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Report

Mixture of water and 2% F500 as extinguishing agent for deletion of lithium-ion-battery fire

1. Preparation of lithium-ion battery package

For all extinguishing experiments we used a lithium-ion battery package with a total storage energy of 1890 Wh (48V, 39Ah) The module consists of 182 parallel and serial connected round cell batteries, the total weight of the module is 10.5 kg.
The thermal trigger of an accident was induced by two glow plugs integrated into the battery package. The glow plugs are operated with a voltage of 12V and a current of 15A. This setup allows the generation of temperatures up to 1400 °C within 1 minute after ignition of the plugs. The battery module is fitted by 8 temperature sensors (type k sensors). The temperature sensors are located on the top and bottom side of the package, two sensors directly close to the glow plugs and two sensors on the edge of the package. The covered temperature range is 20 - 1400 °C with an accuracy of about +- 1 °C. Figure 1 shows the arrangement of glow plugs and temperature sensors on the top side of the battery module. Temperature sensors on the bottom side are located at same places.

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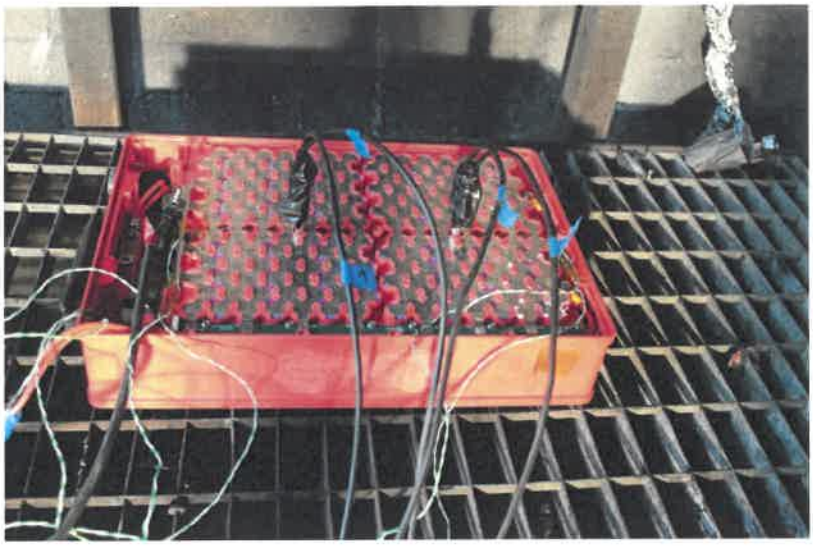

Figure 1: Lithium-ion battery package (1.89 KWh) with integrated glow plugs for thermal trigger of an accident and temperature sensors integrated into the package.

2. Experiments

The experiments for thermal runaway and attempts to delete the induced fire are performed in a test chamber with connected gas cleaning system. Above the battery package at a distance of 0.5 m there are two nozzles mounted that allow a well defined injection of the extinguishing agent F500 (refer to fig. 2 and 3). The extinguishing agent consists of a mixture of pure water and 2% F500. In addition to the 8 temperature sensors a digital camera was installed in the chamber for monitoring and documentation of the experiment and also a thermal camera for measuring the thermal distribution on top of the battery package. This allows real-time monitoring of the thermal runaway in the chamber, the data rate of the monitoring system was 10 Hz. All data are transmitted in real-time to the control room and the extinguishing system was operated manually, depending on the progress of the thermal runaway. As an example, the measurement protocol as distributed to the control room is shown in fig. 4.

Figure 2: View into the test chamber after inducing a thermal runaway by ignition of the two glow plugs. Above the battery package the two nozzles for introduction of the extinguishing agent (water and 2% F500) are shown.

