Passive Fire Protection for Lithium Battery Shipments & Extinguishment of Lithium Battery Thermal Runaway

Federal Aviation Administration

Presented to: Triennial Meeting

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Background

- **Lithium batteries have been the cause of fires in small personal electronic devices and larger “bulk” quantities and continue to grow in popularity and use.**
  - Small-scale incidents
    - Approximately 64 cargo/baggage incidents have been recorded by the FAA since 1991. [3]
  - Incidents involving large quantities of cells
    - A battery fire caused an accident in Dubai in 2010. [2]
    - An aircraft fire involving lithium batteries occurred in 2006. [1]
    - Numerous lithium-ion car fires have occurred.
  - Properly extinguishing lithium battery fires involves ensuring that cell-to-cell propagation of thermal runaway is prevented; Thermal runaway of a single cell lasts for only a short time and wouldn’t be as much of a hazard if propagation was prevented.

Introduction (packaging)

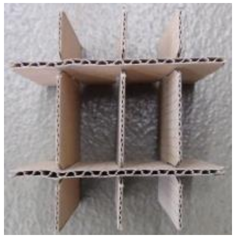
- **Batteries are shipped in various configurations.**
  - Lithium-ion and lithium-metal cells are generally shipped either adjacent to each other without any separation *or* with a divider material such as cardboard or foam.
  - Lithium-ion-polymer batteries are generally placed individually in a molded plastic carton.

Li-Ion

Li-Ion-Po

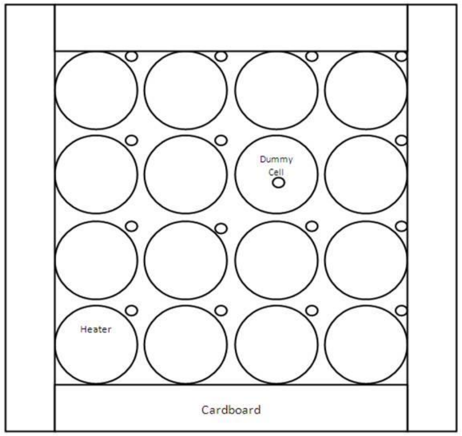
Objective (packaging)

- **The objective of the packaging study was to determine an effective packaging configuration to prevent the propagation of thermal runaway of 18650-sized batteries.**
  - Vary state-of-charge of the cells. (based on 2600 mah capacity)
  - Vary divider materials.
    - Cardboard
    - Cardboard treated with fire-retardant spray
    - Aramid
    - ABS plastic
    - Aluminum
  - Water packet above the cells.



Setup (packaging)

- **Tests were performed in battery boxes with a 16 cell capacity and a thermocouple on each cell.**



- **One of the 16 cells was replaced with a cartridge heater which was used to initiate thermal-runaway in the adjacent cells.**
- **Tests were conducted within a 64 ft³ chamber with a constant ambient air temperature.**

Test Procedures (packaging)

- **Data collection began and the heater was powered on.**
- **When the first cell began thermal runaway the heater was powered off.**
- **Data collection continued until all cells propagated *or* Temperature decreased enough to signal that propagation would no longer occur.**

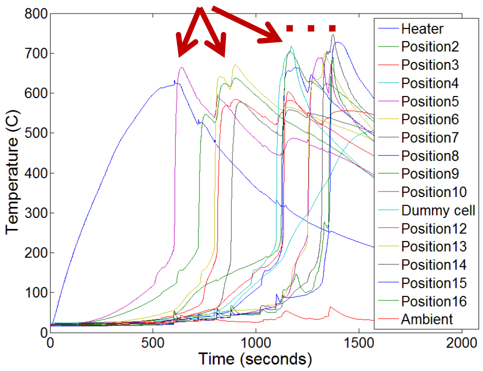
Tests Performed (packaging)

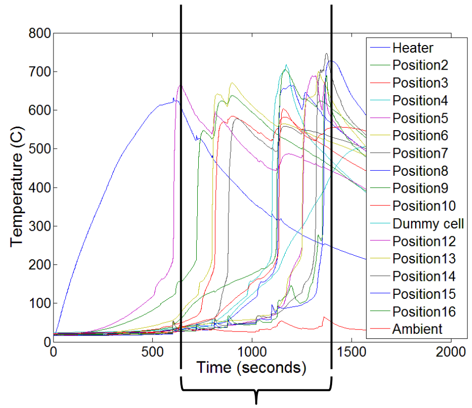
State of Charge	Cardboard Separators (as shipped)	Aluminum Separators	Fire Retardant Cardboard	Water Pack Above the Cells	Acrylic
30%					
40%					
50%	x2				
60%					
70%					
80%					
90%					
100%					

Data Processing (packaging)

