Lithium Battery Thermal Runaway Vent Gas Analysis

Composition and Effect of Combustion

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Federal Aviation Administration

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Background

- Numerous explosions have occurred during large scale battery tests.
  - The class-C cargo area in a 727 exploded in full scale tests conducted by Harry Webster (see the Fire Safety website)
  - Two cargo containers exploded in tests conducted by Dhaval Dadia
  - A combustion test showed pressure rise in a $10m^3$ chamber and initiated this study

Background - Class C compartment

- Tests had not been performed to quantify the effectiveness of the onboard extinguishing agent in a lithium battery fire.
  - The required initial halon concentration for class-c compartments is 5%.
  - The required residual halon concentration for the remainder of the flight is 3%.
- Pressure relief valves for the compartment become active at about 1 psid and may cause halon to escape if a relatively small combustion event occurred.

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Objectives

Three series of tests were performed to further understand the gasses vented from lithium batteries.

1. **Small Scale** tests were performed to determine the gaseous composition with multiple cell chemistries and SOC.
2. **Small Scale** tests with $LiCoO_2$ chemistry were performed to determine the pressure rise of combustion for various concentrations of vent gas.
3. **Large Scale** tests with $LiCoO_2$ chemistry were performed to verify the hazard and further evaluate the effectiveness of Halon 1301.

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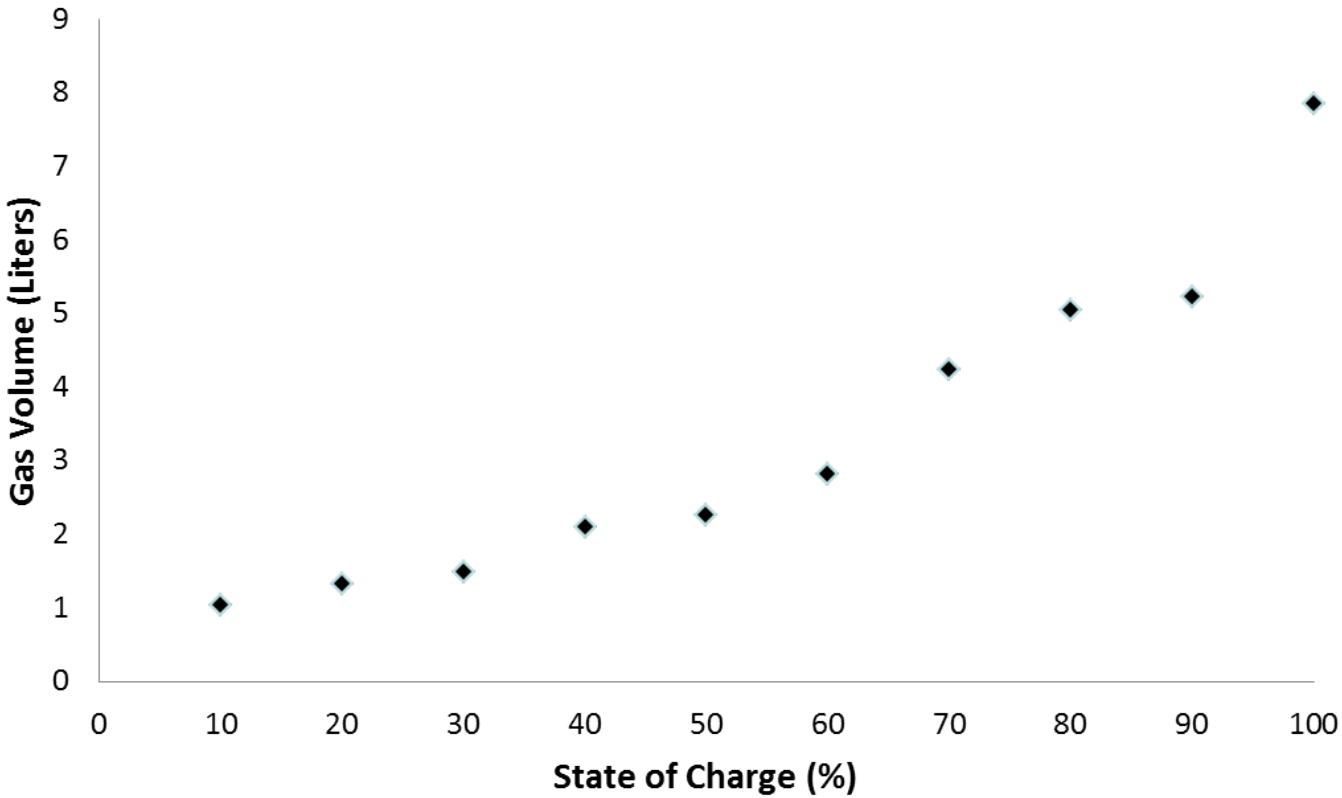
Setup, Procedure - Gaseous Composition

