COOLING OF LITHIUM ION BATTERIES IN FIREFIGHTING

Robert L. Swaim, December 2, 2019
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The basic three requirements for fire are fuel, oxygen, and heat. With enough impact damage and internal or surrounding flammable material, nearly all vehicle batteries are capable of creating a fire. There are numerous examples of lead-acid batteries igniting surrounding materials and lithium ion batteries typically contain a flammable electrolyte with oxygen.

This paper only addresses methods of using water to cool motive batteries and does not address high voltage or the other fuels which may be used in hybrid vehicles. Online emergency response guides must be consulted to know how to disable high voltage systems. Hybrid fuels may include gasoline, diesel, propane, or high pressure hydrogen. Burning hydrogen (Honda Clarity, Toyota Mirai) could be particularly hazardous because the flames can not be seen. Most hybrid and electric vehicles with a high voltage battery for motive power are also equipped with separate 12V batteries, similar to the batteries installed in internal combustion engine (ICE) vehicles.

Emergency Response Guides (ERG) posted online by electric vehicle (EV[1]) manufacturers and Material Safety Data Sheets (MSDS) for fixed installations almost universally call for water to be the primary means of cooling battery fires and dispersing the potentially flammable electrolyte. Lithium ion batteries also contain a plastic membrane between the anode and cathode and melting of the membrane at more than 120-150°C can create heat with an increasing current discharge. The ERG and MSDS documents usually state that thousands of gallons may be required to extinguish lithium ion fires and this amount of water exceeds the capacity of most fire department tanker trucks.

EXTERNAL COOLING:

Vehicle designs work against effective firefighting being able to get enough water to cool the cells, which are the source of heat. The batteries in many EVs are the bottom of a vehicle in order to keep the battery weight and center of gravity low for handling. Application of water to the top of the vehicle or into the cabin can only address burning interior materials and is ineffective for cooling an overheating battery attached to the bottom of a car. The water is shed before reaching the battery mounted under the vehicle because the vehicle body is a separate enclosure from the battery assembly. (Figure 1)

[1] Defined here as any vehicle with a battery large enough for propulsion, including those in hybrids.

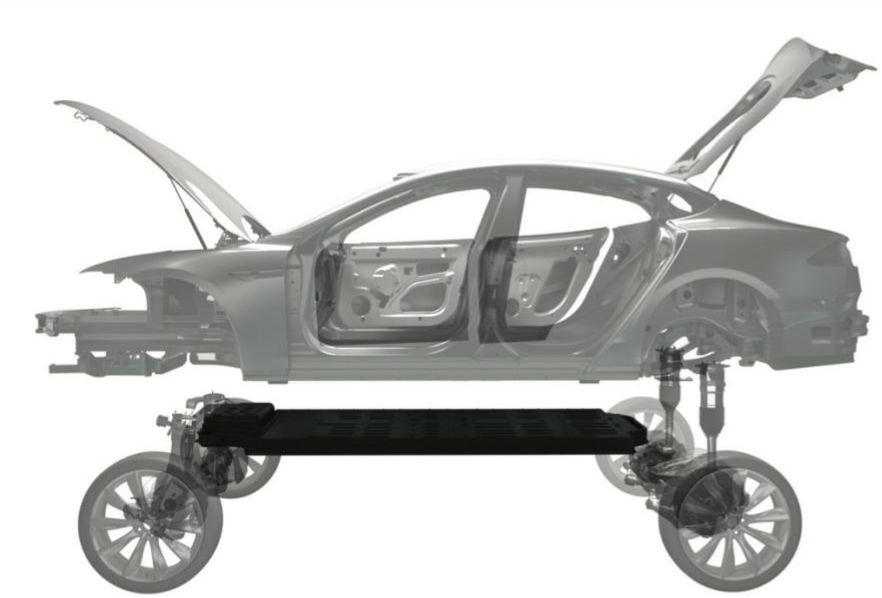

Figure 1. The body (gray) and battery (black) of the Tesla Model S are separate structures. Water in the body will drain out the doors without cooling the battery. Between these separate structures are typically layers of acoustic insulation and waterproofing which can further shed water.[2]

A test involving one model of electric car has shown that cooling the bottom of the battery may be quick and effective if the bottom of the vehicle can be made accessible. (Figure 2) Jacks, long pipes, or other rods could also be used as levers to lift, provided that the potential risk to the personnel and lifting equipment is first recognized. The close proximity to the fire would likely preclude use of a tow truck or other vehicle.

