Packaging Research:

Transportation of Lithium and Lithium-ion Batteries

Background

Several notable aircraft cargo fires

FedEx DC-10-10, N65055
Newburg, NY, 5 Sept 96

UPS DC-8-71F, N748UP
Philadelphia, PA, 7 Feb 06

UPS Boeing 747-400F, N571UP
Dubai, United Arab Emirates, 10 Sept 2010

Ignition sources were not determined

FedEx's Fire Suppression System (FSS), both the active system with cargo foam and the passive system with a Fire Containment Cover (FCC), has been tested with equipment containing lithium-ion batteries and packages of bulk lithium primary cells.

FedEx's Onboard FSS

FedEx's FCC

In order to demonstrate that the FSS can suppress a fire in which equipment containing lithium-ion batteries are present, two full scale live fire tests were conducted.

The first test consisted of 192 laptops packaged and loaded in an AMJ per standard operating procedures. The laptop batteries had a 50% state of charge. The FSS successfully contained and extinguished the fire.

Loading prior to test

Four hours after ignition

Note: Additional laptops were not used due to crushing

The second test consisted of 194 laptops packaged and loaded on a pallet per standard operating procedures with a FCC. The laptop batteries had a 50% state of charge. The FCC successfully contained the fire for four hours.

Prior to ignition

Four hours after ignition

Some fire was noticed on the outside of the FCC, this fire was due to the cargo net burning. This situation has been resolved.

Note: Additional laptops were not used due to crushing

In order to demonstrate the FSS' suppression capabilities on a fire in which a bulk shipment Lithium primary cells were present a series of small tests were first conducted to observe the cells reaction to cargo foam.

The spread of thermal runaways was halted when cargo foam flowed directly over an exposed single layer of CR123 lithium primary cells.

Two full scale live fire tests were conducted.

The first full scale live fire test consisted of a standard fire load in an AMJ with a single layered tray with a quantity of 100 CR123 lithium primary cells inserted into the fire load. The FSS successfully contained and extinguished the fire.

The second full scale live fire test consisted of a standard fire load on a pallet with a single layered tray with a quantity of 100 CR123 lithium primary cells inserted into the fire load. A FCC was placed over the fire load.

The cells created several small holes in the FCC. However flames from the remainder of the fire load did not exit the FCC.

Additional testing was performed to determine the cargo foam's influence in relationship to the cell density in a shipment. The spread of thermal runaways was not halted when cargo foam flowed over a box containing multiple layers of cells.

Two conclusions were reached from these tests.

1. The FSS (cargo foam and/or FCC) will suppress a fire for four hours in which equipment containing lithium-ion batteries are present.

2. Packaging modifications are required in order to make the transportation of “Bulk” lithium cells safer.

Shipments of Lithium and Lithium-Ion cells and batteries are known to be hazardous. Bulk shipments are even more hazardous due to the large quantities and high density of the cells in a package.

Preliminary testing demonstrated that thermal runaways increased in intensity as the thermal event spread from cell to cell.

Preliminary testing also demonstrated that Lithium Primary cells were more energetic than Lithium-Ion Rechargeable cells; therefore primary cells were initially used in the testing.

FedEx's initial testing was based on thermally isolating each cell.

It proved difficult to thermally isolate cells due to the high temperatures produced and the large amount of exhaust gas that even a single cell releases when it vents.

Of the many possible solutions explored, the few that worked were bulky, cumbersome, and significantly increased the weight cost of the packaging.

An alternative to thermally isolating each cell is to cool the cell experiencing the thermal event to a temperature that would not adversely affect the surrounding cells.

The FAA has tried nitrogen as a cooling agent and found it to be ineffective.