Details were previously presented at the last systems meeting and can be found on the web.

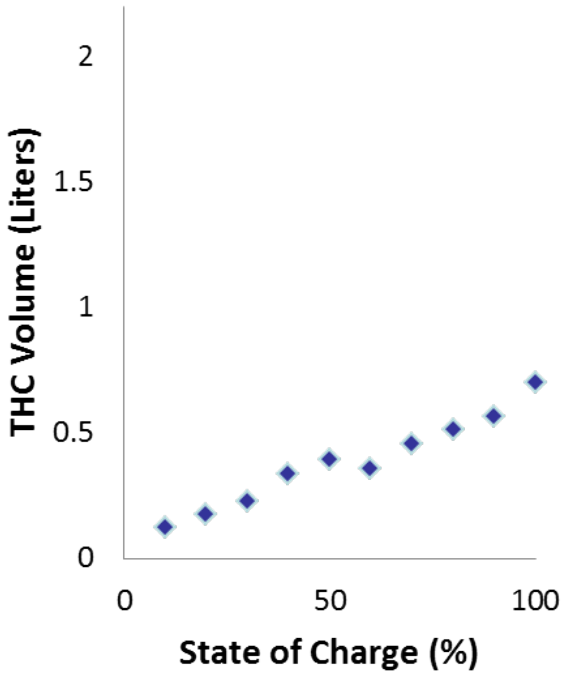
http://www.fire.tc.faa.gov/systems.asp
Presentation date: 10/29/2014
Presentation title: 25. Lithium Battery Thermal Runaway Vent Gas Composition

