ANALYSIS OF SUITABLE EXTIGUISHING AGENTS AND EXTINGUISHING SYSTEMS FOR FIGHTING ELECTRIC CAR FIRES

Work Package 4.5

ALBERO Project

Institut für Sicherheitstechnik/Schiffssicherheit e.V.

WP 4.5. Adaption of fire protection technologies - Analysis of extinguishing agents and extinguishing systems for fighting fires of Li-Ion (vehicle) batteries

Institut für Sicherheitstechnik / Schiffssicherheit e.V.

A comprehensive research was carried out on current recommendations and developments for fighting Li-Ion battery fires. The analysis referred on the one hand to extinguishing agents and on the other hand to extinguishing systems, i.e. technical equipment that can be used for the application of extinguishing agents.

General Extinguishing Agents

General extinguishing agents are extinguishing agents that can be used for a wide variety of fire loads, i.e. not only for Li-Ion fires. In connection with their respective extinguishing effect, a distinction can be made between the following:

extinguishing agent	extinguishing effect
water (in various spray stages, i.e. full jet, spray jet)	cooling
high pressure water mist	cooling, inertisation
water with additives (e.g. F500)	cooling, separation by encapsulation
foam (low expansion foam, light expansion foam)	separation by covering
inertizing extinguishing gases (carbon dioxide, nitrogen, ARGONITE, ...)	inertisation
fluorinated extinguishing gases (NOVEC 1230, FM 200)	chemical interruption of combustion reaction
aerosol (potassium hydrogen carbonate)	chemical interruption of combustion reaction
sand	separation by covering

In the meantime, all these extinguishing agents have been tested with regard to their suitability for extinguishing Li-Ion batteries [1], [2], [3], [4]. In general, the consensus is that once cells have gone into thermal runaway, they cannot be stopped. However, it is possible to prevent the reaction from spreading to other cells by extinguishing the open flames of the initial cells. Water with its cooling effect seems well suited for this purpose. Moreover, it is relatively easy to obtain and in large quantities. For this reason, it has been considered the "agent of choice" up to now. However, it has been shown that the other extinguishing agents can also contain a Li-Ion battery fire well, always with advantages and disadvantages for the particular environmental situation [5]. Extinguishing with water, for example, is sometimes considered explicitly critical in enclosed spaces because hydrogen can form when battery components react with water, posing a risk of explosion [6]. Extinguishing with water also poses the problem of collecting and disposing of the contaminated extinguishing water [7].

[1] J. Kunkelmann: *Studie zur Brandbekämpfung von Lithium-Ionen-Batterien (Akkus) und Lithium-Metall-Batterien*, Karlsruher Institut für Technologie (KIT)Forschungsstelle für Brandschutztechnik, Forschungsbericht Nr. 192, Karlsruhe, 2017
[2] H. Döring, M. Wörz, O.Rohozneanu, K. Spachmann, J. Klee Barillas: *Results of Fire-Extinguishing Tests on Li-Batteries*, Battery Experts Forum N.13, Aschaffenburg, 2017
[3] Petra Andersson, Magnus Arvidson, Franz Evegren, Mourhaf Jandali, Fredrik Larsson, Max Rosengren: Lion Fire: Extinguishment and mitigation of fires in Li-ion batteries at sea, RISE Report 2018:77
[4] M Ghiji; V. Novozhilov; K. Moinuddin; P. Joseph; I. Burch, B. Suendermann G.Gamble: A Review of Lithium-Ion Battery Fire Suppression, Energies 2020, 13(19), 5117
[5] R. Rothe: *Löschmittel im Test – Anwendungsbeispiele am Beispiel der Automobilbranche*, Digitale Fachkonferenz Lithiumbatterien – Logistik. Lagerung. Entsorgung, 2021
[6] L. Derek Mellert, U. Welte, M. Hermann, M. Kompatscher, X. Ponticq, M Tesson, J. Beckbissinger: *Elektromobilität und Tunnelsicherheit –Gefährdungen durch Elektrofahrzeugbrände*, Forschungsprojekt VSS 2016/221 auf Antrag des Schweizerischen Verbands d. Straßen-und Verkehrsfachleute (VSS), 2018
[7] Hinweise für die Brandbekämpfung von Lithium-Ionen-Akkus bei Fahrzeugbränden, Deutsche Gesetzliche Unfallversicherung e.V. (DGUV), 2020; https://publikationen.dguv.de/widgets/pdf/download/article/3907

Extinguishing agent specifically for Li-Ion fires

Due to the increasing prevalence of Li-metal and Li-ion batteries and the special fire progression of such batteries, attempts have been made in recent years to develop extinguishing agents that are as specific as possible to this fire load. Some currently advertised examples are listed below.

