Lithium Battery Thermal Runaway Initiation Variation

Federal Aviation Administration

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By: FAA Fire Safety

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Introduction

- **Lithium Metal**
  - There are numerous methods to initiate thermal runaway in a lithium metal cell.
    - Overheat
    - Overvoltage
    - Reverse Charge
    - Internal short circuit
    - Damage
  - How does the maximum temperature rise and gas production vary?
  - How consistent is the temperature rise and gas production for a specific method?
- **Lithium Ion**
  - How does a change in heating rate effect thermal runaway?
    - Maximum temperature
    - Gas composition

Test Setup

- **Tests were carried out in a 21.7L combustion sphere.**

Pressure Transducer

Gas collection port for sample bag.

In all tests, air was removed and replaced with 14.7 psia N_2 before thermal runaway initiation

Test Setup

- **Lithium Metal Cells**
  - $LiSO_2$
    - Overheat
  - $LiMnO_2$
    - Overheat
    - Overcharge
    - Reverse charge
  - $LiFeS_2$
    - Overheat
    - Overcharge (if cells are available without PTC)
    - Reverse charge (if cells are available without PTC)
  - LiCFx
    - Overheat
    - Overcharge
    - Reverse Charge
- **Lithium Ion Cells**
  - $LiCoO_2$
    - Slowest heating rate (.3 C/min)
    - Fastest heating rate (26.7 C/min)
    - 5 to 10 C/min