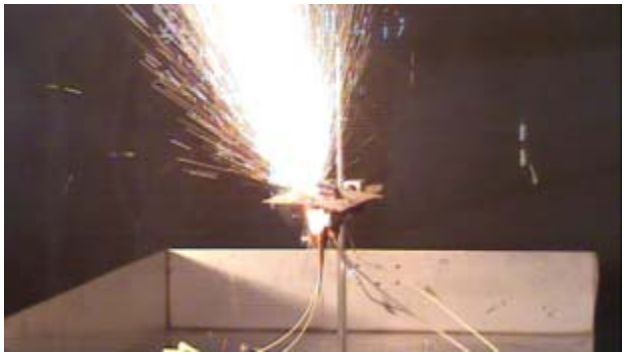
FedEx decided to use a liquid cooling agent.

Testing was performed to determine the fluid composition, viscosity, and release rate. It was determined that a mixture of liquid and gel provided the proper saturation and dwell of the cooling agent on the cells.

Cooling Concept:

- A pouch containing a liquid coolant is placed above the cells.

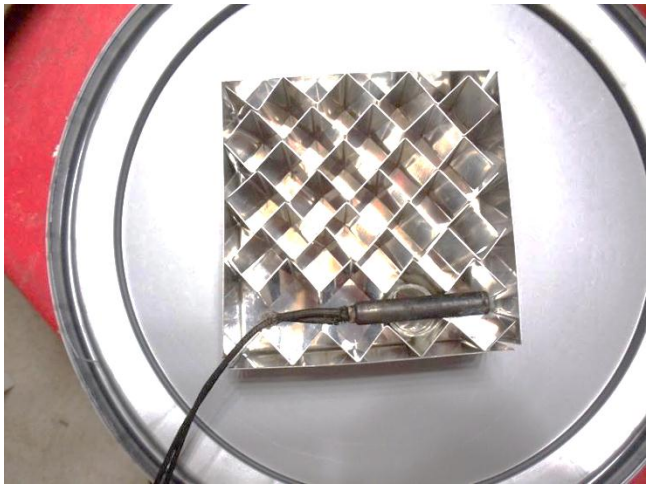
- When a cell experiences a thermal event, the heat from the cell ruptures the pouch thereby releasing the coolant.



- The coolant flowing over and around the cells decreases the temperature and prevents other cells from experiencing temperatures that would cause additional thermal runaways.

Only the cell forced into thermal runaway vented

In determining a coolant, a cartridge heater was used as a substitute for a battery experiencing a thermal runaway.



Pouches containing various liquids, gels and combinations there of were placed above the heater. Thermal couples were used to determine which coolants worked best to cool the heater.

When ruptured all the fluid would quickly exit the pouch. This required the pouch to hold enough fluid to submerge all the cells.

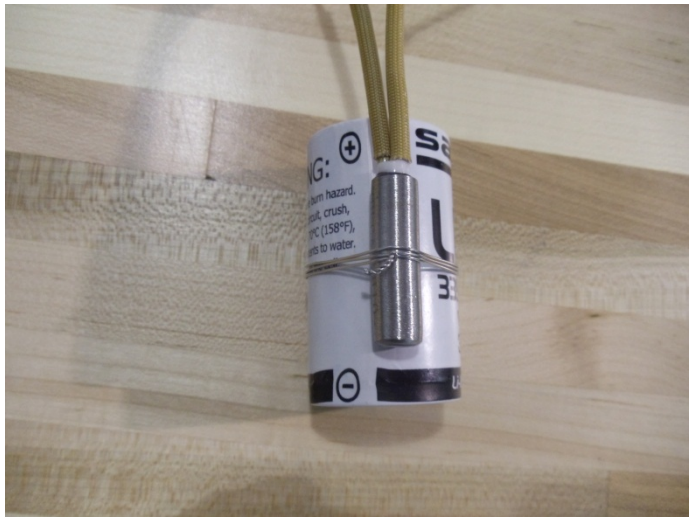
The addition of a gel helped meter the fluid flow through the rupture in the pouch, reducing the amount of fluid required. Too much gel and not enough fluid would be released to cool the cell and the thermal runaway would spread. Too little gel and the pouch would be depleted of fluid to soon and the thermal runaway would spread.