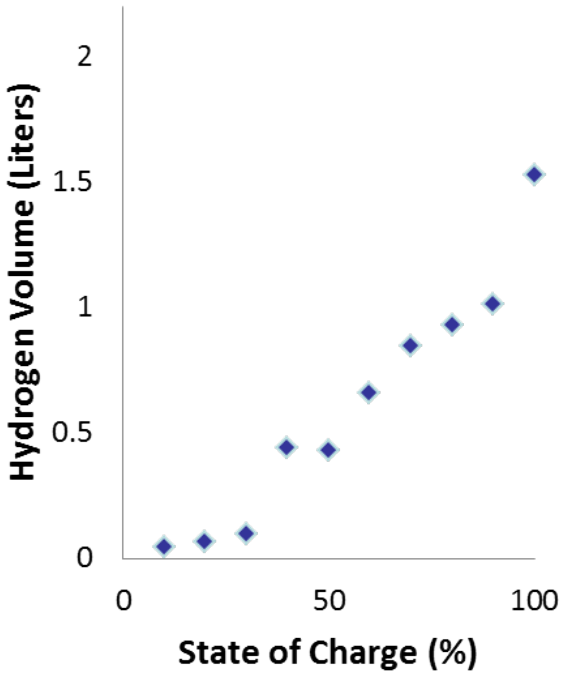
Results - Gaseous Composition

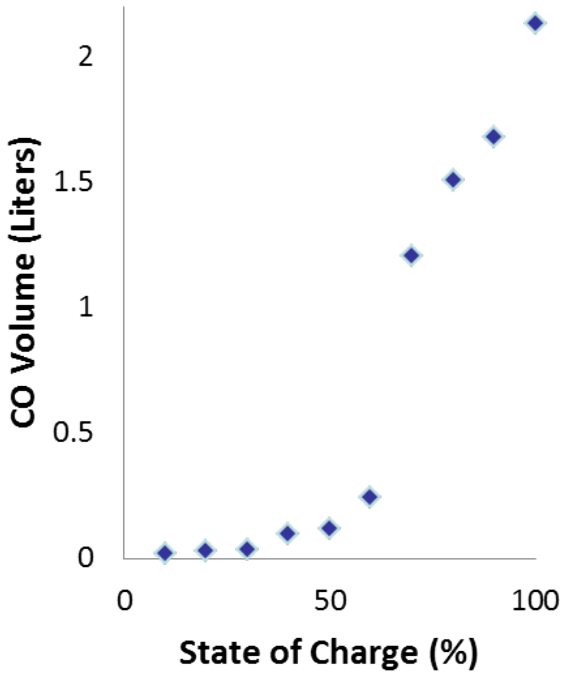


Total gas volume emitted increases as SOC increases.

Results - Gaseous Composition

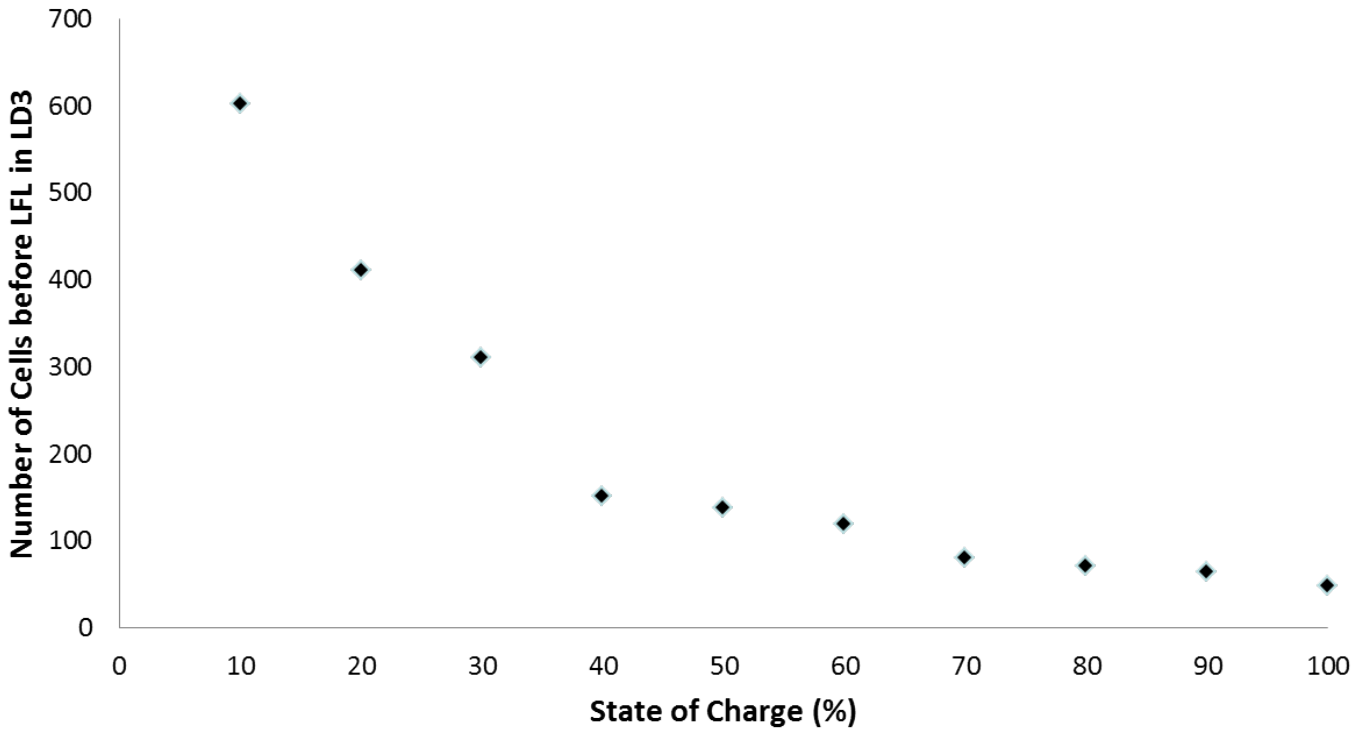






THC, H_2, and CO increased as charge increased.