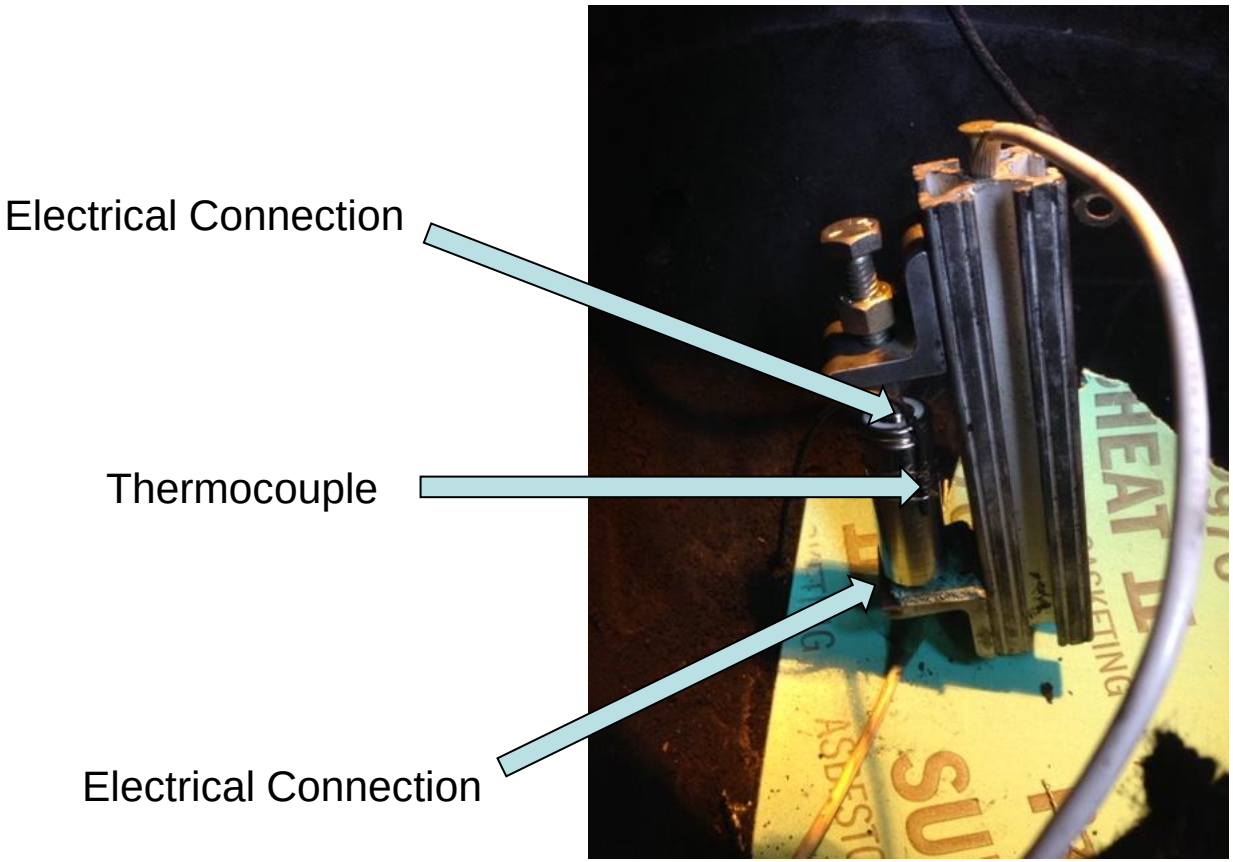
Gas Analysis

- **Partial pressures were used to determine gas volumes.**
- **GC, NDIR, FID were used for gas concentrations.**

Example Test Setup (Heater Strip)

Heater Strip Capacity: 28 volts, 1.5 amps

Example Test Setup (Overvoltage/Reverse Charge)



Overvoltage/Reverse Charge

Results $LiMnO_2$ 123a

	Heater	Overvoltage	Reverse Charge
Gas Volume (L)	1.95	2.91	Unable with PTC
THC (%)	16.438	8.5	Unable with PTC
Hydrogen (%)	27.48	26.14	Unable with PTC
CO (%)	24.59	15.97	Unable with PTC
CO2 (%)	22.143	N/A	Unable with PTC
Max Temp. (C)	564	690	Unable with PTC

	Gas Volume (L)	Max Temp. (C)
Heater Test 1	1.95	564
Heater Test 2	1.95	626
Heater Test 3	1.83	656

Overvoltage test: voltage varied. Initially it was set to 1.5*nominal and maintained for about a day. It was then increased gradually until runaway occurred.

Results LiCFx A

	Heater	Overvoltage	Reverse Charge
Gas Volume (L)	1.77		Unable with PTC
THC (%)	26.1		Unable with PTC
Hydrogen (%)	37.9		Unable with PTC
CO (%)	3.6		Unable with PTC
CO_2 (%)	2.4		Unable with PTC
Max Temp. (C)	587.8		Unable with PTC

	Gas Volume (L)	Max Temp. (C)
Heater Test 1	1.7714	587.8
Heater Test 2	1.7714	660.9
Heater Test 3	1.594	657.8

Results $LiSO_2$ D

	Heater	Overvoltage	Reverse Charge
Gas Volume (L)	6.774	N/A	N/A
THC (%)	4.6	N/A	N/A
Hydrogen (%)	.189	N/A	N/A
CO (%)	0	N/A	N/A
CO_2 (%)	.346	N/A	N/A
Max Temp. (C)	N/A	N/A	N/A

$LiSo_2$ did not show a thermal runaway temperature increase

Results $LiFeS_2$ AA

	Heater	Overvoltage	Reverse Charge
Gas Volume (L)	1.0599	N/A	N/A
THC (%)	23.82	N/A	N/A
Hydrogen (%)	56.4	N/A	N/A
CO (%)	6.016	N/A	N/A
CO_2 (%)	0	N/A	N/A
Max Temp. (C)	555.6	N/A	N/A

Note: Heater temperature needed to reach 445C for runaway to occur

Results Heating Rate

Average gas and temperature values

	Low Heating rate	5 to 10 C/min	Fast Heating rate
Gas Volume (L)	1.19	1.77	1.44
THC (%)	19.6558	14.85	17.2
Hydrogen (%)	28.2395	27.4455	24.33
CO (%)	6.029	10.875	8.3271
CO_2 (%)	33.22	25.725	28.1
Max Temp. (C)	275.1*	367.8	364.47*