The pouches containing a combination of liquids and gels became known as Gel Packs.

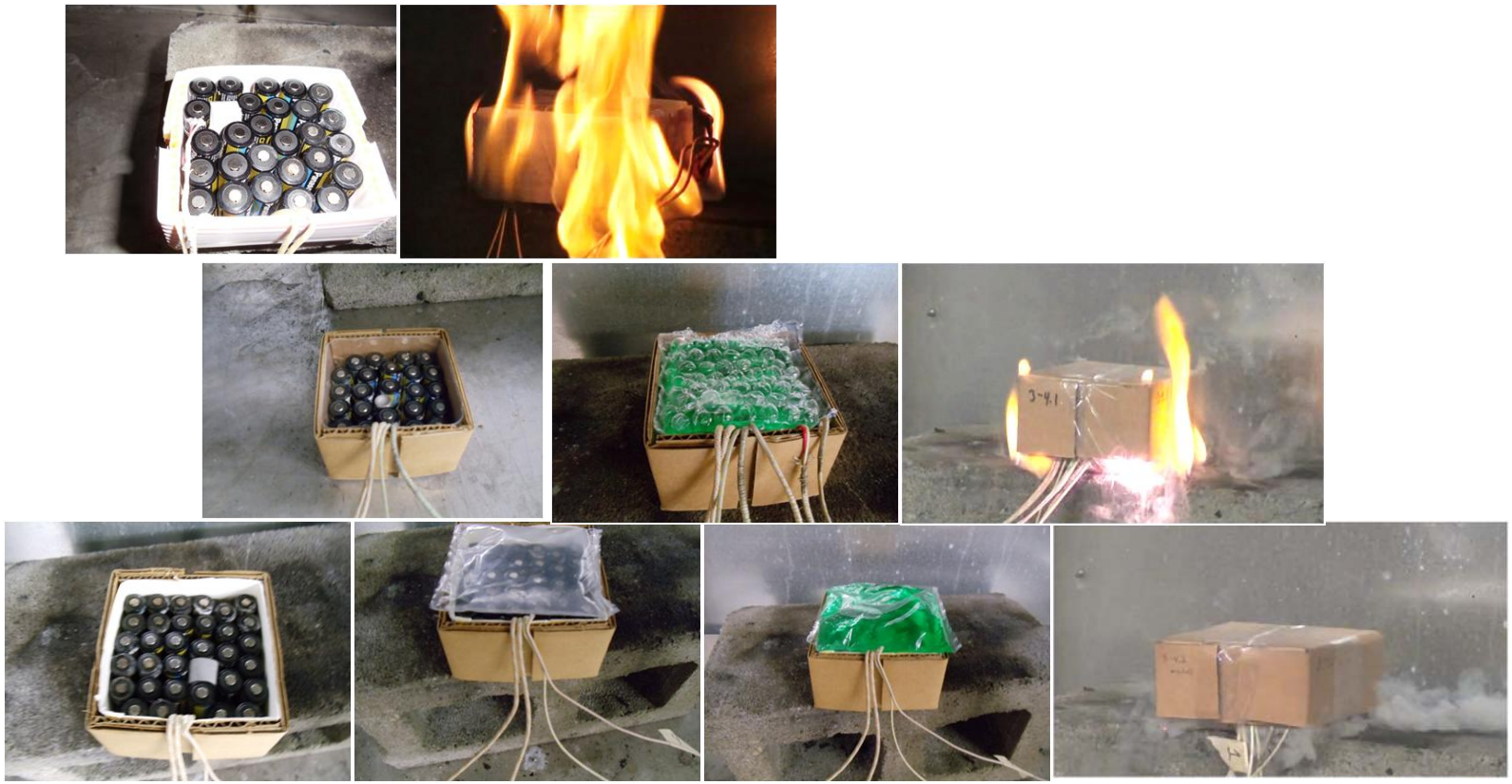
Thermal runaways in cells were induced by securing a cartridge heater to a single cell.