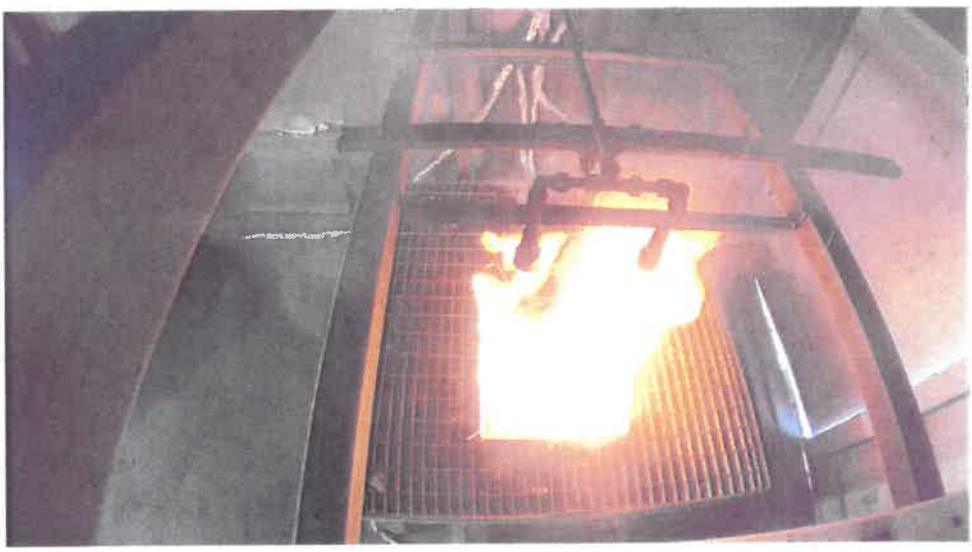

Figure 3: View on top of the battery package during the thermal runaway.

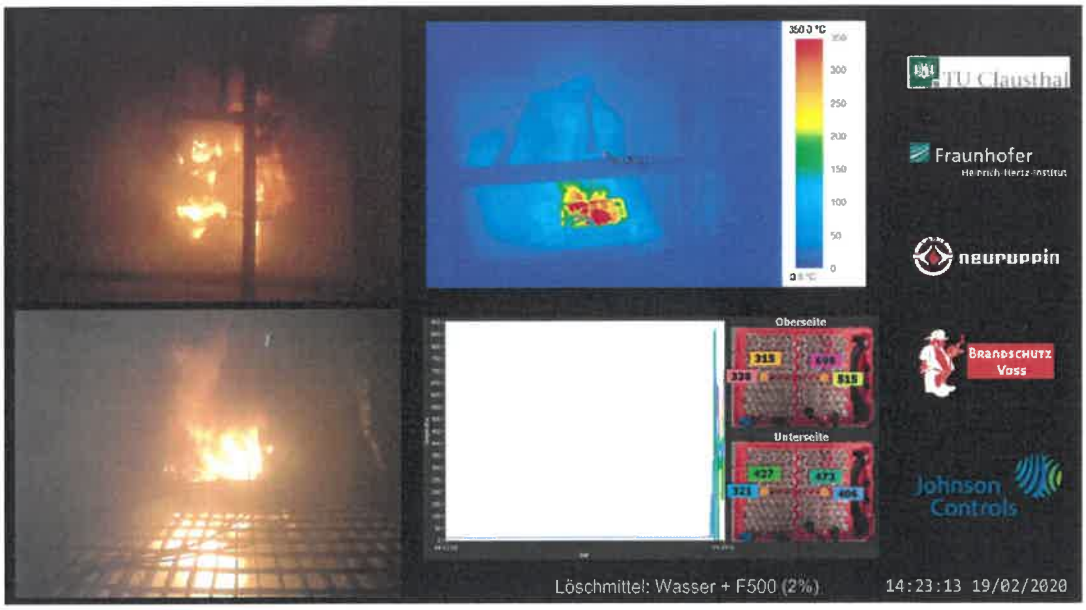

Figure 4: Example of the measurement protocol as can be seen in real time during the experiment in the control room. On the top, right side there is the image of the thermal camera shown, below the arrangement of the temperature sensors and corresponding data.

In the following we show a typical temporal development of the experiment:

15:05:57	Start, heating with glow plug (U=12V, i=15A)
15:06:15	Temperature increases for sensors close to glow plug
15:06:33	first smoke appears
15:06:57	Explosion of the battery package
15:07:02	Power supply for heating glow plugs off
15:07:34	Start of flame formation at battery package
15:08:02	First short fire extinguishing (water and 2% F500) pulse (duration 5 sec), instant reduction of flame
15:08:25	new but much less flame formation
15:08:33	short fire extinguishing pulse (duration 5 sec), no flames
15:11:27	again short fire extinguishing pulse (duration 5 sec), no flames anymore
15:14:44	Temperature of sensore decrease continuously down to T < 80 °C, no new flame/fire formation
15:18:27	again short fire extinguishing pulse (duration 5 sec)
15:33:55	Temperature down to T < 50°C, End of experiment

Figure 5 shows the battery package at end of experiment.

