Lithium-Ion Battery Fire Suppression Testing

Lithium-ion batteries (LiB) are becoming a mainstream power source in our homes, offices, and cars. These rechargeable batteries are found in our smart phones, lap tops, power tools, and even power our electric cars.

Lithium-ion batteries are energy-dense and contain flammable electrolytes and vapors. If the batteries are damaged, crushed, or overheated they can spontaneously burst into flame and begin venting toxic flammable gases which may ignite nearby batteries. Moreover, if they are overheated or overcharged, thermal runaway and cell rupture can occur which in some cases can lead to leakage, explosion, or fire. Batteries can reignite after the fire seems to be completely out, creating a nightmare situation for fire departments, tow truck drivers, and salvage yards.

The suppression method used to control such fires should suppress any LiB fire and control any rise in battery temperature. If not sufficiently cooled, thermal runaway reactions may continue, spread to adjacent cells, and the battery could re-ignite. This poses a major challenge for LiB fire suppression systems. Therefore, it is even more important to cool the cells in a large battery pack to prevent this heat propagation, than to extinguish fires from a single cell. LiB firefighting strategies must be based on both extinguishing the burning cell and cooling the burning cell and its neighbors.

USING WATER OR FOAM TO COOL?

An excerpt taken from the user's manual of a Tesla Model 3, the most popular electric vehicle (EV) manufacturer on the market, states: "There must not be fire, smoke, or heating present in the high voltage battery for at least one hour before the vehicle can be released to second responders (such as law enforcement, vehicle transporters, etc.). The battery must be completely cooled before releasing the vehicle to second responders or otherwise leaving the incident. High voltage battery should be stored in an open area at least 50 ft (15 m) from any exposure."

Currently the suggested best practice to extinguish an EV fire is with "copious amounts of water." Water is an excellent cooling medium due to its high heat capacity and latent heat of vaporization. In the Tesla Model S Emergency Response Guide, it states "It can take between approximately 3,000-8,000 gallons of water, applied directly to the battery, to fully extinguish and cool down a battery fire; always establish or request additional water supply early." Referring to his practical experience, however, Austin Fire Department Division Chief Thayer Smith, states that the extinguishment of a Tesla fire "can use 30,000 – 40,000 gallons of water Compared to 500 -1000 gallons for a gas-powered vehicle.

While water is relatively inexpensive, it is not always available. Is it the best tool to:

- Properly cool a LiB?
- Control reignition or thermal runaway?
- Save precious labor hours from potentially waiting around for reignition to occur?
- Minimize property damage?
- In water conservation or drought locations?
- Limit hazardous amounts of run-off?

With EV fires consuming hundreds of gallons of water and burning at such high temperatures is the use water alone the best tool for fire suppression with these toxic and explosive technologies? Multiple tests have been conducted to show alternative options including the use of a cooling foam, different firefighter suppression tactics, and using an alternative piece of fire suppression equipment.

TESTING PARAMETERS

This study was conducted to see if controlling the temperature of the LiB would prevent the batteries from reignition caused by thermal runaway. The study included three separate tests using different types of Lithium-ion batteries (pouch and cylinder).

1. The first test used standard everyday household batteries from a battery powered drill and paint sprayer. Both were 20 V batteries: one pouch and one cylinder configuration.
2. The second test utilized a pouch battery taken from an electric vehicle. A small EV would have approximately 65 pouch packs to power the car.
3. The third test used an 18650-cylinder module with 440 individual batteries in the module. Typically, 14 modules can be found in an electric vehicle.

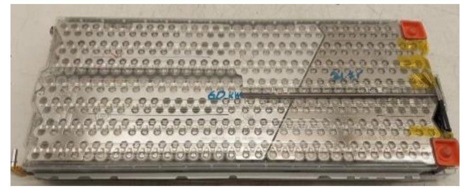
Testing was conducted at the Jackson County Fire Training Center in Jefferson, GA on October 4, 2022, at approximately 1:00 pm EST.

Battery Positioning

The batteries were placed on the center of a steel burn grate with an electric burner directly underneath the battery. Two burners were used for the large cylinder module. Each grate was contained in a burn tray.

2 household batteries on burner

Pouch Battery



Cylinder Module

Fire Ignition

To induce fire and thermal runaway the batteries were placed on a steel grate with an external ignition source (household electric burner placed underneath the battery).

Once the battery packs were ignited and fully engulfed in flame the burner's electrical cord was pulled, shutting off the heat to the fire. This allowed the fire to burn on its own and documented testing began.