Results - Gaseous Composition



The calculated number of cells required for an explosive mixture in an LD3 ($150 ft^3$) decreases as SOC increases.

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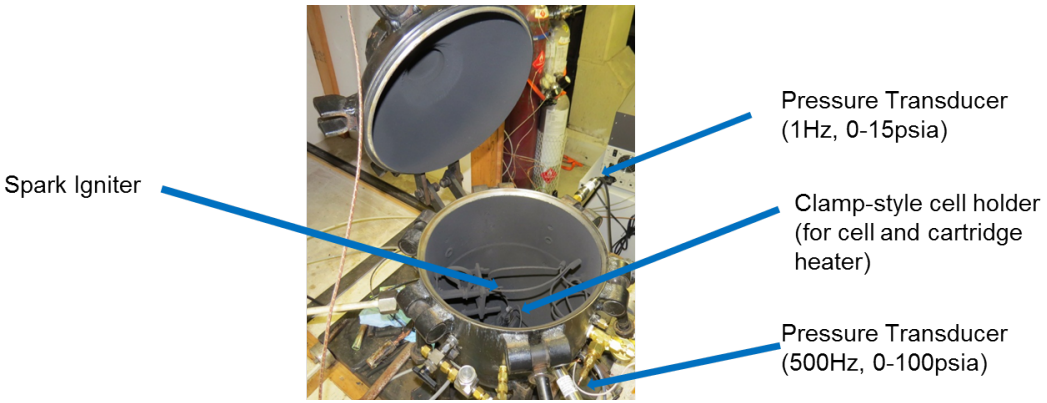
Setup - Pressure Rise