During initial testing the cartridge heater activated the cooling devices, releasing the coolant, before the cell went into thermal runaway.

In subsequent tests, the cartridge heater was insulated from the rest of the test article to prevent the cartridge heater from influencing other cells, packaging or cooling devices.



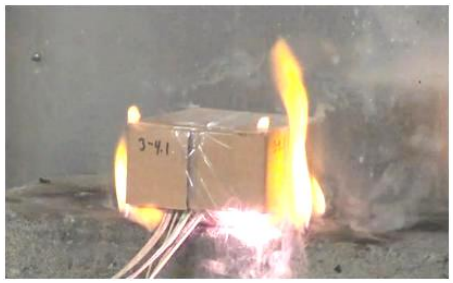
Testing was performed to determine the appropriate materials and configurations to use in the construction of the packaging. Consideration was given to existing packaging materials.



The venting gases auto ignited when they mixed with ambient air, causing the cardboard packaging to burn on the outside, not on the inside. By expanding the gel pack to have an interference fit with the packaging, the venting gases cool while passing through the coolant and prevents the auto ignition.

Gel Packs . . .

…only over cells

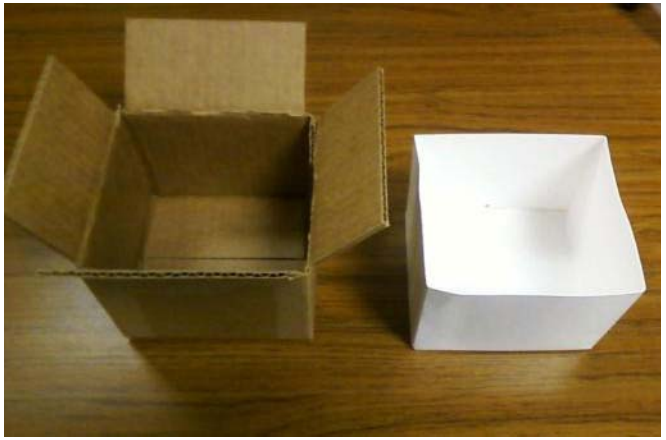


… barely touching inside of box

…interference fit with inside of box

Modifications to the existing bulk packaging to optimize the cooling concept are required.

The liquid coolant has a tendency to soak into any absorbent material, i.e. cardboard. Therefore the cells have been placed in a coated tray in order to retain the fluid.