Temperature

The temperature of the battery packs was tested several times throughout each incident. Taking the temperature was necessary to show the cooling effect after fire suppression began. A Thermal Imaging Camera (TIC) was also used to reveal where the runaway heat was inside of the battery box. The TIC also helped the firefighters assess the need for continued suppression.

Fire Suppression Agent

This test was conducted with an AFFF replacement foam, Pyrocool Green™. This product contains two powerful ultra-violet absorbers that have a remarkable ability to cool a fire. This heat-dissipating action absorbs more heat energy than plain water without the creation of steam.

Fire Suppression Systems

1. **Test 1** – Used two standard everyday household batteries one from a battery powered drill and the other a paint sprayer. With this burn, an Intelagard Macaw® Backpack was deployed for fire suppression using the Pyrocool at a 1% mix.

Macaw System Capabilities:

a. 5-gallons per minute (GPM)
b. 100 PSI operating pressure
c. Discharge hose length - 5 feet
d. Throw distance - 30 feet
e. Expansion ratio – The Macaw's 5-gallon tank was filled with water and 1% Pyrocool to create 175- gallons of fire suppression foam.

2. **Test 2** - Utilized a pouch battery taken from an electric vehicle. This burn was extinguished using the Intelagard Merlin® Handcart.

Merlin Handcart System Capabilities:

a. 10-gallons per minute (GPM)
b. 100 PSI operating pressure
c. Discharge hose length – 20 feet
d. Throw distance – 45 feet
e. Expansion ratio - Two 7-gallon tanks were filled with water and 1% Pyrocool to create 490-gallons of fire suppression foam.

3. **Test 3** - 18650-cylinder module. Fire suppression was tactics included the use the Intelagard Merlin MP compressed air foam system.

Merlin MP System Capabilities

a. 10- gallons per minute (GPM)
b. 100 PSI operating pressure
c. Discharge hose length – 20 feet
d. Throw distance – 45 feet
e. Expansion ration - 24-gallon tank of water mixed with 1% Pyrocool to create 840 gallons of fire suppression foam.

As a precautionary method, the fire training center supplied a pumper truck and ambulance crew.

Fire Suppression Activities

Fire suppression was conducted by the Jackson County Volunteer Fire Department. Firefighters were in full turn-out gear including breathing air. As fire suppression tactics are different for an EV fire vs. a structural fire, guidance was provided in the classroom portion of the training as well as during the live burn demonstrations.

Firefighters were also provided training on how to use the Intelagard fire suppression equipment. Training included:

a. Turning on the air cylinder
b. When to use wet/dry setting
c. How to properly activate the discharge handset
d. System was already filled with proper water to foam ratio and ready for operation

Fire Suppression Testing

1. Burners were ignited using an electric coil.
2. Heat was left on until these visible signs occurred:
    a. Flames, arcing, or projectiles
    b. Battery was fully engulfed in flame
3. Fire suppression began within one minute after the burner was turned off. Firefighting operations continued until all signs of combustion ceased and battery temperature reached ambient.

Battery Disposal

After testing batteries were transported in a secondary containment. All batteries were placed into a waterproof case filled with Pyrocool and transported by car back to Denver. Once returned to Denver batteries were properly disposed of at the Recycling Connections in Henderson, CO.

RESULTS

1. Test #1 Household appliance batteries – I cylinder and 1 pouch battery

1:30 pm – Electric burner turned on

1:37 pm - Batteries caught fire

1:39 pm – burner unplugged temperature 590F

1:39 through 1:41 popping with shooting shrapnel

1:42 pm – flames and smoke (Grey/black - Yellow/orange - Heavy White)

1:43 pm - popping with debris traveling 70 ft

1:43 pm - Fire suppression began – only one application of foam applied. No reignition and no evidence that thermal runaway occurred. Did not obtain final temperature.

Fire suppression used 1 – 2 gallons of water/Pyrocool mix from the Macaw tank.

2. Burn #2 – 1 module of pouch batteries (A123)

1:55 pm - Electric burner turned on. Starting temperature 92°F
1:57 pm - White smoke
1:58 pm - Grey smoke
1:59 pm - Yellow/orange smoke. Temperature 482°F. Flames begun
2:00 pm – Temperature was 743°F
2:09 pm - Temperature was 805°F. Electric burner unplugged.
2:16 pm – Lost flames. Electric burner plugged back in. Flames began again.
2:17 pm – Fire suppression began. Immediately cooled to 315°F
2:19 pm – Temperature 80°F
2:20 pm - 80°F. Additional foam applied. Thermal runaway did not appear to occur.