- **Tests were quantified in two ways:**
  - Tests were quantified by the average of the peak temperatures.
  - Tests were quantified by the amount of time required for complete propagation.
- **Other qualitative results were observed.**

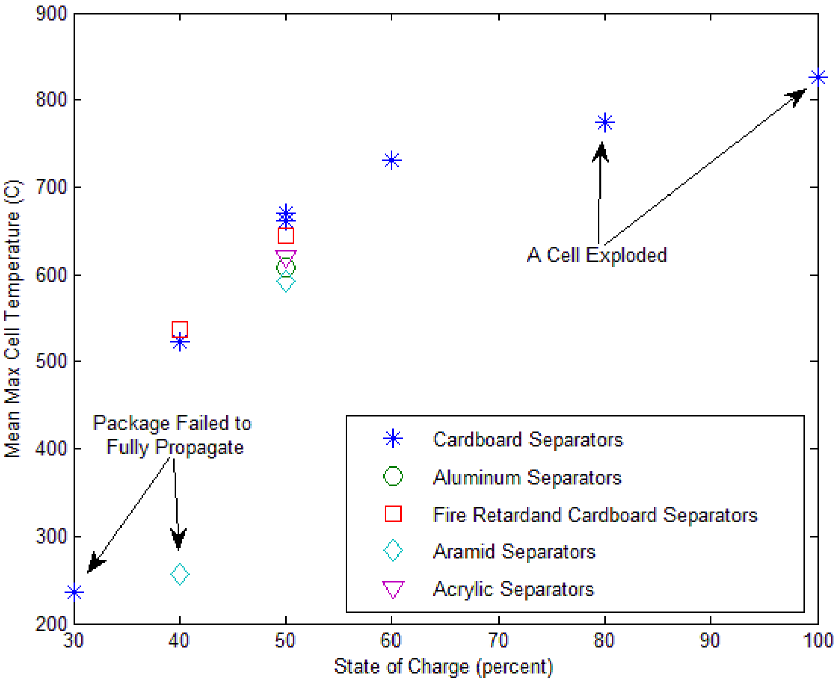
Mean of peaks





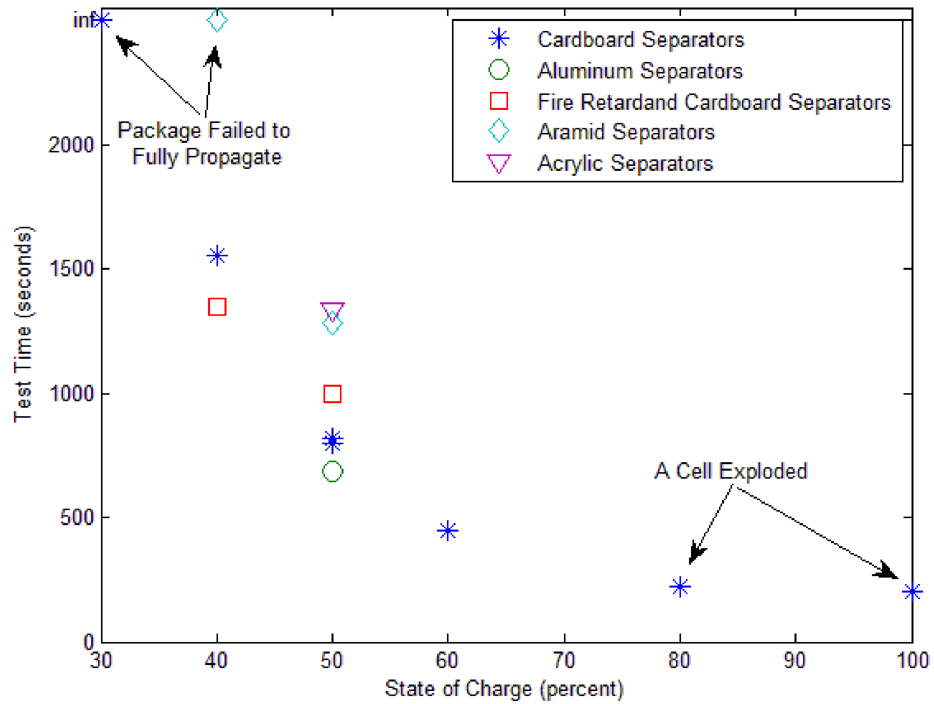
Time for propagation

Results (packaging): temperature



- **The average maximum temperature of the cells increased as state-of-charge increased.**
- **Insulating materials decreased the temperatures.**

Results (packaging): propagation time



- **The time required for the entire package to burn increased as state-of-charge decreased.**
- **Insulating divider materials increased the propagation time of the package.**

Other Results (packaging)

- **The packet of water above the cells prevented propagation.**

- **Explosions of the cells stopped propagation.**

- **Packages with the treated cardboard remained intact with cells at 50% SOC**

Un-treated

Treated

Summary (packaging)

