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Suppressing Lithium-ion Electric Drive Vehicle Battery Fires with Water

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March 5, 2015
Introduction

- FPRF research project:
  - NFPA
  - DOE/INL/DOT/NHTSA
  - AAM/OEMs
  - SAE

- Project Goal:
  - Collect data to supplement current comprehensive training program for emergency responders to prepare them for their role in safely handling incidents involving electric vehicles (EVs)
Introduction
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How large is the hazard zone?
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Should the battery be allowed to burn?
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What about electrical shock hazards?

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Is current PPE appropriate?

What about electrical shock hazards?

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How large is the hazard zone?

Should the battery be allowed to burn?

Are there projectile hazards?

How effective is water as a suppressant?

How long do we suppress to control and then extinguish the fire?

Is current PPE appropriate?

What about electrical shock hazards?
How effective is water as a suppressant?
Test Plan Overview:

- Location: MFRI
- Number of Tests: 6
- Battery Types Tested: 2
- Data Collected:
  - Suppression time/water volume
  - FF tactics and observations
  - Electrical measurements
  - Water runoff sampling
  - Internal battery temperatures and cell voltages
  - Temperatures and heat fluxes at various locations
  - Photography, thermal imaging, HD videos
- Suppression: Fire department hand line
Batteries

- Three batteries generously donated from automotive manufacturer “A”
- Three batteries generously donated from automotive manufacturer “B”
Battery A

- 4.4 kWh battery
- Plug-in hybrid electric vehicle (PHEV)
- Installed under the rear cargo compartment of the vehicle.
- Enclosed in a metal case
- Li-ion battery cells
# Battery A

![Image of Battery A](image)

## HV Battery Assembly

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery assembly voltage</td>
<td>346 V</td>
</tr>
<tr>
<td>Number of Li-ion battery cells in the battery</td>
<td>288 cells</td>
</tr>
<tr>
<td>Li-ion battery cell voltage</td>
<td>3.6 V</td>
</tr>
<tr>
<td>Li-ion battery cell dimensions</td>
<td>4.42 x 4.35 x 0.56 in.</td>
</tr>
<tr>
<td></td>
<td>(112.2 x 110.6 x 14.1 mm)</td>
</tr>
<tr>
<td>Li-ion cell weight</td>
<td>0.54 lbs (245 g)</td>
</tr>
<tr>
<td>Li-ion battery assembly dimensions</td>
<td>32.4 x 38.1 x 14.9 in.</td>
</tr>
<tr>
<td></td>
<td>(822.4 x 967.8 x 378.4 mm)</td>
</tr>
<tr>
<td>Li-ion battery assembly weight</td>
<td>333 lbs (151.1 kg)</td>
</tr>
</tbody>
</table>
Battery A
Battery B

- 16 kWh battery
- Extended range electric vehicle (EREV).
- T-shaped battery spans nearly the length of the vehicle
- Mounted underneath the vehicle floor pan that separates the battery assembly from the passenger compartment.
- Li-ion battery cells
Battery B

<table>
<thead>
<tr>
<th>Type:</th>
<th>rechargeable energy storage system comprising multiple linked modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size/case:</td>
<td>5.5-foot-long T-shaped; glass-filled polyester structural composite with aluminum thermal radiation shield and steel</td>
</tr>
<tr>
<td>Mass (lb / kg):</td>
<td>435 / 198.1</td>
</tr>
<tr>
<td>Battery chemistry:</td>
<td>lithium-ion</td>
</tr>
<tr>
<td>Thermal system:</td>
<td>liquid active thermal control</td>
</tr>
<tr>
<td>Cells:</td>
<td>288 prismatic</td>
</tr>
<tr>
<td>Combined electric/extended driving range:</td>
<td>Up to 350 miles</td>
</tr>
<tr>
<td>Warranty:</td>
<td>eight years / 100,000 miles</td>
</tr>
<tr>
<td>Energy:</td>
<td>16-kWh</td>
</tr>
</tbody>
</table>
Battery B
MFRI: Suppression Testing

- 3 tests conducted each for Batteries A & B
  - 2 tests of battery alone
  - 1 test with interior finishes
**VFT**

- Designed by Exponent in conjunction with Tactical Incident Systems
  - Resembles modern EV
  - Opens in rear to allow for battery installation
  - Battery carriages roll each battery type into position
  - Allowed testing batteries in multiple locations
VFT
Fire Exposure: Burners and Burner Train

1. Manual shut off valve
2. Solenoid valve
3. Mass flow controller
4. Regulator assembly
Burner Arrangement

- Four burners
- All connected to burner train
- Produced 400 kW
- Positioned under battery
Firefighter Suppression Protocol

- 4 Firefighters
  - 2 on hose line, 2 support
- Water flow = 125 gpm
- 1.75 inch line
- ~75 psi city water supply
A Series
A Series
A Series
A Series (1 min - Ignition)

Battery Only

Battery & Interior
A Series (2 min)

Battery Only

Battery & Interior
A Series (4 min)

Battery Only

Battery & Interior
A Series (6 min)

Battery Only

Battery & Interior
A Series (8 min – Burners Off)