Expanded Glass Granules

Some manufacturers offer an extinguishing agent consisting of small glass foam pellets. They are sold, for example, under the name Pyrobubbles or Extover [8], [9]. The extinguishing effect is based on a separation effect that occurs when the glass beads hit the burning battery and then melt there, forming an insulating layer. The main disadvantage of this system is that it is difficult to use in an extinguishing system. To protect larger areas, a large quantity (volume, weight!) would have to be kept in stock accordingly. A further disadvantage is that a not inconsiderable part of the granulate simply rolls away when applied in unconfined areas and therefore cannot act at the source of the fire. An advantage is that hardly any damage is caused by the extinguishing agent. However, good results are achieved with these materials in structural fire protection - walls can be filled with this material straight away - and for transport systems of Li-Ion batteries. In the event of a fire of Li-Ion batteries, such packaging provides good protection against the spread of fire.

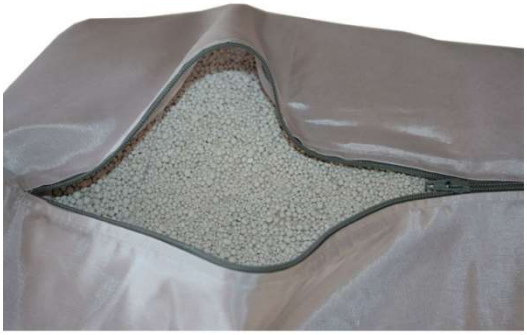

Figure: "lithium fire protection cushion" filled with expanded glass beads

source: https://brandschutzcenter.expert/shop/product/llithium-brandschutzkissen-2-kg/

[8] https://www.lion-care.com/loeschmittel/pyrobubbles
[9] https://www.poraver.com/extover/

AVD - Dispersed Vermiculite

These extinguishing agents are grouped under the name Aqua Vermiculite Dispersion (AVD). Vermiculite is a naturally occurring sheet silicate. Due to its high content of silicon oxides, it is chemically relatively similar to glass. The mineral is broken down into very fine particles and dispersed in water in the smallest possible quantities. In this way, it can be applied as a fluid to the burning Li-Ion battery with the aid of a fire extinguisher. The water evaporates there and the remaining vermiculite crust provides a separation effect between the damaged battery and the environment [10]. The advantages, disadvantages and areas of application are similar to those of glass granules. An additional disadvantage is the relatively rare occurrence of vermiculite [11].

[10] www.lithex.de
[11] https://de.wikipedia.org/wiki/Vermiculit

Extinguishing Gel

Extinguishing gels, which are offered by various manufacturers, are also used to form an air-impermeable separating layer on the burning Li-Ion battery that closes as tightly as possible. Compared with granules, they have the advantage that the extinguishing agent adheres more quickly to the source of the fire. Extinguishing gels are available either ready-prepared in fire extinguishers [12] or as an admixture for the water jet, similar to a foaming agent [13]. The use in extinguishing systems for the protection of larger rooms does not seem to have been implemented at present. However, especially in connection with use on ships, it must be noted that gel formation may be limited when the admixture is used with salty seawater [14].

[12] https://www.jockel.de/images/dateien/Produktdatenblatt_Gel-Feuerloescher_web.pdf
[13] https://www.creasorb.com/product/creasorb/de/produkte/firesorb/
[14] http://www.flameguard.ch/docs/fireex_gel_pruefbericht.pdf

Extinguishing Systems (External Attack)

Extinguishing systems refer to technical equipment or devices that are used to apply the extinguishing agent. Within the ALBERO project, only those that have been developed specifically for extinguishing electric vehicles are considered below.