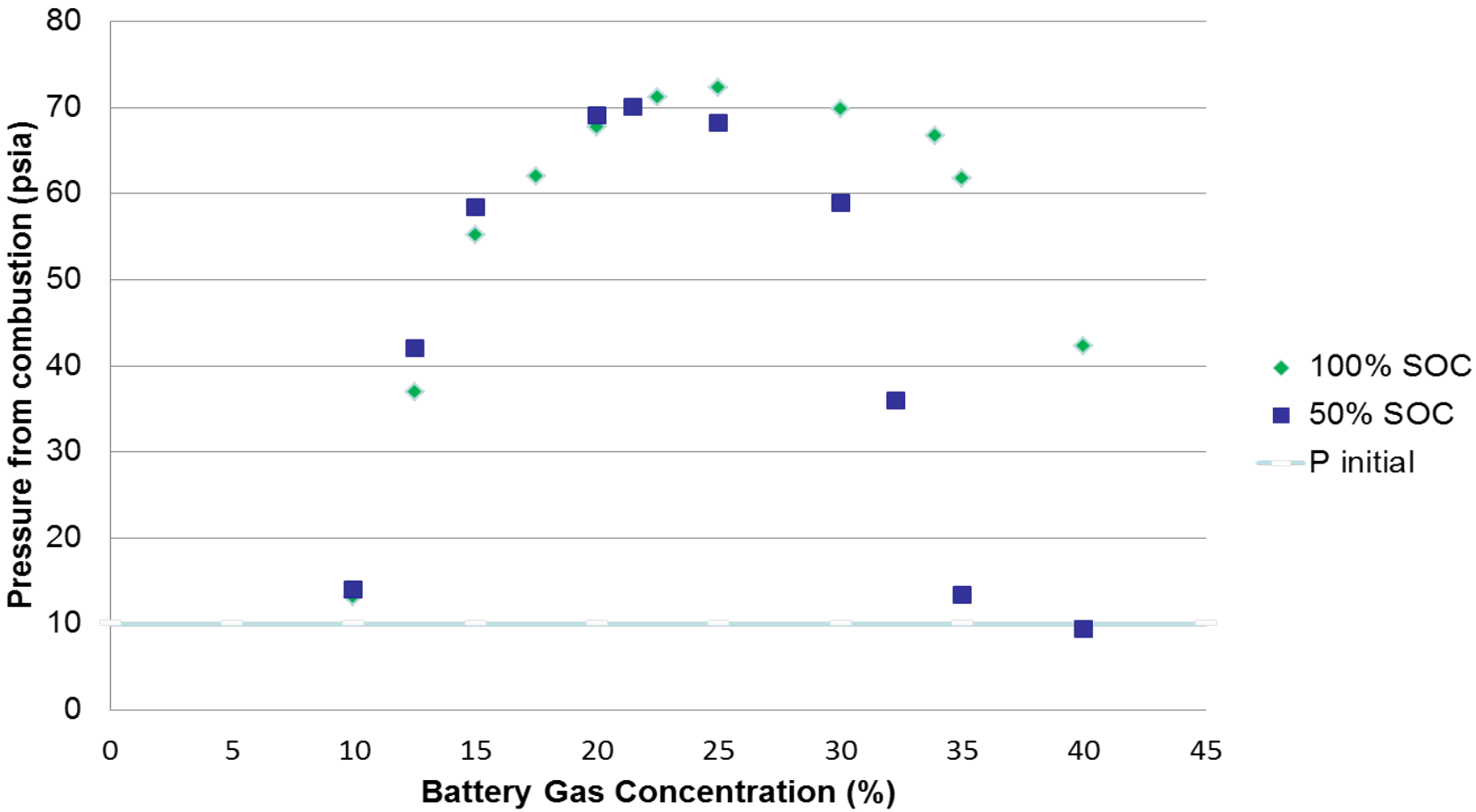
Cells vented into combustion sphere and the gases were stored in a heated storage tank.