- **The temperature of the cells *increases* with higher states of charge.**
- **The temperature of the cells *decreases* with insulative materials (Propagation slows down so cells have more time to cool).**
- **The time required for a package to burn *decreases* as state-of-charge increases.**
- **The time required for a package to burn *increases* with more insulative materials.**

Introduction (Extinguishment)

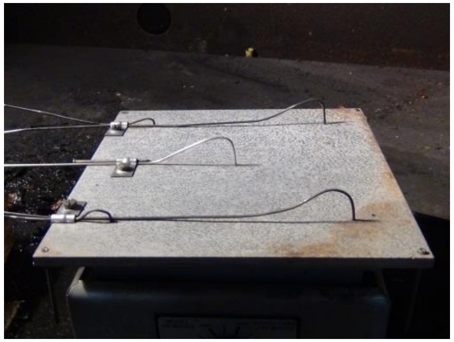
- **Battery Fire Extinguishment**
  - Previous tests at the FAA showed that water was effective at stopping thermal-runaway of a lithium battery.
  - Battery companies suggest a variety of extinguishing agents such as dry chem., CO_2, Foam, Lith-X, Powdered graphite and Water

Objective

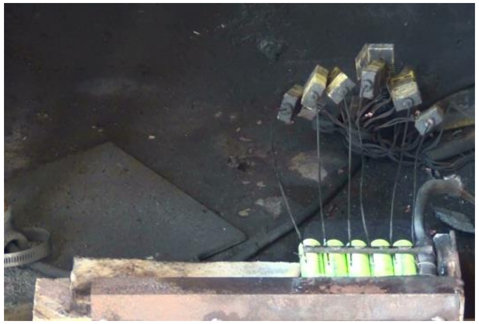
- **The objective of the extinguishment study was to determine the effectiveness of fire extinguishing agents in preventing thermal-runaway propagation.**
  - Cooling effectiveness with a hot-plate: Water, AF-31, AF-21, Aqueous A-B-D Agent, Novec 1230, Purple-K, Halotron, Halon 1211, Fe-36, FM-200
  - Handheld extinguishing agents on a lithium battery fire: Water, AF-31, AF-21, Aqueous A-B-D Agent, Novec 1230, Purple-K, Halotron, Halon 1211, Fe-36, FM-200

Setup (extinguishment)

- **Hotplate Tests: Extinguishing agents were applied to a hotplate from 8 inches above the plate and temperature drop was recorded.**



- **Lithium Battery Tests: 5 cells (Li-Ion and Li-Metal) and a cartridge heater were aligned, thermal runaway was initiated and the effectiveness of each agent was recorded.**

