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Report on the Cooling Tests at the Trauen Fire Test Site in March 2021

Reasons for Carrying out the Experiments

Due to the increasing number of alternative powered vehicles, it is also necessary to address the associated hazards and to develop countermeasures. Since the protection of the traction battery in battery-electric vehicles and the protection of the gas tank in gas-powered vehicles plays an important role, we investigated the effectiveness of various cooling / extinguishing devices. In addition to protecting the battery / gas tank from external heating, these tests also serve to evaluate the effectiveness of the cooling in the event of a malfunction of the traction battery.

Experimental Setup

The test was set up by using a battery / gas tank dummy, which made it possible to produce reproducible initial temperatures and to record temperatures at different positions inside the dummy. For cooling, a sprinkler mounted at a height of approximately 2 metres above the vehicle deck (see also arrangements investigated) and the boundary cooling device also designed in project AL-BERO (see also section Boundary cooling device) were investigated.

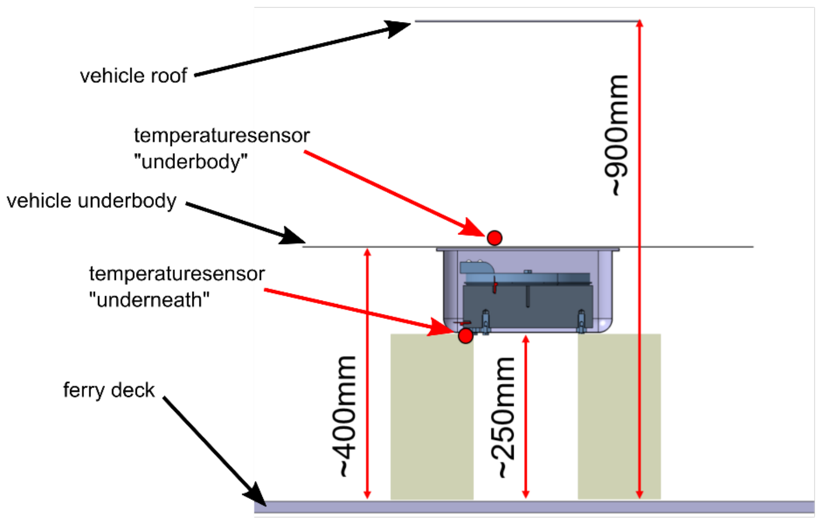

Figure 1: vehicle mock up

The setup of the vehicle mock-up can be seen in Figure 1. This consists of the battery/gas tank dummy described below and several steel plates which simulate various relevant areas (roof and underbody) of a vehicle as well as the vehicle deck of the ship. The temperatures around this dummy are measured by the two thermocouples marked in red.

Battery/Gas Tank Dummy

Since the experimental setup should be used multiple times and must be operated with the existing energy sources available on the test site, the setup shown in Figure 2 was designed.

Figure 2: View Inside the Open Battery / Gas Tank Dummy

This consists of an aluminium block (approximately 20 kg), which serves as a heat accumulator and has a similar heat capacity as typical lithium-ion cells, two electric burner plates with 2600 watts each to heat up the system, as well as an enclosure that simulates the typical battery housing. An air gap between the housing and the aluminium block insulates the block. There is direct contact between the aluminum block and the housing at only 6 screw connection points, which provides good insulation.