Fire suppression used approximately 4-gallons of water/Pyrocool mix from the Merlin Handcart tank.

3. Burn #3 – 1 module of 18650-cylinder batteries (440 individual batteries)

2:44 pm - Electric burners turned on (due to size of battery two burners were used). Starting temperature 84°F
2:46 pm - Flames
2:47 pm – Burners unplugged

2:48 through 2:53 pm - popping and flying debris

2:50 pm – Temperature 500°F
2:53 pm - Debris pops vertical approximately 25 ft range

2:53 pm - Temperature 900°F
2:54 through 2:57 pm – Temperature 1000-1300°F, Smoke -Yellow/ orange/ grey
3:00 pm – Fire suppression began. Temperature 1600°F (max reading possible with the device) – rapidly cooled to 400°F

3:01 pm – Temperature 140°F
3:02 pm – Temperature 123°F, additional foam applied, temperature 80°F
3:03 pm – no smoke or flames temperature at ambient.

Fire suppression used 10-gallons of water/Pyrocool mix from the Merlin MP tank.

After 1 hour of extinguishment all batteries were loaded into a secondary container filled with Pyrocool. The batteries were then transported by a vehicle from Georgia to Denver. After returning to Denver, all batteries were checked for stranded energy (electrical voltage remaining after complete disconnection from any source). The battery from the third test (18650-cylinder module) still maintained a 4.2 V charge no other batteries had a remaining charge.

CONCLUSION

In a world where LiB and EV's are becoming a mainstay in all homes and communities firefighters need to prepare for hotter and more difficult fires to extinguish. On average, an EV fire ranges in temperature from 2000 – 4900°F making the use of water inefficient. With these high temperatures the oxygen will separate from the water molecule and will then become a fuel for the fire.

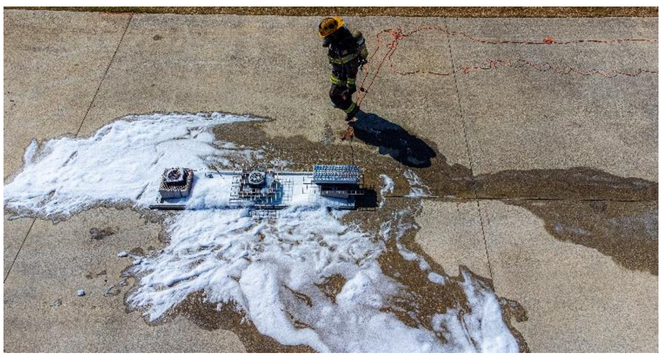
In a report by Envista Forensic, fire ignition establishes that the cathode of the battery can catch fire. The burning lithium creates a metal fire existing at temperatures of 2,000 degrees Celsius/3632 degrees Fahrenheit. Attempting to douse the fire with water is inadvisable since this could lead to a hydrogen gas explosion!

With the unique ability of the Pyrocool Green to rapidly absorb heat and cool a fire this drastically reduces the potential for thermal runaway to occur. By cooling the battery modules and the cells in the modules, the chemical reaction and trapped energy is less likely to occur. In all three tests conducted the burned batteries returned to ambient temperature (80°F) in 2 minutes or less.

Copious amounts of water is not a realistic SOG. Water is a scarce resource. Some departments do not even have access to water hydrants. This means the ability to expand a water-foam mixture becomes a necessity.

Currently, extinguishment of an EV fire can consume up to 30,000 gallons of water. (On average, a fire truck carries between 500 – 1,000 gallons of water.) This makes Intelagard systems an essential tool for fire suppression of LiB fires. Intelagard CAFS will expand the limited amount of water carried on a truck, eliminating the need to call in a support tank or go through an expensive drafting procedure. With the patented Enviroshield® technology, the Intelagard systems can take one gallon of water and convert it into 35 gallons of fire-fighting foam. In the scale testing conducted, only 16-gallons of water were used to extinguish all three fires with no reignition. This limited amount of water drastically reduced the amount of runoff and minimized any damage that may have been caused by water.

The combination of Intelgard's proprietary CAF equipment in conjunction with the Pyrocool's exothermic cooling capacity has demonstrated to be the only practical and safe method to extinguish LiB fires.



Notice the limited amount of runoff after 2 LiB fires had been extinguished.

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