Figure 5: Battery package at the end of the experiment.

The temporal distribution of the temperature for all 8 sensors is shown in fig. 6. After inducing a thermal runaway by heating with glow plugs an instant temperature increase up to 1400 °C is obtained. After introduction of a first fire extinguishing pulse (mixture of water with 2% F500, duration 5 sec) the temperature decreases down to 400 °C and after a second extinguishing pulse (5 sec duration) a continuous decrease of the temperature is obtained. In all experiments no second fire formation was obtained after introduction of an extinguishing pulse as described before. When using 4.5 liters of extinguishing agent (mixture of water and 2% F500) the battery fire was completely deleted and no new flame formation was detected anymore.

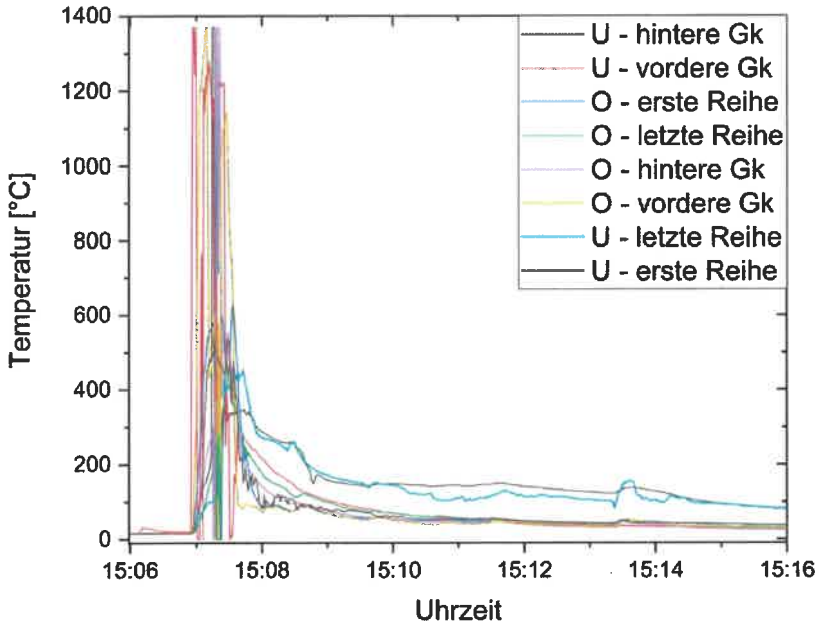

Figure 6: Temporal distribution of temperature measured by the sensors from starting thermal runaway up to complete deletion of the battery fire.

3. Summary

The addition of F500 (2%) to water as an extinguishing agent results in significant reduction of surface tension contrary to pure water without F500. As a result, when applying the mixture of water and 2% F500 on the battery package the extinguishing agent covers the package as a thin film on all surface sides – which does not happen when using pure water. Due to the high temperature (T>1300 °C) the extinguishing agent evaporates and the energy necessary for this process comes from the hot battery package. As a result, the package cooles down very efficiently which is obtained in the temperature profiles (refer to fig. 6). Since the extinguishing agent covers all surfaces due to the reduced surface tension a very fast and efficient cooling process is obtained and no new flame formation is obtained. Finaly, the fire is completely deleted.

Further experiments that we have performed with another lithium-ion battery package (2 kWh storage energy) supports the interpretation of our results reported above. Again a thermal runaway was introduced to the battery package in a way described before and the we tried to delete the flame formation of the battery by using 50 liter pure water as extinguishing agent. However, this experiment failed. Even after longer time (t < 20 min) there was continuously new flame formation obtained. In a second step the same experiment was performed, but now using a mixture of water and 2% F500 as extinguishing agent. Now after application of 5 liter of such mixture the fire was completely deleted and no new flame formation was obtained anymore.

Conclusion:

Using a mixture of water with 2% F500 as extinguishing agent for deletion of lithium-ion battery fire is significantly superior to using only pure water. There is less need of the extinguishing agent and there is no new fire/flame formation for experimental conditions as described before. When using 4.5 liters of a mixture of water and F500 lithium-ion battery fires (1.89 kWh/48V, 39 Ah/182 cells Type 18650, weight of the package 10.5 kg) can be deleted completely without any new fire/flame formation.

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