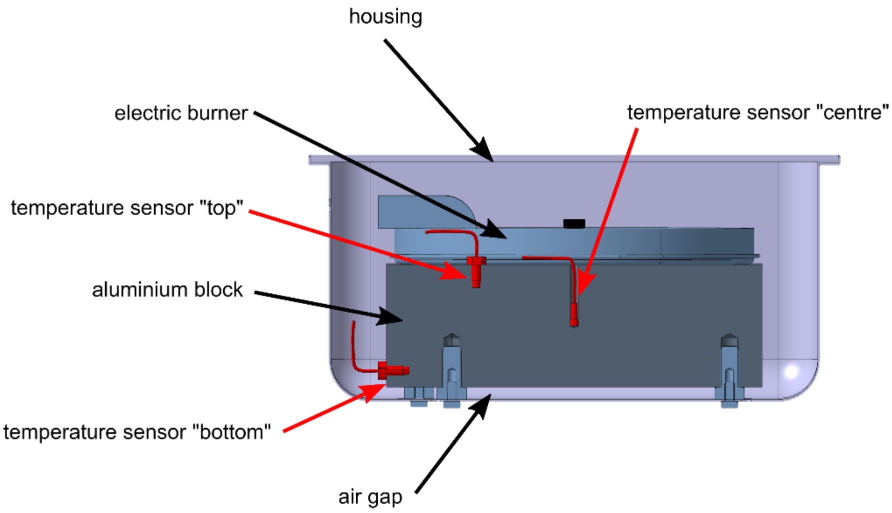

Figure 3: Sectional View of the Battery / Gas Tank Dummy

To determine the temperatures inside this assembly, 3 thermocouples are installed in the aluminium block. The positions of these sensors can be seen in Figure 3, which shows a sectional view of the assembled battery/gas tank dummy.

Boundary Cooling Device

The basic idea of the Boundary Cooling Device (BDC) is to spray water onto the underbody of the vehicle, where the battery is typically located, for cooling the battery and in addition to create a wall of water between the affected vehicle and the surrounding area to prevent the possible spread of fire. For this purpose, a prototype of the boundary cooling device shown in Figure 4 was built.

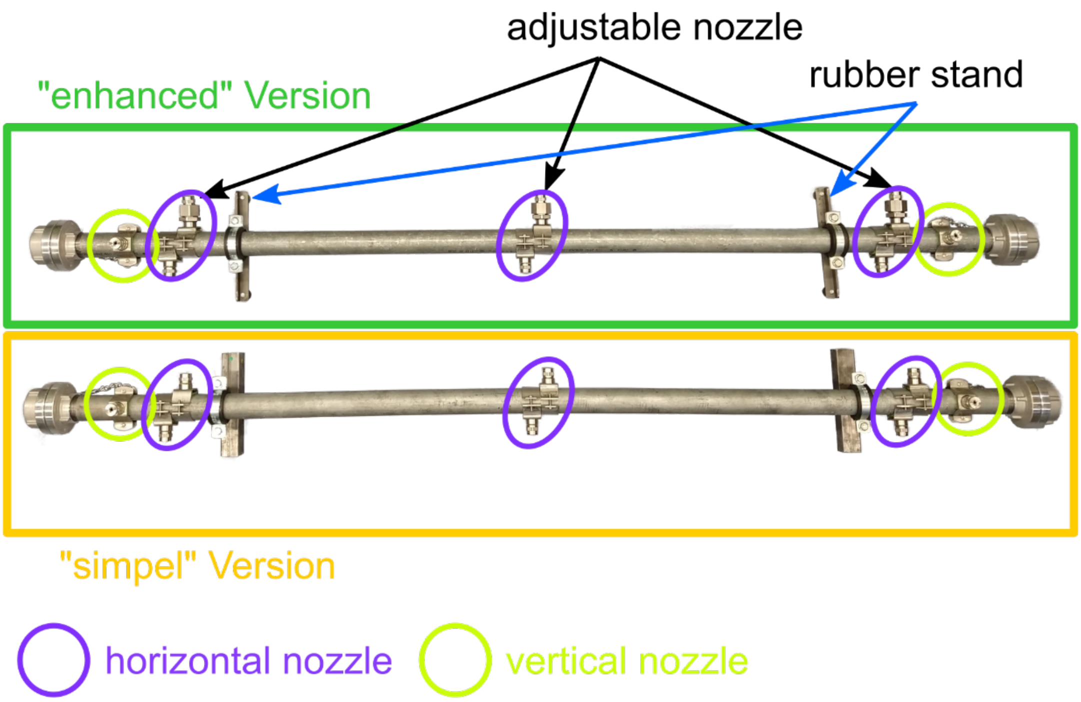

Figure 4: Manufactured Prototype of the Boundary Cooling Device

Here you can see that two different versions of the boundary cooling device were manufactured. These differ in the stands, which are flatter in the "enhanced" version and have a rubber pad, as well as the three horizontal nozzles, which are adjustable in this version. Both versions have 6 vertical nozzles with a spray angle of 60° to spray the underbody of the vehicle with water and 2 horizontal nozzles with a spray angle of 90° to create a shielding wall of water to surrounding vehicles. For the tests described below, only one nozzle was aimed directly at the test setup.