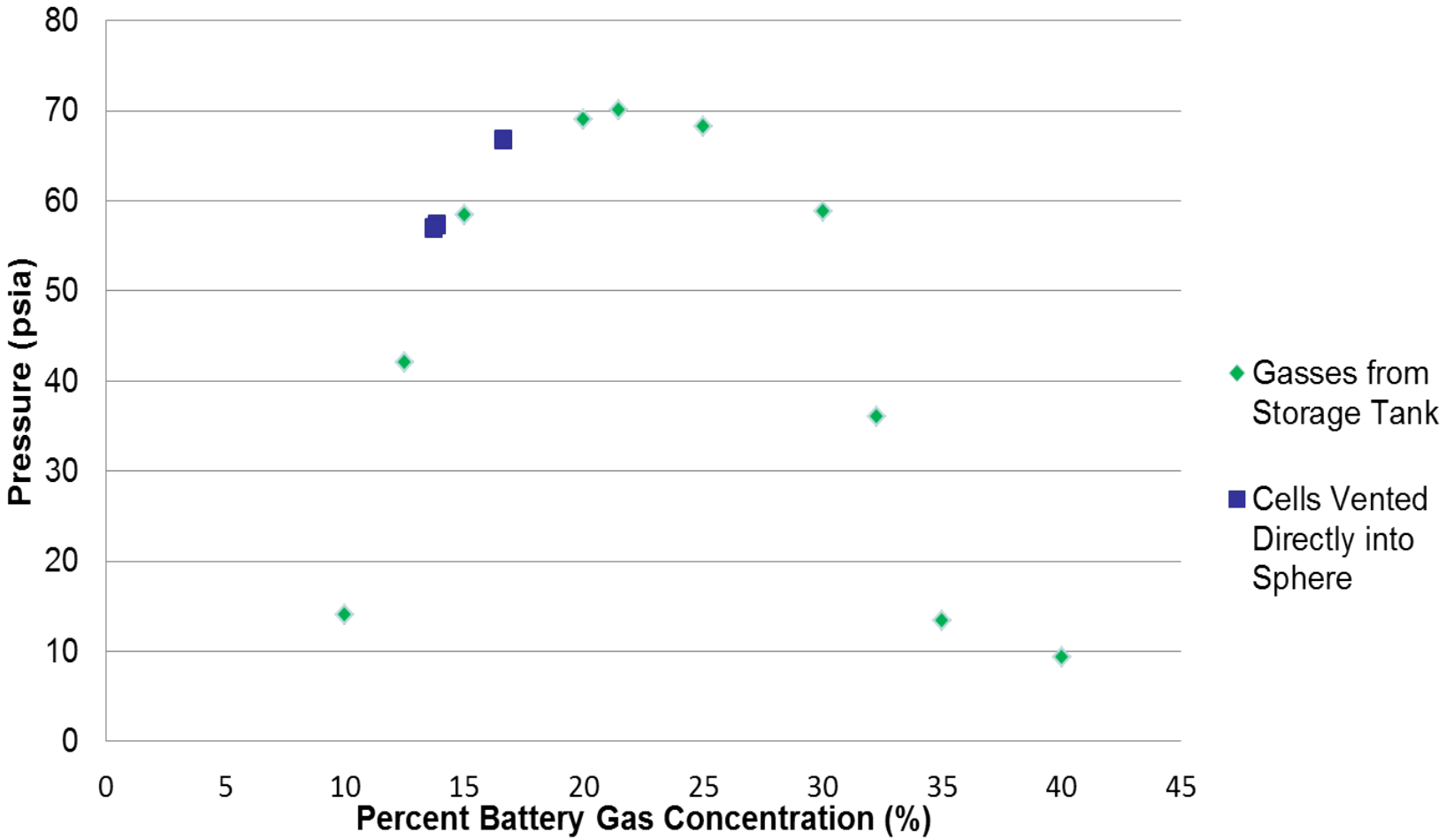
Combustion Sphere

Vent Gas Storage Tank

Results - Pressure Rise



Results - Pressure Rise



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Setup - Validation and Halon Effectiveness

Setup - Validation and Halon Effectiveness

Stoichiometric equation was used to determine the required vent gas concentration for cells at 50% SOC to be 12.4%.

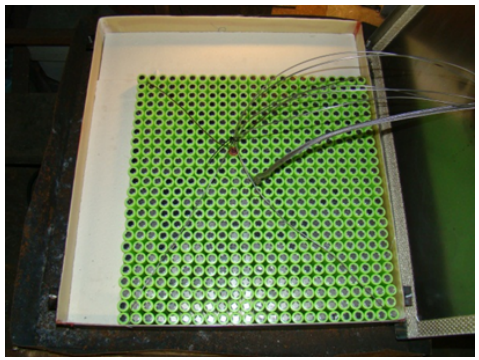
Calculation assumed:

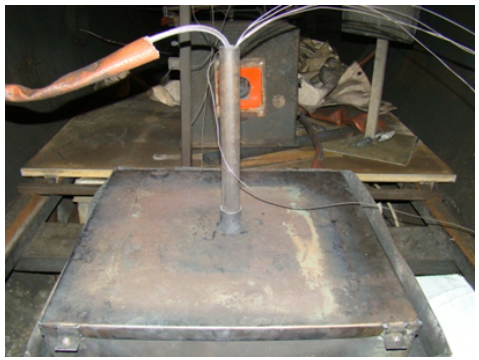
- Concentration THC = Concentration C_3H_8 = 17.55%
- Concentration H_2 = 19.22%
- Concentration CO = 5.2%

550 cells produce 1237.39 liters or 12.34% concentration in the 10m^3 chamber.

Setup - Validation and Halon Effect.