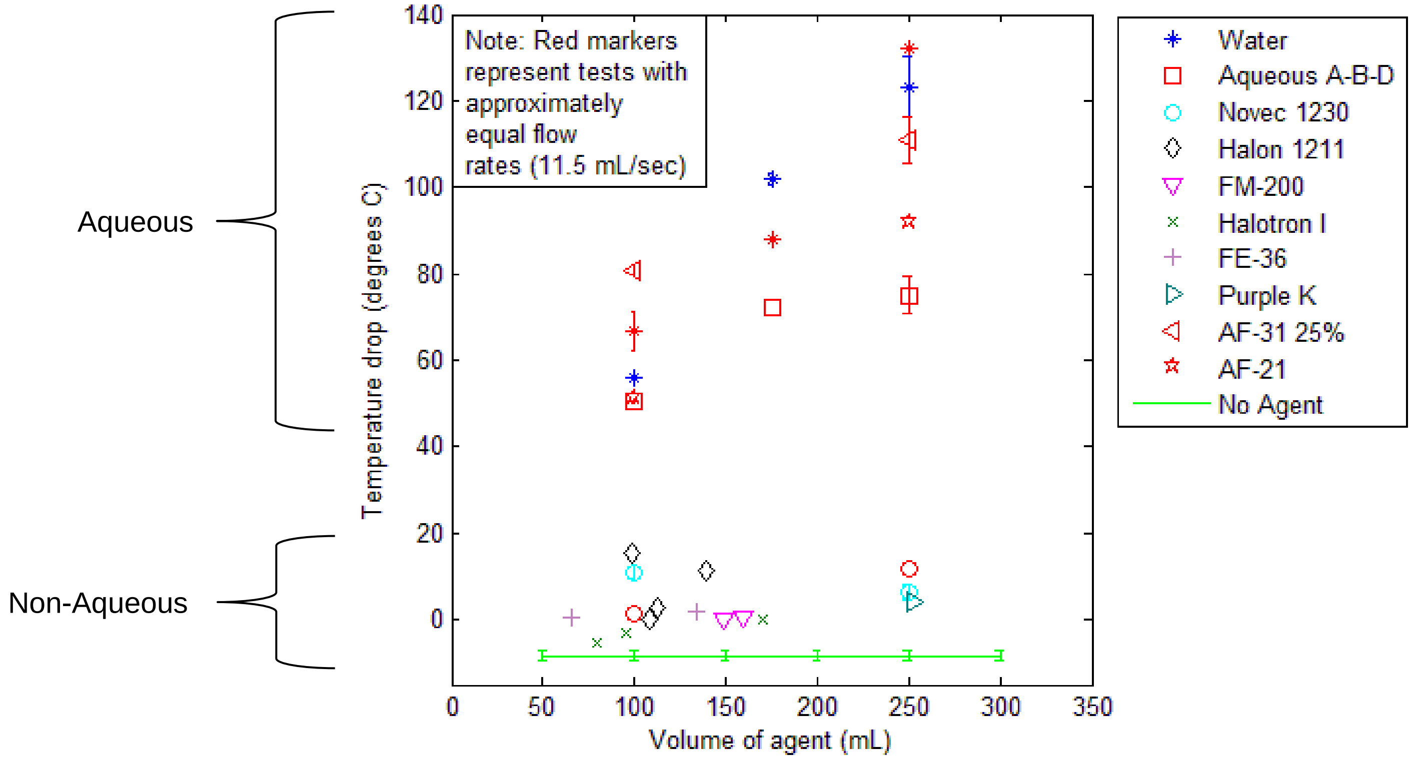


Tests Performed (extinguishment)

Various volumes of each agent were tested

	Hot Plate	Lithium-ion	Lithium-metal
Baseline (No Agent)	X4	X4	X7
Water	X14	X3	X1
Aqueous A-B-D	X5	X3	X1
AF-21	X2	X3	X1
AF-31	X4	X2	X1
Novec 1230	X6	X3	X1
Halon 1211	X4	X2	X1
FM-200	X2	X2	X2
Halotron I	X3	X2	X2
FE-36	X2	X1	X2
Purple-K	X1	X2	X1
CO2		X2	

Results (hotplate tests)



- **Aqueous extinguishing agents cooled the plate more than the non-aqueous agents.**

Results (hotplate tests)

Water | Aqueous A-B-D Agent | Novec 1230 | Halon 1211 | FM-200

Halotron I | FE-36 | Purple-K | AF-31 25% (aqueous) | AF-21 (aqueous)

Application of each agent to the hotplate

Results (extinguishment)

- **Streaming Tests**
  - Lithium-ion cells failed to propagate with aqueous streaming agents.
  - Lithium-ion cells continued to propagate with non-aqueous streaming agents.
  - Lithium-metal cells failed to propagate with aqueous and non-aqueous streaming agents. (Note: propagation continued with one test of purple-k, one of Halotron I and one of FE-36)

Results (extinguishment)

- **The lithium-metal cells generally showed one of four behaviors during thermal runaway.**

1)

Vent holes were in alternate locations.

2)

Cell vented through pre-existing vent holes at the positive terminal.

3)

Internal components were partially ejected.

4)

Internal components were fully ejected.

Shown in order of most common to least common

Summary (extinguishment)

- **Aqueous agents cooled the hotplate more than non-aqueous agents.**
- **Aqueous agents were more effective at stopping propagation in lithium-ion and lithium-metal cells.**

Future Tests

- **Perform cardboard (as shipped) tests with another Lithium-ion chemistry**
- **Perform packaging tests with lithium-metal cells.**
- **Vary the packaging separation distance between each cell.**
- **Once conditions that prevent cell propagation are determined they may be verified with a full box test.**

Questions or Suggestions?

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Citations

- [1] Thurber, Matt. "Cargo Carriage of Lithium Batteries Suspected in Some Accidents." *AINonline*. Aviation International News, Feb. 2012. Web. 01 Nov. 2012. <http://www.ainonline.com/aviation-news/aviation-international-news/2012-02-01/cargo-carriage-lithium-batteries-suspected-some-accidents>.
- [2] "Air Accident Investigation Interim Report." General Civil Aviation Authority, n.d. Web. 1 Nov. 2012. <http://www.gcaa.gov.ae/en/ePublication/admin/iradmin/Lists/Incidents%20Investigation%20Reports/Attachments/16/2010-Interim%20Report%20B747-400F%20-%20N571UP%20-%20Report%2013%202010%20-%20Rev%201.pdf>.
- [3] "BATTERIES & BATTERY-POWERED DEVICES." FAA Office of Security and Hazardous Materials Safety, n.d. Web. 1 Nov. 2012. <http://www.faa.gov/about/office_org/headquarters_offices/ash/ash_programs/hazmat/aircarrier_info/media/Battery_incident_chart.pdf>.