Arrangements Investigated

The arrangement of the individual components of the test setups are briefly described below. The following variants were defined:

- No additional cooling (convection)
- Sprinkler
- Boundary Cooling Device from side
- Boundary Cooling Device from underneath
- Boundary Cooling Device from underneath + sprinkler

No Additional Cooling

As a reference for the experiments in which active cooling is used, a setup without additional cooling is also examined. The test configuration shown in Figure 5 is used for this purpose.

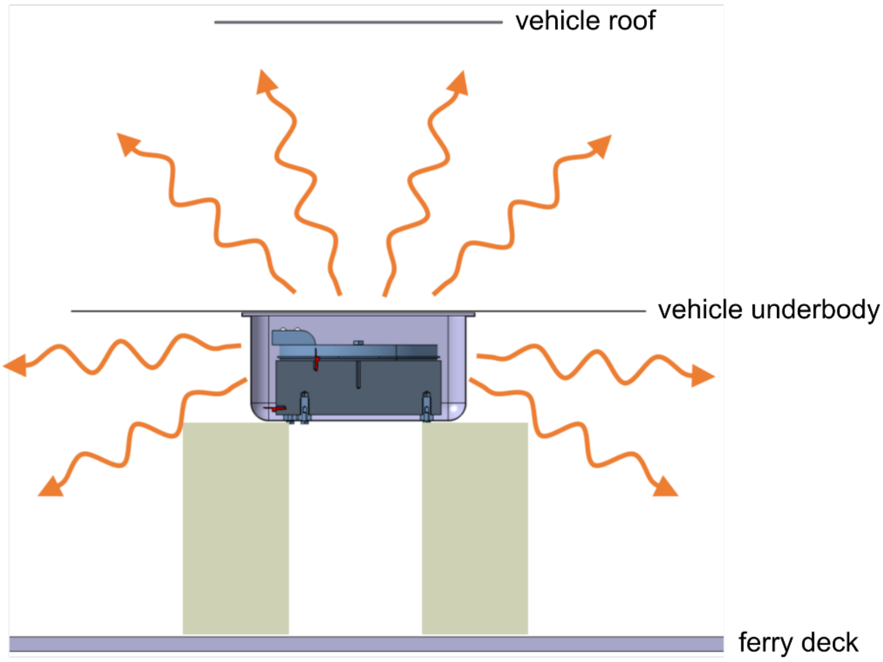

Figure 5: Test Configuration "No Additional Cooling"

This consists of the battery/gas tank dummy as described above, which stands on spacers on the vehicle deck and the metal plates that simulate the vehicle underbody and the vehicle roof.

Sprinkler

The experimental setup with sprinkler uses the setup shown in Figure 6.