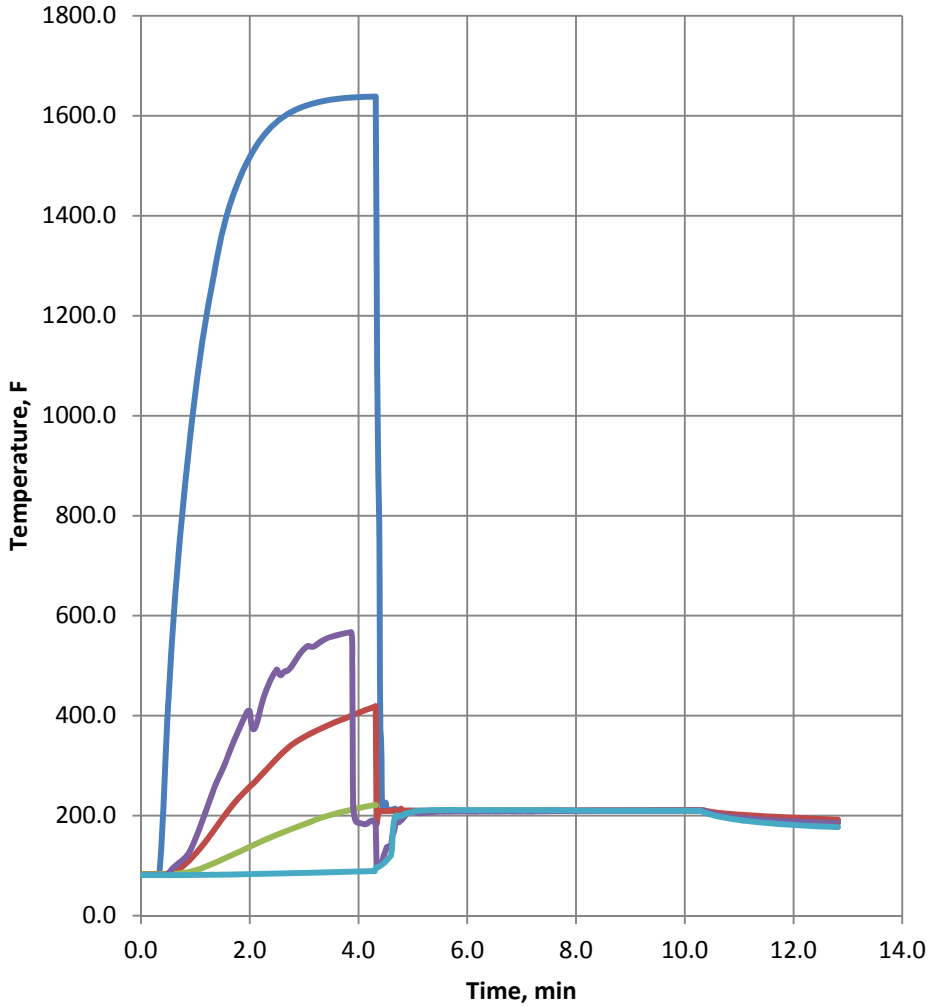


A buffer was required between the cells and the gel pack. Without a buffer the liquid in the gel pack would start to boil before the pouch ruptured. Thereby cooling the top of the cell and allowing the bottom of the cell to continue to heat and vent out the side.

Thermocouples were placed at various locations within the packaging.

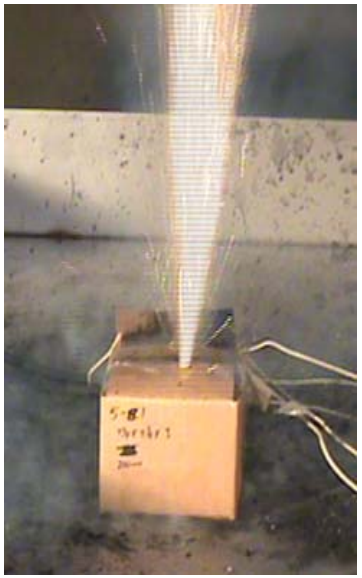
The cartridge heater reached over 1600°F before the cell vented. Once the cell vented, rupturing the gel pack, all the temperature readings decreased or increased to just over 200°F.

The cartridge heater was unplugged after 10 minutes.



Actual thermal couple graph of Gel Pack cooling batteries

To date burn testing has been successfully performed on CR123 lithium primary, 18650 lithium-ion (typically found in laptops) and “D” size lithium primary cells.