*Temperature from only one test

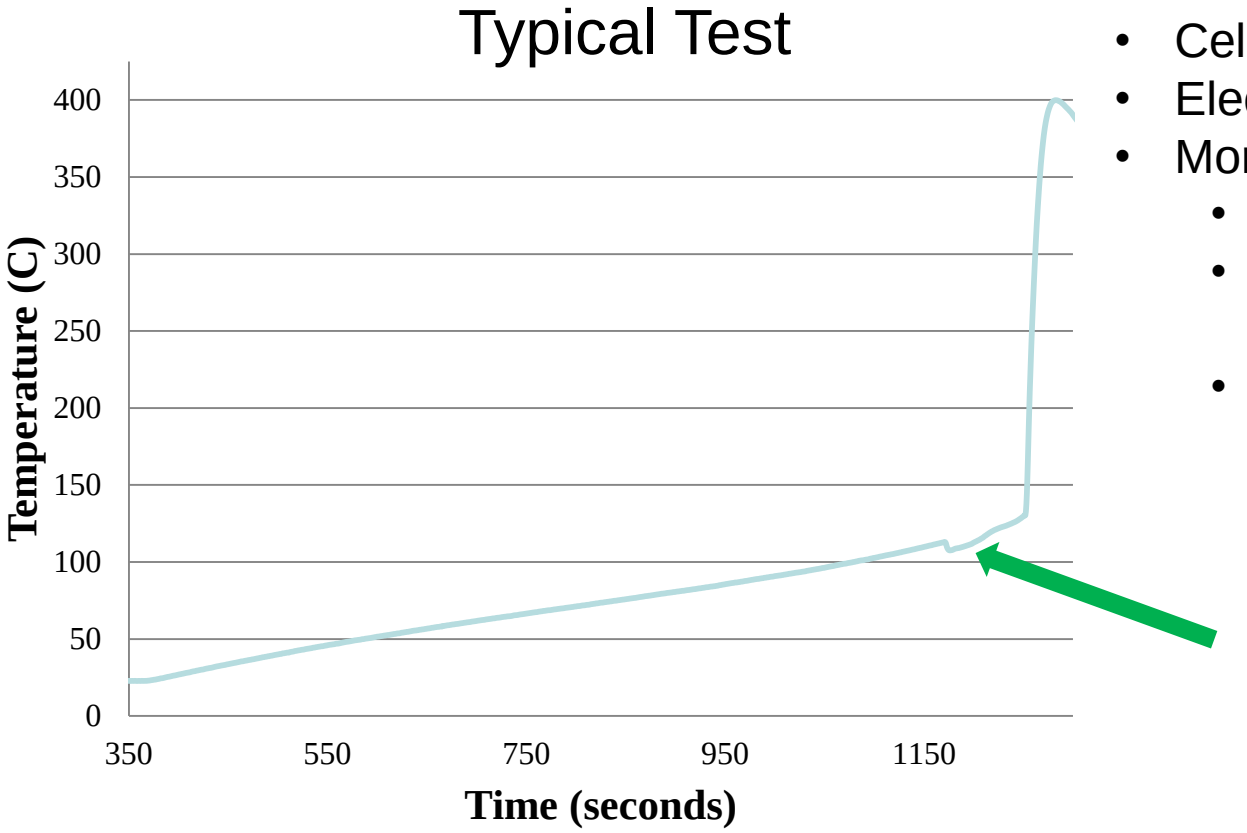
Results Heating Rate

Standard Deviation

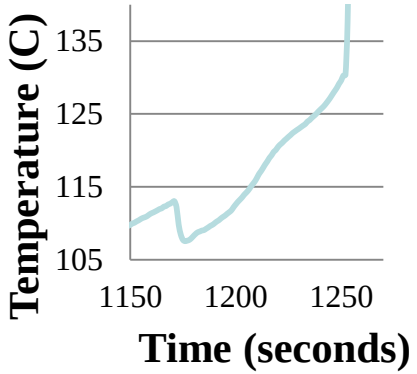
	Low Heating rate	5 to 10 C/min	Fast Heating rate
Gas Volume (L)	.26	0	.066
THC (%)	5.33	.15	.79
Hydrogen (%)	4.83	1.18	2.26
CO (%)	1.07	.825	1.55
CO_2 (%)	5.67	3.83	1
Max Temp. (C)		32	

Results Heating Rate

- **Largest cause of gas variation**



- Cell ruptures from pressure
- Electrolyte evaporates
- More time before runaway
  - More evaporation
  - Less electrolyte available to react during runaway.
  - Less gas volume.



Summary

- **Lithium metal**
  - Consistency in heater strip results.
  - 1.5*nominal voltage wasn't sufficient to cause runaway after a day.
  - At higher c-rates PTCs interfered with additional overvoltage, reverse charge tests.
- **Lithium ion**
  - The lower heating rate resulted in lower temperature increase, less gas volume, less consistency
    - A larger amount of electrolyte evaporated from the cell before runaway.
  - 5 to 10 C/min and higher resulted in higher temperatures and gas volume

Questions?

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