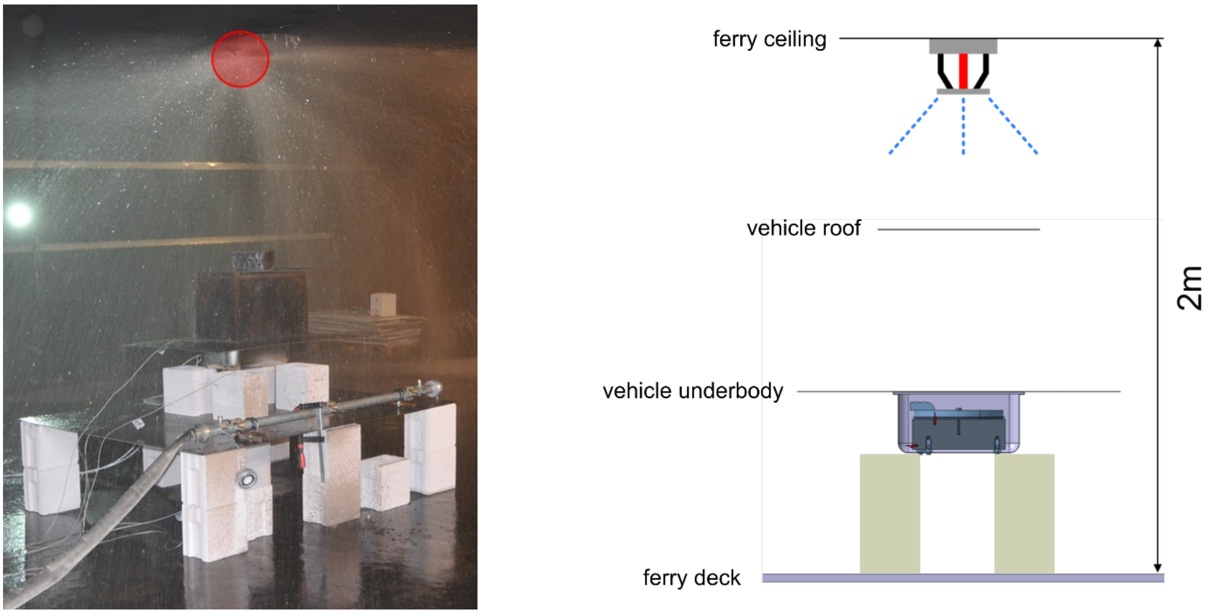

Figure 6: Test Configuration "Sprinkler"

This is based on the setup of the experiments without additional cooling, however an additional sprinkler is installed in the centre of the experimental setup at a height of 2 metres.

BDC from the Side

The setup of the experiment with the boundary cooling device from the side is shown in Figure 7.

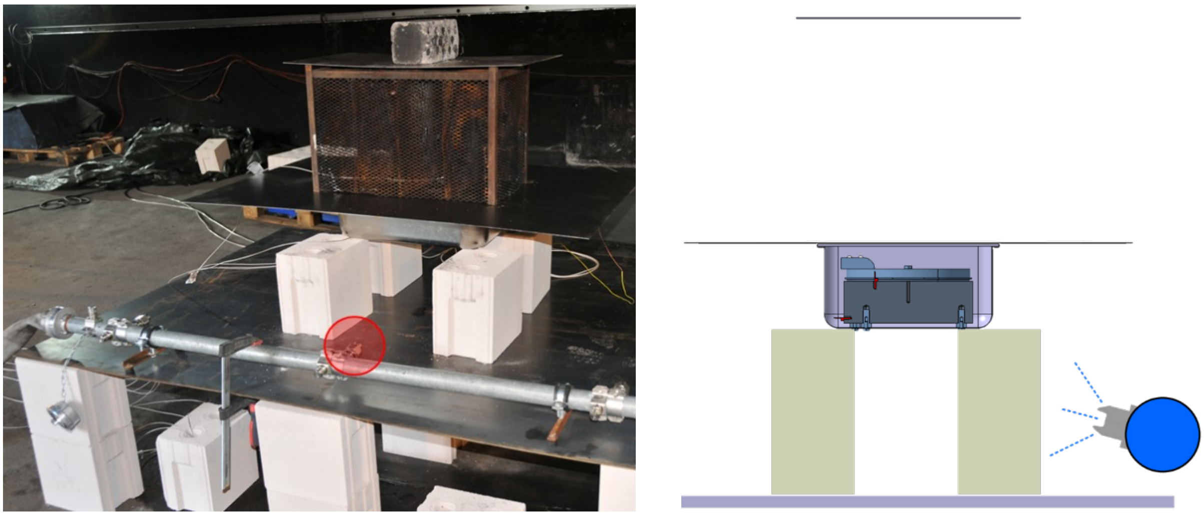

Figure 7: Test Configuration "BCD from Side"

Here, the centre nozzle of the boundary cooling device is used, which has a spray angle of 60°. In this experimental setup, the nozzles that were not needed were still supplied with water.