- Cartridge heater was placed at the center of the 550 $LiCoO_2$ cell array.
- Type-k thermocouples were attached to cells at 4 corners and one was attached adjacent to the cartridge heater.
- Array of cells was enclosed in a steel container with a chimney to create a rich fuel mixture and prevent premature ignition.
- A fan was present to mix.
- Spark igniter at center of chamber.
- Additional instrumentation:
  - 2 THC analyzers at different heights to check for stratification
  - An H_2 analyzer
  - A CO, CO_2, O_2, Halon 1301 analyzer

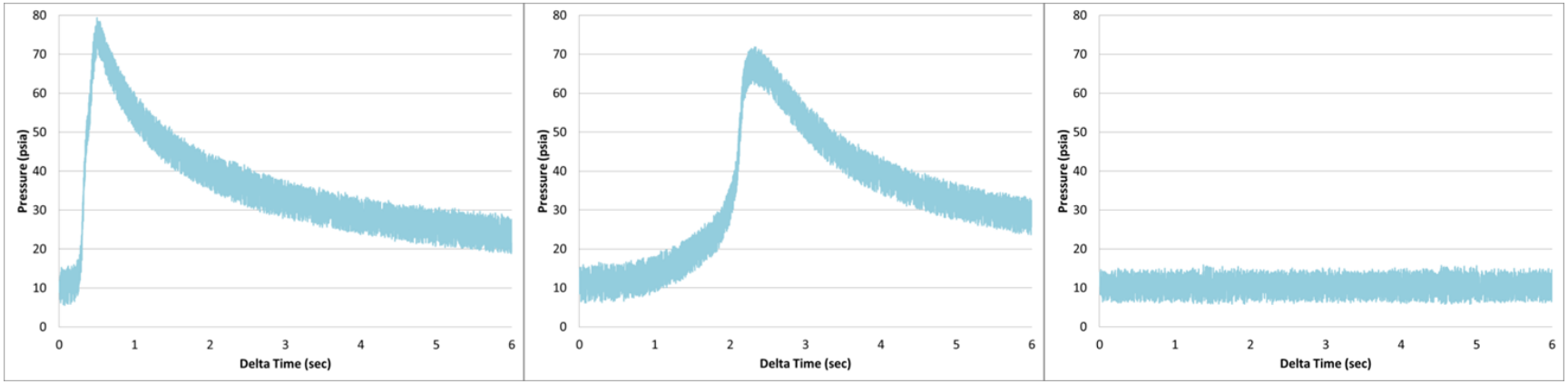




Procedure - Validation and Halon Effect.

- Baseline Test
  - The chamber was vacuumed to -6 psi
  - Thermal runaway was initiated with 550 lithium-ion $LiCoO_2$ cells at 50% SOC.
  - A fan was present to adequately mix gasses.
  - After all cells vented, the spark igniter was activated.
- Test with Halon 1301
  - The chamber was vacuumed to -6.53 psi for $\approx$ 5% halon or -7 psi for $\approx$ 10% halon and halon was bled in to increase the chamber pressure to -6 psi.
  - Thermal runaway was initiated.
  - After all cells vented, spark was activated

Results - Validation and Halon Effect.



No Halon 5.28% Halon 10.43% Halon

Elapsed time from spark ignition

Results - Validation and Halon Effect.

	Predicted Conc. from small scale tests	Actual Conc., No Halon	Actual Conc., 5.28% Halon	Actual Conc., 10.43% Halon
THC	2.47	2.50	2.77	3.20
H_2	2.70	2.74	3.50	3.54
CO	0.71	1.40	1.50	2.04
CO_2	3.58	3.97	3.42	4.73

Concentrations were predicted for 8.8m^3 to take into account items in the chamber that would reduce the chambers effective volume.

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Summary

- Volume of gas emitted from cells increased as SOC increased.
- THC, H_2 and CO increased as SOC increased
- The number of cells that can vent in an LD3 before the LFL is reached decreased as SOC increased.
- Vented gas composition can vary with differing cell chemistries.
- Combustion of vented gasses from Li-ion cells produced a pressure pulse of 75psia.
- Halon 1301 was less effective than previously thought at preventing combustion of battery gasses.
- Small scale tests reasonably predicted gas concentrations for large scale tests.

Questions, Discussion?

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