Battery Only

Battery & Interior
A Series (9 min – Start Suppression)

Battery Only

Battery & Interior
A Series (12 min)

Battery Only

Battery & Interior
A Series (15 min)

Battery Only

Battery & Interior
A Series (25 min)

Battery Only

Battery & Interior
A Series (30 min)

Battery Only

Battery & Interior
A Series (60 min)

Battery Only

Battery & Interior
Test A3
### A Series Results Summary

- **Summary of Water Flow Calculations**

<table>
<thead>
<tr>
<th>Test</th>
<th>Suppression Time (min)</th>
<th>Total Water Flow (gal)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>2.20</td>
<td>275</td>
<td>Battery Only</td>
</tr>
<tr>
<td>A2</td>
<td>3.53</td>
<td>442</td>
<td>Battery Only</td>
</tr>
<tr>
<td>A3</td>
<td>9.77</td>
<td>1060</td>
<td>Battery + Interior Components</td>
</tr>
</tbody>
</table>
A Series Results Summary

- **Observations summary:**
  - No projectiles
  - Popping heard/Arcing observed
  - Off-gassing preceded re-ignition events
  - Re-ignition 22 hours after test
  - Water flows increased over traditional ICE
B Series
B Series
B Series (1 min - Ignition)

Battery Only

Battery & Interior
B Series (2 min)

Battery Only

Battery & Interior
B Series (4 min)

Battery Only  Battery & Interior
B Series (6 min)

Battery Only

Battery & Interior
B Series (8 min)

Battery Only

Battery & Interior
B Series (10 min)

Battery Only

Battery & Interior
B Series (12 min)

Battery Only

Battery & Interior
B Series (15 min)

Battery Only

Battery & Interior
B Series (21 min – Burners Off)

Battery Only

Battery & Interior
B Series (22 min – Suppression Starts)

Battery Only

Battery & Interior
B Series (30 min)

Battery Only

Battery & Interior
B Series (45 min)

Battery Only

Battery & Interior
B Series (60 min)

Battery Only

Battery & Interior
### MFRI: B Series Results Summary

#### Summary of Water Flow Calculations

<table>
<thead>
<tr>
<th>Test</th>
<th>Suppression Time (min)</th>
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</thead>
<tbody>
<tr>
<td>B1</td>
<td>14.03</td>
<td>1754</td>
<td>Battery Only</td>
</tr>
<tr>
<td>B2</td>
<td>21.37</td>
<td>2639</td>
<td>Battery Only</td>
</tr>
<tr>
<td>B3</td>
<td>9.32</td>
<td>1165</td>
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</tr>
</tbody>
</table>
B Series Results Summary

- **Observations summary:**
  - No projectiles
  - Popping heard/Arcing observed
  - Off-gassing preceded re-ignition events
  - Water flows increased over traditional ICE
## Results Summary

- **Summary of Water Flow Calculations for all Tests**

<table>
<thead>
<tr>
<th>Test</th>
<th>Suppression Time (min)</th>
<th>Total Water Flow (gal)</th>
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</table>
“Unable to extinguish the fire - concentrated efforts on cooling the metal”

“There was tremendous heat”

“Consider 2 hose lines + backup: 1 for front and 1 for the rear to prevent chasing the fire”

“Floorboard (i.e. floor pan) makes fire harder to extinguish”
“These fires were worse than a conventional vehicle fire – harder to extinguish”

“EV fire behaves differently from traditional fire”
Key Findings

- Tests with EDV battery and interior finishes/upholstery was more intense than battery alone tests.
- Water alone (no additives) able to suppress the battery fires.
- Total water volumes for extinguishment varied widely throughout the tests.
- As the battery size increased and/or when the battery was less accessible, there was a significant increase in the total volume of water to extinguish the fire.
Key Findings

- Times for extinguishment ranged from 6 to 49 minutes
  - Does not include re-ignition - in one test, 22 hours later.
- In two fires the associated time to suppress the fire was greater than what was available from a single SCBA cylinder.
- Suppression efforts could last for one hour or more.
- Factors, including the size, position within vehicle, and access to battery will significantly influence the total time necessary for suppression.
Recommendations and Future Work

- Full-scale fire suppression testing of actual consumer EDVs
  - Collision vs. non-collision scenarios
  - Cell formats different than this series (i.e. 18650s)
  - New firefighter tactics (i.e. constant water application and two hose line team)
- Free burn full-scale EDV fires to compare and contrast the advantages and disadvantages of letting EDV fires burn out rather than suppressing.
- Evaluation of novel or alternate nozzle designs that may allow direct application of water to EDV batteries located below the vehicle underbody assembly.
- Evaluation of water additives/cooling agents/chemical suppressants
Acknowledgements

- Our thanks to:
  - Kathleen Almand, Executive Director, FPRF
  - Casey Grant, Research Director, FPRF
  - Marty LePore and the staff of MFRI
  - Karen Carpenter and the team at SwRI
  - AAM/SAE/DOE/DOT/NHTSA/INL
  - Exponent team

- Special thanks to the automotive manufacturers who generously donated batteries for testing
Questions?

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