BDC from Underneath

Figure 8 shows the experimental setup with the boundary cooling device under the battery/gas tank dummy.

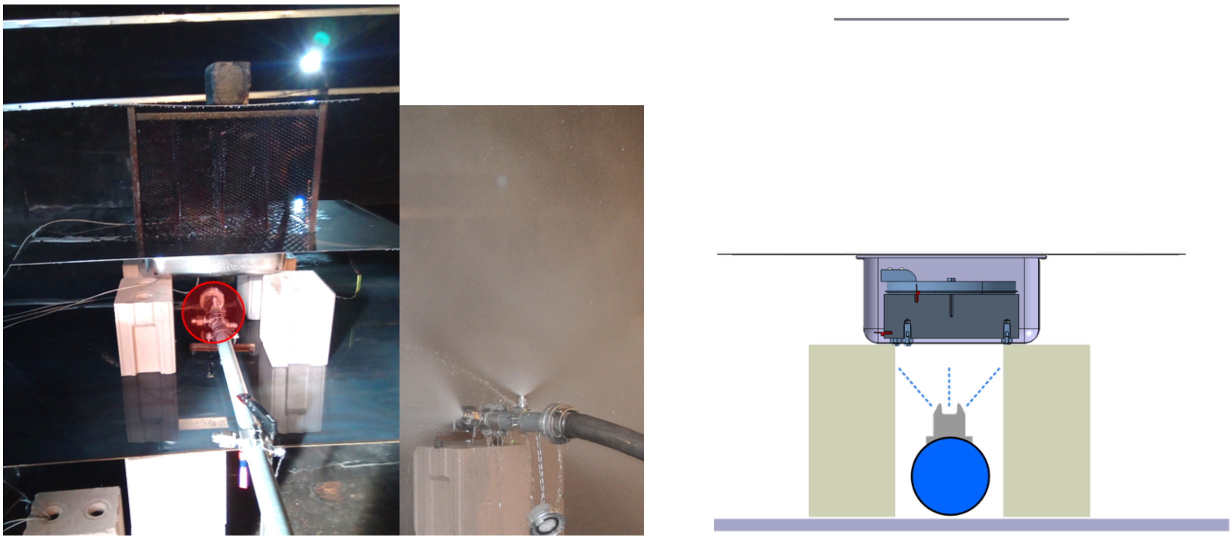

Figure 8: Test Configuration "BDC from Underneath"

Also in this case, all nozzles of a pipe of the BCD were supplied with water. The front, vertical nozzle of the BDC was used to spray the battery/gas tank dummy. This nozzle has a spray angle of 90°.

Boundary Cooling Device from Underneath + Sprinkler

For the investigation of the combined use of the BDC and sprinkler, the setup shown in Figure 9 was used.

Figure 9: Test Configuration "BDC from Underneath + Sprinkler"

Here, the positioning of the individual components corresponds to that of the individual tests.

Test Procedure and Measurement Results

Test Procedure

After positioning all the necessary components for the experimental setup under investigation, the heating phase was started. This phase started with the maximum heating power of the two electric burner plates (approx. 5200W total power), but decreased to a power of approximately 3000W after a temperature of 450°C above the burner plates was reached. This heating phase was stopped when a temperature of 373°C was exceeded at the middle temperature measuring point of the battery/gas tank dummy by switching off the power supply. In order to always achieve comparable starting conditions for all tests, a cooling phase was carried out without additional cooling until the test start temperature was reached, which was defined as 371°C. Once this temperature was reached, the cooling device to be tested was activated and the measurement time started. Measurements were taken for 15 or 30 minutes, after which the cooling device was switched off and the heating phase was started over again by switching on the heating to carry out subsequent tests. Each test configuration was measured twice.

Measurement Results

The results are presented on the basis of the temperature curves at the different measuring positions. For this purpose, the measurement data of the second measurements are displayed as a solid line, for better comparability, a best fit line is also drawn as a dashed line for the respective configurations.