Underbody Cooling

Water spray systems, e.g. on car decks or in parking garages, only apply water to a burning vehicle from above. However, for electric vehicles with the batteries installed in the underbody, cooling from below would probably be more effective. To this end, a wide variety of tools have recently been developed to bring water to the vehicle from below, if possible. Within the ALBERO project such a boundary cooling device has been prototyped by the partner FKFS and tested in initial trials [15].

[15] https://alberoprojekt.de/index_htm_files/Bericht%20Test%20Boundary%20Cooling%20Device.pdf

Extinguishing Container

A particular hazard in electric vehicle fires is re-ignition, often hours after the fire appears to have been extinguished. A safe means for comprehensive cooling and prevention of re-ignition is to contain the entire vehicle in a sealed container and then flood it with water. This method has already become established outside Germany as well [16], [17]. The Ellermann Company has developed a special roll-off container, the so-called Red Boxx [18], especially for this purpose. With the help of a winch, the damaged vehicle is pulled into the container, then sealed and flooded.

Figure: Red-Boxx
source: https://www.empl.at/fileadmin/user_upload/Website/PDF_Downloads/FW/Werkfeuerwehren/Abrollbehalter-Red-Boxx.pdf

[16] https://www.presseportal.de/blaulicht/pm/131419/4395403
[17] https://electrek.co/2019/06/01/tesla-fire-supercharger/
[18] https://www.container-ellermann.com/redboxx/

The system is only suitable for accidents in open terrain, as handling the large rolling container on the vehicle deck or in a parking garage is not practical. A major disadvantage is also the need to get close to the damaged vehicle to attach the winch or a crane hook to pull or lift the car into the container. For this reason the idea was developed within the ALBERO project not to bring the car into the container, but to drive the container over the car:

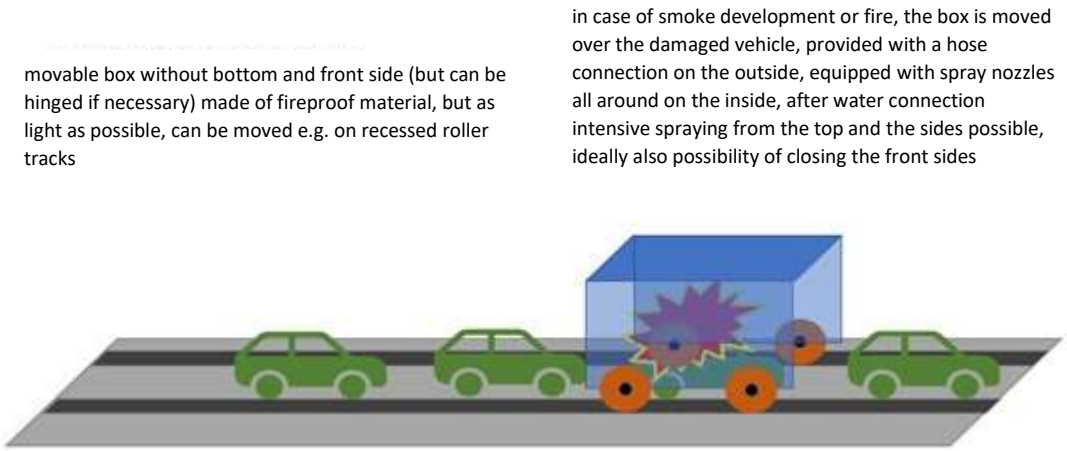

Figure: ALBERO idea: mobile roll container for separation and cooling of burning electric vehicles

E-Extinguishing Lance

Vehicle batteries are made up of several modules, which in turn are integrated into a stable housing so that the battery cannot be damaged. Cooling or extinguishing agents cannot therefore attack the battery cells directly, which reduces the cooling or extinguishing effect. Scientific experiments have shown that water attack directly in the battery enclosure leads to significantly faster success [19]. Therefore, it is basically a good approach to use an extinguishing system to introduce the cooling water directly into the interior of a vehicle battery. Special extinguishing lances have been developed for this purpose [20]. The nozzle tip is to be hammered into the battery with the aid of an impact tool in order to introduce water directly there.