Figure 2. Tesla Model S extinguished by lifting side of car to cool the bottom of the battery. This car re-ignited twice more over a 16 hour period.[3]

[2] Source: https://www.tesla.com/sites/default/files/downloads/2014_Model_S_Emergency_Response_Guide_en.pdf

[3] Source: https://abcnews.go.com/Technology/tesla-opens-investigation-car-burst-flames-times/story?id=59930420

The problem is that having the battery mounted to the bottom of a car makes it generally too close to the ground for an effective wide-spread spray of cooling water in the few inches of space. (Figure 3) Flat tires or the collapse of adjustable suspension additionally restrict this space. Use of a fan nozzle may help cool the bottom if the vehicle if it can not be lifted.

Figure 3. This burning electric vehicle is too close to the ground to cool the bottom of the battery and venting flame along the rocker panel prevents jacking from at least the near side to expose the bottom of the battery.[4]

While the front of impact damaged vehicles may be in flames, firefighters should be extremely aware of battery vents located along the rocker panels. Heat internally progresses from overheating battery modules to adjacent battery modules, leading to propagation and pressurized flame may spontaneously emanate from the battery vents, to the sides of the car. (See Figure 4)

Figure 4. Burning Tesla Model S in parking garage shows the extent of pressurized flames which destroyed the adjacent car.[5]

[4] Source: https://patch.com/massachusetts/barnstable-hyannis/electric-car-engulfed-flames-provincetown-cvs

[5] Source: https://www.scmp.com/news/china/society/article/3007170/tesla-starts-investigation-after-car-explodes-chinese-car-park

Even if fire is not currently present at the vents on either side of the vehicle or if the fire initially appears to be out, the rocker panels should be widely avoided. If victim extrication is needed and because of this potential hazard, a flame proof blanket may be laid over the door sills immediately upon opening the doors.

In addition to concerns listed above, the damage to the front and avoidance of the sides may restrict the placement of jacks or other lifting devices to the rear of a vehicle for water to cool the bottom.

Cooling the bottom of the car as a technique would not be effective for vehicles in which the battery is not fully exposed along the bottom surface, so the battery configuration would need to be known or refer to the vehicle manufacturer ERG. (Figure 5)

Figure 5. The BMW i8 battery is in a central tunnel minimizing exposure to cooling the bottom of the vehicle.

External also cooling does not prevent re-ignitions from occurring at any time, so both electrical and potential fire hazards must be accounted for after a burning EV is extinguished. Because the heat can destroy electrical insulation materials within a battery, EVs have had re-ignitions days and weeks after a fire. Impact and fire damage have been found to trap high voltage and kilowatts of energy in isolated modules. Unburned cells will likely still contain flammable electrolyte, so the damaged battery may still contain fuel, oxygen, and potential ignition energy.

Finally, external cooling does not affect the state of trapped electrical energy and depletion of that trapped energy is highly recommended. While how to accomplish this depends on the vehicle involved, internal flooding has been found effective.

INTERNAL FLOODING OF BATTERIES:

Busses, trucks, locomotives, and other commercial vehicles operate in congested areas where it is impractical to allow a fire to burn itself out, especially if the fire is releasing potentially toxic material in the smoke. Some ship and fixed energy storage battery installations similarly may confine people to the area of a battery fire. Due to this, some ships and fixed installations are designed with plumbing so that water can be released directly into a module (group of cells) if an overheat condition is detected.[6] This can both extinguish an overheated condition before it becomes a fire and minimize damage to an isolated module, rather than destroy an entire battery which may fill the space of a large room.

For the design of the Zoe automobile, manufacturer Renault has provided firefighting access for water to flood the battery interior. The battery is typical in being a flat pack along the bottom of the car, but has a raised portion beneath the rear seats. In the event of an overheating battery, firefighters can open a rear door, pull out the rear seat, and puncture the foil dust cover on an opening to flood the battery. (Figures 6 and 7)

Figure 6. Renault Zoe battery fire during test. Rear seat cushions have been removed.[7]

Figure 7. Opening beneath rear seat following Renault Zoe battery fire test.[8]

Rather than requiring thousands of gallons, the Renault method only needs enough water to fill the battery container and extinguish any other flammable materials. Renault has repeatedly demonstrated this feature in Europe and shown that a battery fire may be extinguished within a single minute after removal of the seat cushion. More information may be found at:

[6] The module may also be isolated electrically so that an energy path from other battery modules is not introduced to a potential ground path and make the situation worse.