Figure 10 shows the temperature curves for the measuring point in the middle of the aluminium block.

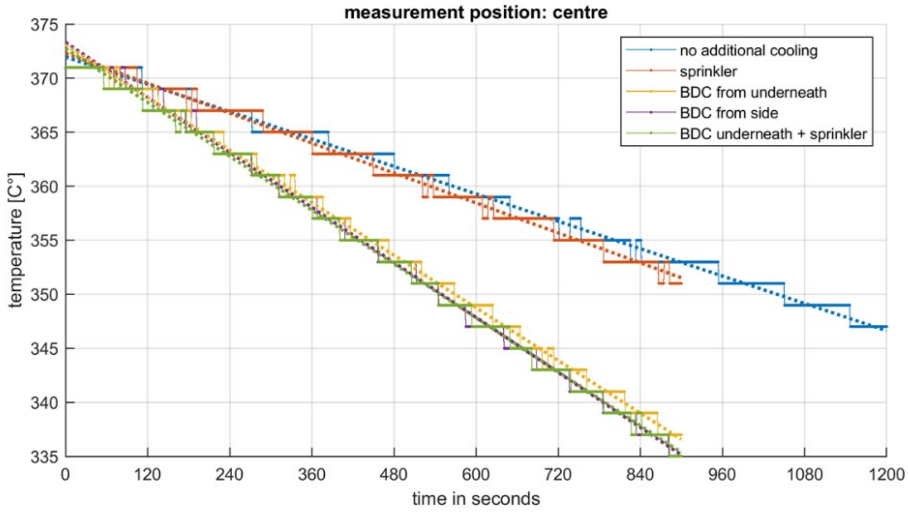

Figure 10: Temperatures at the Measurement Position "Centre"

In this diagram it can be seen that the use of the sprinkler does not cause a significant increase in the cooling speed compared to the reference cooling curve (no additional cooling /convection only). This can be explained by the fact that only very small amounts of water reach the enclosure by bouncing off the lower plate and that changes in the cooling curve are mainly caused by the reduction in ambient temperature. It can also be recognized, that the test setups BDC from underneath, BDC from the side and BDC from underneath + sprinkler lead to accelerated cooling of the aluminium block. These three test setups lead to very similar cooling curves.

To evaluate the dissipated power, an average dissipated power is calculated using the temperature change at this measuring position over the test duration. This average power can be found in Table 1 for the five configurations.

Table 1: Dissipated Power of the Individual Configurations

Test Configuration	**Dissipated Power**	**Change according to reference**
No Additional Cooling (Reference)	374 W	-
Sprinkler	418 W	+ 12%
BDC from Side	792 W	+ 112%
BDC from Underneath	748 W	+ 100%
BDC from Underneath+ Sprinkler	792 W	+ 112%

If we take a closer look at the dissipated powers, the overall low power levels are noticeable. Although a percentage increase in the dissipated power of up to 112% can be achieved through the additional measures, the total cooling capacity is lower than expected.