Figure: E-Extinguishing Lance
source: https://www.murer-feuerschutz.de/e-loeschlanze/

In some handling tests, however, it was found that this impact can damage the battery even more and thus provoke ignition in the first place [21]. The use of these systems is therefore expressly discouraged [7]:

Caution!

Hand-held extinguishers are available on the market which penetrate the battery housing in order to introduce extinguishing water into the interior of the battery. In doing so, the operating crew is in the immediate vicinity of the battery. since, according to the current state of the art, this procedure cannot be brought into line with dguv regulation 49, § 26 "danger from electric current", no recommendation can be made for this method at present. among other things, its use is associated with the risk of in some cases considerable flash fire formation and a risk of electric shock to the operating crew that cannot be ruled out (e.g. electric arc, dangerous flow through the body). The vehicle manufacturers also prohibit the opening and damaging of high-voltage batteries in their instructions for use.

Figure: Warning Note of DGUV [7]

[19] O. Willstrand: Fire Suppression Tests for Vehicle Battery Pack, Swedish Energy Agency Report Project No. 45629-1,
[20] https://www.murer-feuerschutz.de/e-loeschlanze/
[21] http://www.feuerwehr-eggenfelden.com/images//Beitraege/Download/Elektrofahrzeuge.pdf

Fire Blanket, Fire Blanket Device

Extinguishing blankets have the advantage of being very flexible and mobile. Additionally the low price compared to permanently installed extinguishing systems is very attractive for many users. So far, however, there have been only a few tests on the effectiveness of extinguishing blankets in fighting electric vehicle fires. Initial tests show that the fire appears to be well contained, but when the blanket is removed, re-ignition occurs immediately [22], [23]. Extinguishing blankets have the disadvantage that emergency personnel have to get relatively close to the damaged vehicle in order to cover it. There are therefore initial approaches to parking the car in a kind of "tent" from the outset and closing this tent in the event of an accident [24].

Figure: "fire tent" for electric cars [24]

[22] https://www.youtube.com/watch?v=yO8cVWOqZcg
[23] https://www.kfv-segeberg.org/infothek/loeschdecke-e-auto/
[24] https://www.stoebich-technology.de/en/produkte/e-mobilityprotector-1

There are also developments of special extinguishing blankets that release inerting gases when heated and are thus supposed to achieve an extinguishing effect even faster. The problem here, however, is that the gases can only act if the car is as completely and tightly packed as possible. Again, people would have to get close to the cover. This system [25] is therefore recommended primarily to prevent re-ignition, i.e. after the initial fire has been extinguished.

Figure: wrapping for damaged electric vehicles
source: https://www.gelkoh.de/2020/06/16/libarescue-das-innovative-bergesystem-fuer-e-fahrzeuge/

[25] https://protect.ibena.de/de/news/ibena-entwickelt-brandschutzdecke-f%C3%BCr-elektroautos.html

For the special case "car deck on a ro-ro ferry", further special features must be taken into account when using a fire blanket: As a rule, the parking situation on the ferry is very tight. It must be investigated whether it is possible to apply the fire blanket quickly even under these conditions and whether it can also then prevent the spread of fire. In addition, the question arises whether on a floor made of steel under a fire blanket such high temperatures may arise that the strength of the metal is impaired or whether the effect of heat conduction through the metal into other areas on board is intensified by the blanket.

Extinguishing Systems (Internal Attack)

As already mentioned above, the effect of a coolant or extinguishing agent is particularly effective if it can act directly on the battery cells. Against this background, there are now developments to install capsules with extinguishing agent (gas, powder) in the battery housing and to trigger these in the event of overheating in the battery housing [26].

[26] https://pubs.acs.org/doi/full/10.1021/acs.nanolett.5b01167

Another approach is a "filler neck" for water directly into the battery, built into the design from the outset [27] - a concept that, however, has not yet been sufficiently taken up by car manufacturers.

[27] https://patents.google.com/patent/JP5849692B2/en