[7] Source: https://www-esv.nhtsa.dot.gov/Proceedings/24/files/24ESV-000252.PDF

[8] Source: https://www-esv.nhtsa.dot.gov/Proceedings/24/files/24ESV-000252.PDF

https://group.renault.com/en/news/blog-renault/electric-vehicles-groupe-renault-works-hand-in-hand-with-fire-services/

IMMERSION FLOODING OF BATTERIES:

European countries are widely adopting EVs and as a result have had to learn how to effectively extinguish EV fires in congested cities. The most effective method to quickly extinguish these fires has been immersion of the vehicle in a tank of water. Each of these:

1. Immediately extinguishes a burning vehicle.
2. The tanks could be used effectively for other containment, such as hazardous materials.
3. Isolates a burning vehicle from being able to damage other surrounding vehicles.
4. Without water, the container can allow transport of a burning vehicle or other hazard to a less populated location.
5. Containers can isolate environmental concerns such as electrolyte, foam, and other fire fighting residues.

Notes:

1. While concerns have been expressed about flammable hydrogen gas release from placement of charged batteries in water, this method of firefighting has been successful and there have been no known problems. The reason for putting a burning or smoking vehicle in water in the first place has been because a fire already existed.
2. This would also be effective for ICE vehicles.
3. Putting salt in the water has been successfully used to deplete residual trapped electrical energy by letting the vehicle soak for days.

The following are three examples of how this has been done:

The Netherlands have a custom designed tank with a crane which can lift the vehicle. (Figure 8) While the depth would also submerge burning interior materials, three apparent negative aspects to this would be the expense of the custom design; requirement for two pieces of equipment, each of which must reach the scene; and the depth which may pose a drowning hazard.

Figure 8. Smoking BMW i8 placed in water for 24 hours.[9]

A second method shows how an ad hoc version of the first was created with a dump truck, crane, and tarp. (Figure 9) The (presumably non-flammable) tarp was used to prevent water from leaking out of the dump truck faster than the water level can be raised. This had the benefits and negatives of the custom equipment.

[9] Source: https://www.brandweer.nl/en

Figure 9. Ad hoc equipment for immersion of electric auto.[10]

As a third method, any local fire department could adapt a simpler and less expensive version of the above with a common roll-off trash container and the truck used for delivery. The container (Figure 10) would be dropped in front of the vehicle with the rear door open. The cable from the delivery truck (Figure 11) would be placed over the front wall of the container so that a chain with hooks could drag the burning vehicle inside. Shut the doors, drop a weighted (sand bags) non-flammable tarp as a crude door seal and then fill sufficiently to submerge the battery.

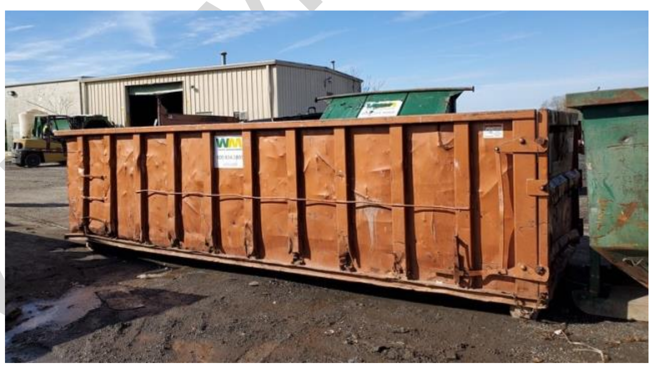

Figure 10. Photo of an open top roll off dumpster with a side hinged rear door.

[10] Source: https://www.moto.ch/wp-content/uploads/2019/06/Muldenkipper-E-Smart-bild.de_.jpg


Figure 11. The end of the roll-off truck cable which is used to deliver the container could be also be used to drag a vehicle into the dumpster.