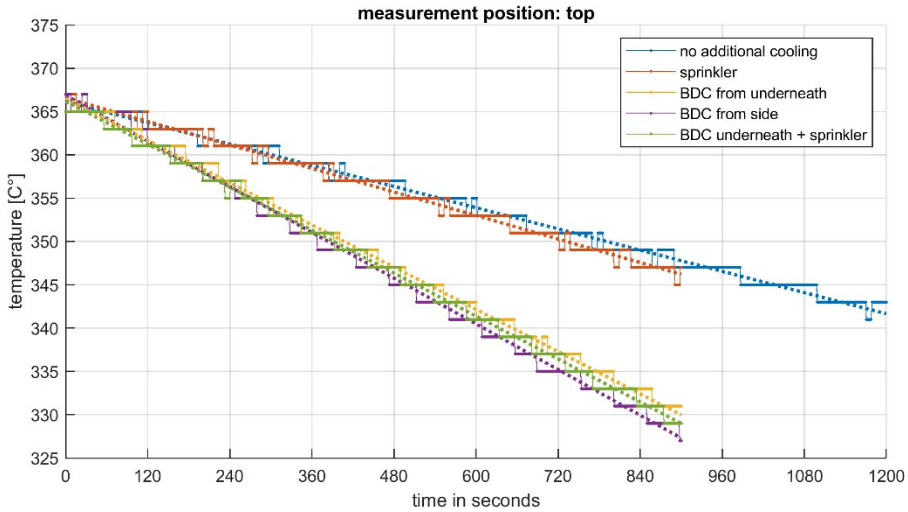

Figure 11: Temperatures at the Measurement Position "Top"

Figure 11 shows the temperature curves of the measuring point "Top". Here, too, it can be seen that the use of a sprinkler system results in no or only very slight changes in temperature at this measuring point. The temperature curves are similar to those of the "Middle" measuring point.

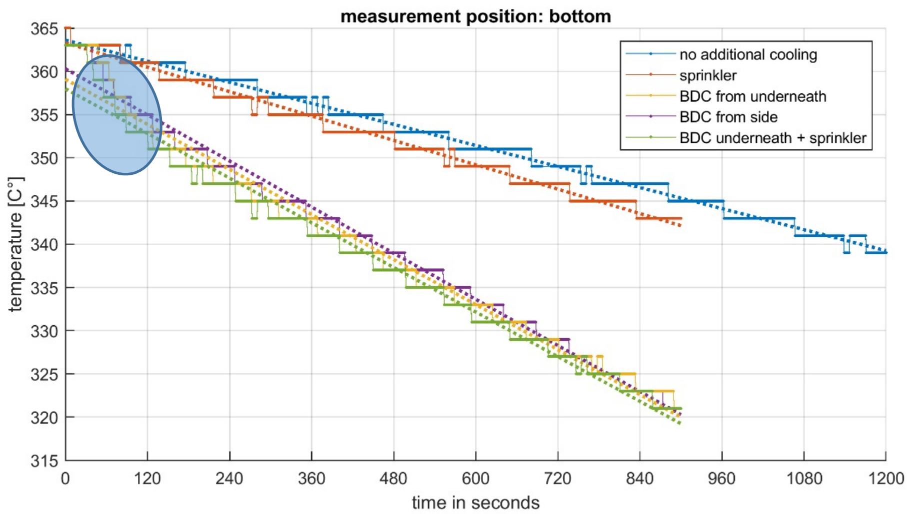

Figure 12: Temperatures at the Measurement Position "Bottom"

Due to the positioning of the measuring point "Bottom" (see Figure 12) near a fastening bolt between the aluminium block and the housing, a temperature jump can also be seen here during the tests with direct exposure of the housing to water.

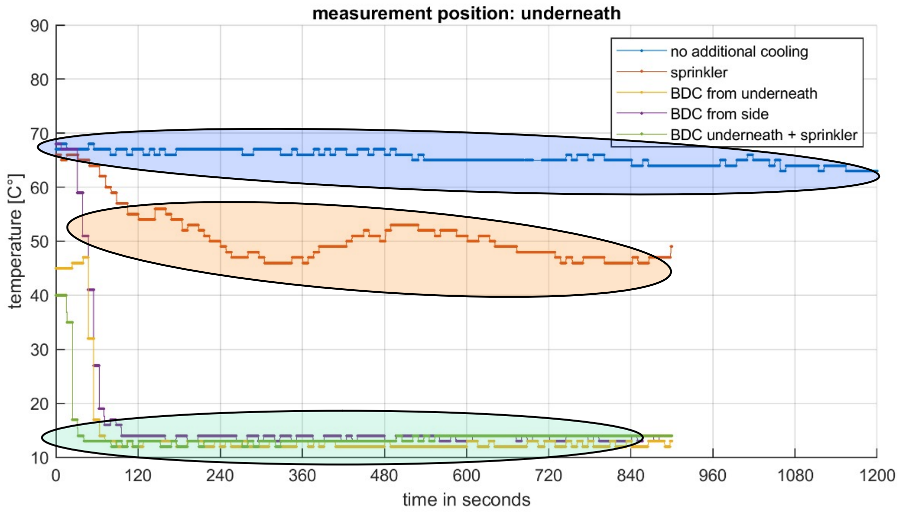

Figure 13: Temperatures at the Measurement Position "Underneath"