Thermal Events - Sparks and Flames blow through box

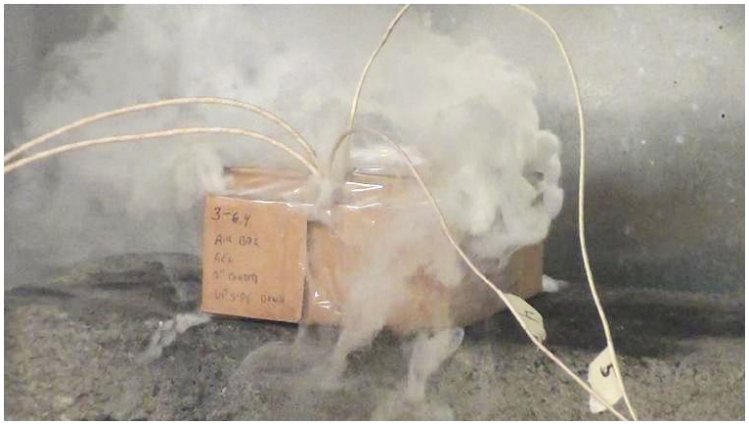
CR123

18650

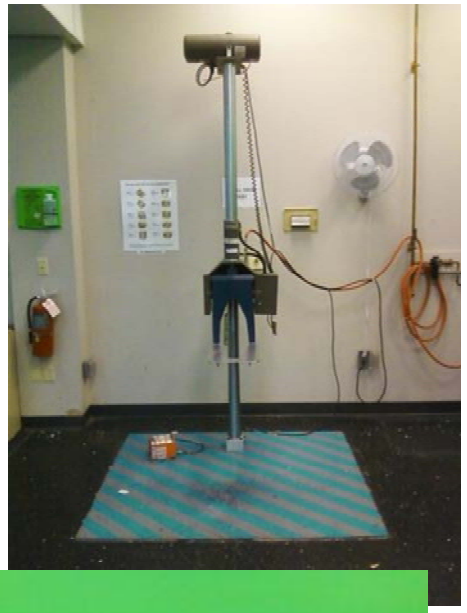
33550
D size

Gel Packs prevented jets of sparks and flames from exiting the box. Only the cell experiencing the thermal runaway vented.

Testing was performed to determine the package's ability to prevent thermal runaways as a function of the package's orientation (right side up, upside down, on its side).



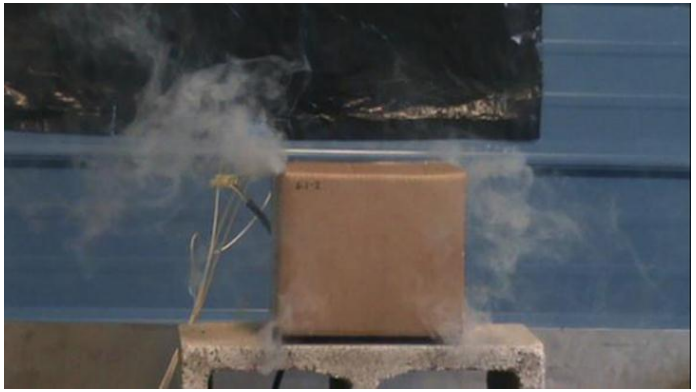
Vibration and drop testing of the packaging was performed.



Due to the environmental testing, inserts have been developed to hold the gel packs. The inserts also perform the task of “buffer” which eliminates the need for previously used devices.

Bulk Battery Packaging – Refinements





CR123 Lithium Primary
99 Per Box w/ Gel Packs
Two Boxes Per Carton
Only One Cell Vented



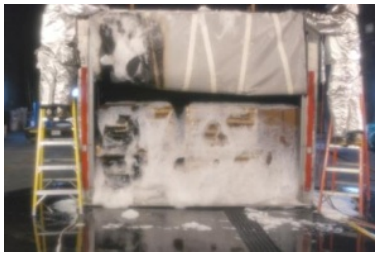


33550 Lithium Primary
25 Per Box w/ Gel Packs
Four Boxes Per Carton
Only One Cell Vented

Conclusions

FedEx's Fire Suppression System, both the active foam and the fire containment cover, have been proven to suppress a fire in which equipment containing Lithium-Ion batteries were involved.

(Laptops were used in these tests)

Several years of research, testing and development has produced the Gel Pack / Cooling concept.


Gel Packs will stop the spread of a thermal runaway in a bulk shipment of Lithium or Lithium-ion cells.

Testing of multi cell Lithium batteries is in progress.