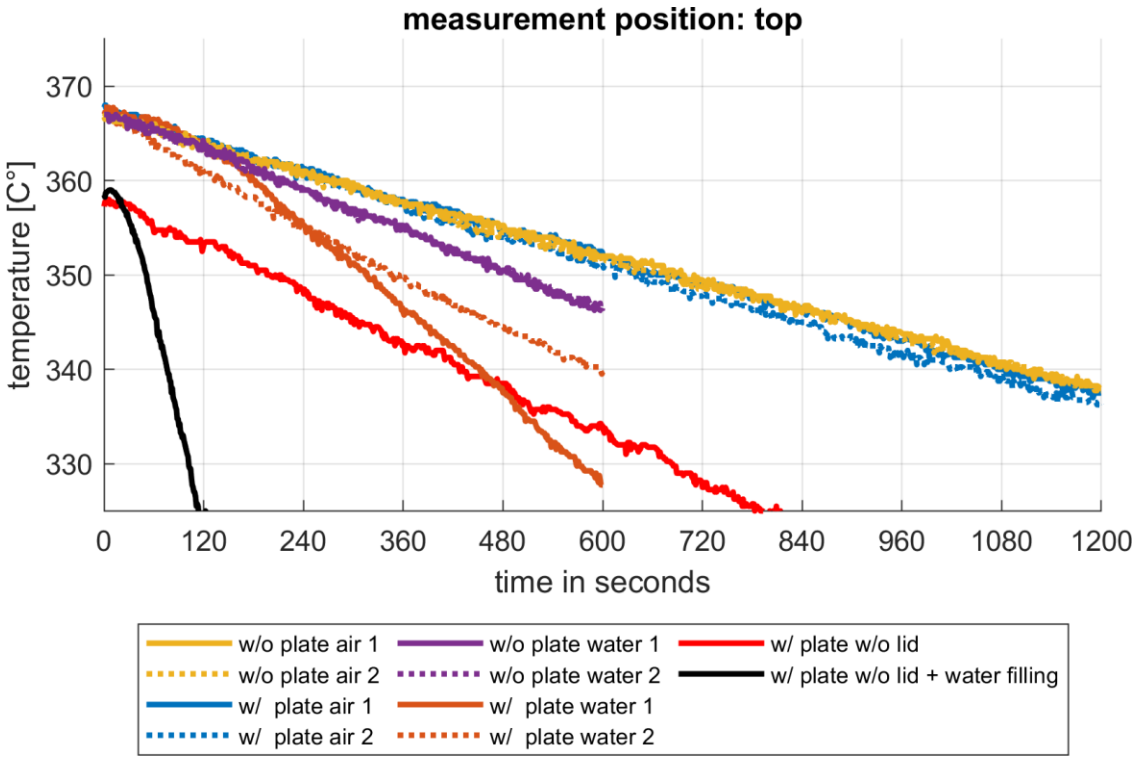

Figure 8: Temperatures Over the Different Setups at the Measurement Position "top"

These temperature curves correspond to expectations and follow the temperatures of the measurement position “middle”. The lower start temperature for the two setups with the open lid is noticeable, which can be explained by the lower thermal insulation when the lid is open.

Figure 9 shows the temperatures determined at the measurement position at the bottom. These also correspond to the expectations and show similar characteristics to those of the measuring point at the top.

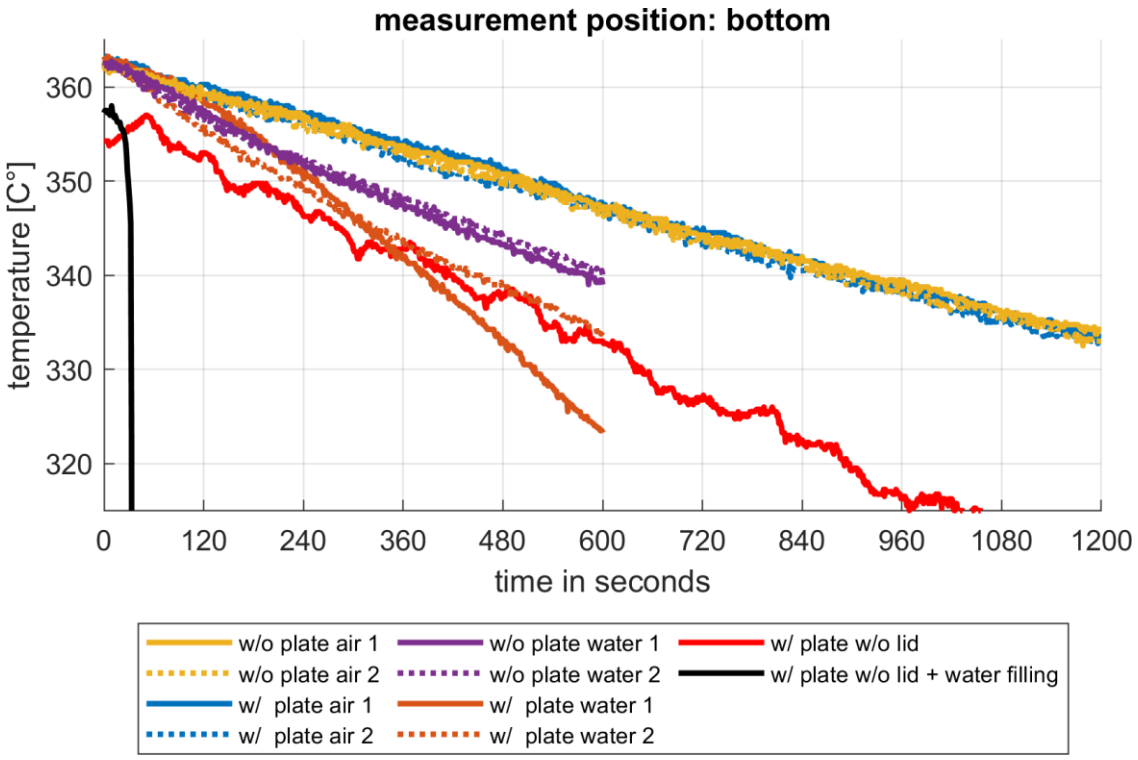

Figure 9: Temperatures Over the Different Setups at the Measurement Position "bottom"

Summary

The additional cooling experiments show that the power dissipated by spraying the underside of a battery dummy clearly depends on the thermal conductivity of the heated aluminium block and the housing. Due to the different designs of traction batteries and the resulting very different thermal connections between the cells and the housing, no general statement can be made about the effectiveness of additional cooling. However, it can be stated that the dissipated power is increased by the use of water. By filling the battery housing directly with coolant, a significantly higher cooling effect could be achieved. Though, this would require a constructive adaptation of the traction battery, which would pose additional challenges such as sealing against moisture ingress and the accessibility for first responders.