By examining the data in Figure 13, which shows the temperature of the measuring point "Underneath", the influence of the exposure of the housing surface to water can be seen. Since this temperature corresponds approximately to the surface temperature of the dummy it can be seen that without additional cooling measures, the temperatures only drop very slowly. The activation of the sprinkler leads only to a slight reduction in the temperature of the enclosure. However, the experimental configurations with the BDC underneath, the BDC on the side and the BDC underneath with activated sprinkler lead to a significant reduction in the temperature of this measuring point. It can be concluded that a gas tank could be cooled quickly and effectively with the help of the direct wetting measures (BDC below / BDC at the side / BDC below + sprinkler).

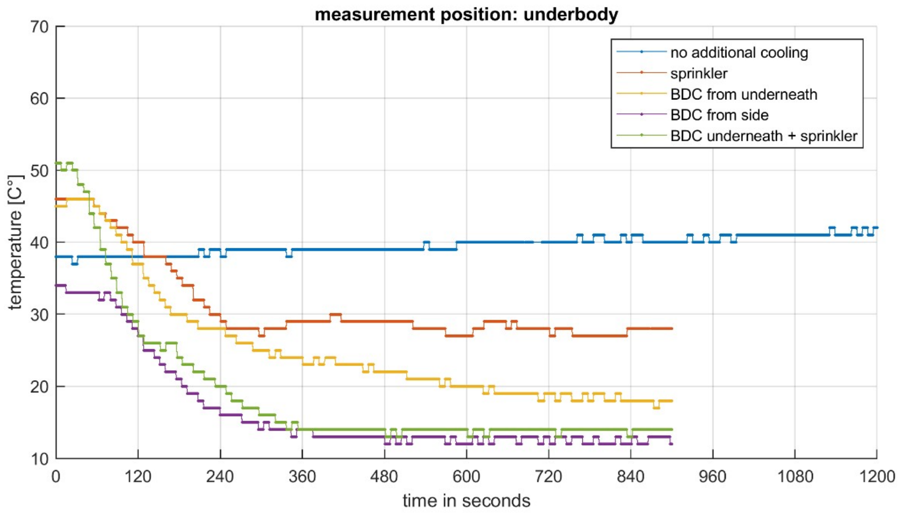

Figure 14: Temperatures at the Measurement Position "Underbody"

The temperature curves in Figure 14 show the temperatures reached above the housing of the battery/gas tank dummy. Due to the different conditions before the tests (water on the underbody plate, holding time of the temperature), the tests start with different temperatures, but by examining the curves it is possible to see how much water reaches the upper side of the vehicle underbody plate in the respective configurations.

Summary

The tests carried out have shown, that the heat dissipation of a battery system or a gas tank can be improved by using suitable cooling devices. In addition, it can be noted that the use of a sprinkler system has only a very small effect on an energy storage system mounted under the vehicle. Despite this low cooling effect, an existing sprinkler system should nevertheless be activated in order to prevent the spread of a fire that may occur in the course of damage. If we look at the temperature curves of the temperature sensor underneath the test setup, which is exposed to conditions comparable to those of a gas tank, we can conclude that the temperature of a gas tank can be significantly reduced by the BCD, as this is typically not installed in an insulated manner. However, if the temperature curve of the measuring point inside the aluminium block and the calculated dissipated heat energy are considered, it becomes clear that the heat dissipation can be improved, but is still very low in relation to the stored energy due to the air gap insulation. Since this behaviour is strongly dependent on the thermal connection of the aluminium block (batteries) to the housing and this is very low in the test setup used, further tests should be carried out with a higher thermal connection since different cooling and insulation concepts are also used in real vehicles.