ENERGY RELEASE OF LITHIUM ION BATTERIES AT DIFFERENT STATES OF CHARGE

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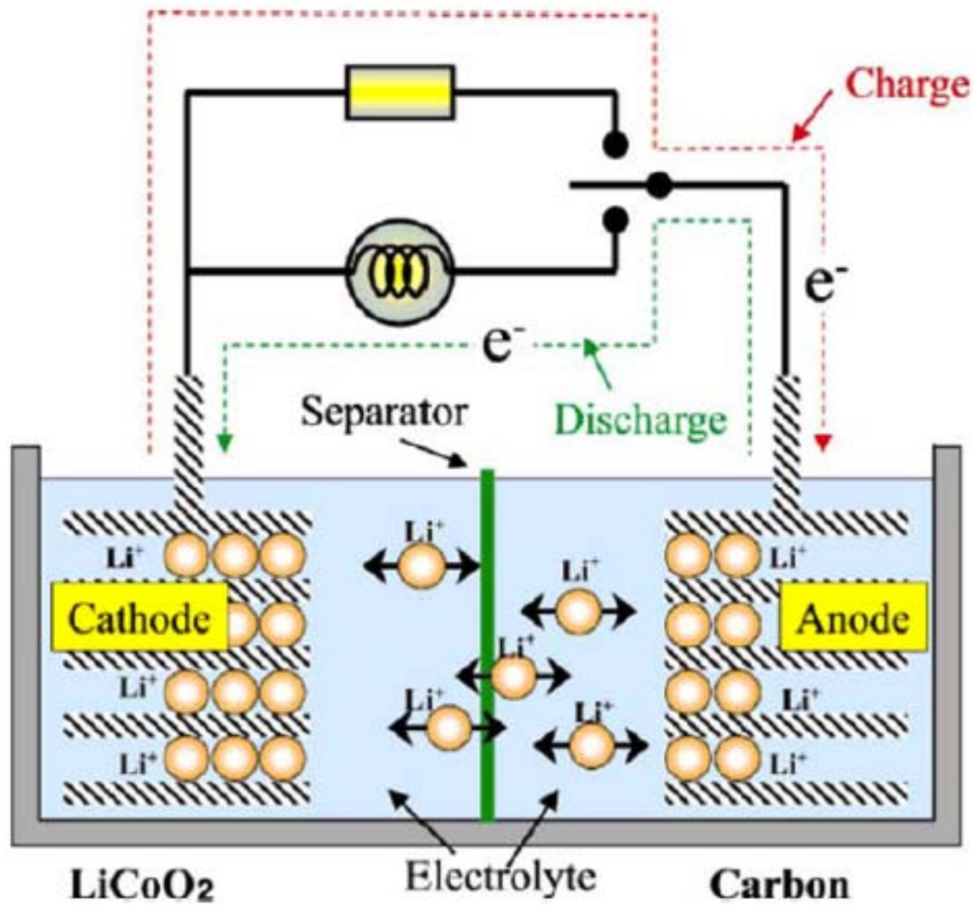
Objective

- **Characterize energy released from batteries at different states of charge (SOC)**

Typical Li Ion Battery

- 18650: 18 mm diameter, 65 mm length
- ~ 44 g
- Anode
  - Graphite, Copper
- Cathode
  - Li oxide, aluminum
- Separator
  - PE or PP membrane
  - Regulates ion flow
- Electrolyte
  - Organic combustible



Causes of Thermal Runaway

- Thermal
  - Critical temperature triggers
    - Due to heat source
    - Separator melts, inoperative

- Mechanical
  - Physical damage
    - Li dendrite grows to cause short

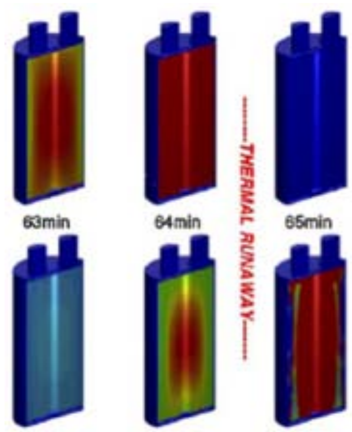
- Electrical
  - Overcharge
  - Rapid discharge

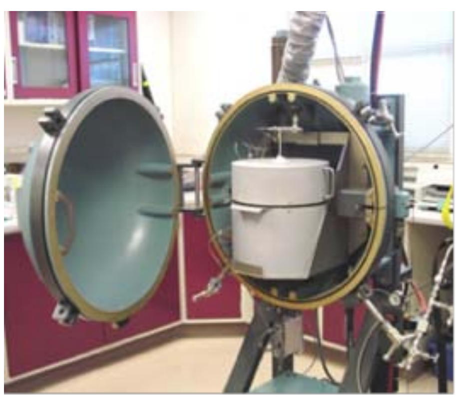
All lead to temperature increase and acceleration of chemical decomposition

Background

- 0ver 30 years of R&D on Li-ion batteries
- Increasing applications
- Modeling of Runaway
  - Sophisticated
  - Up to 6 decomposition reactions
  - CFD thermo-chem-electrical analyses
- Experimental
  - Component studies
  - DSC, ARC devices

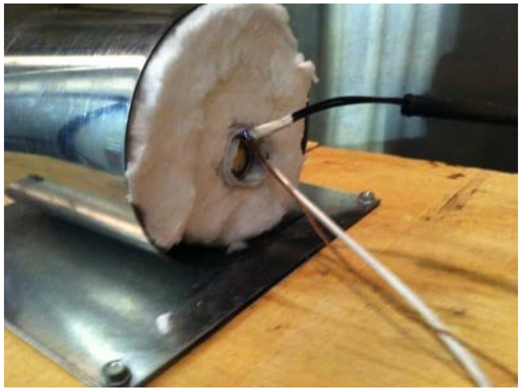
Car



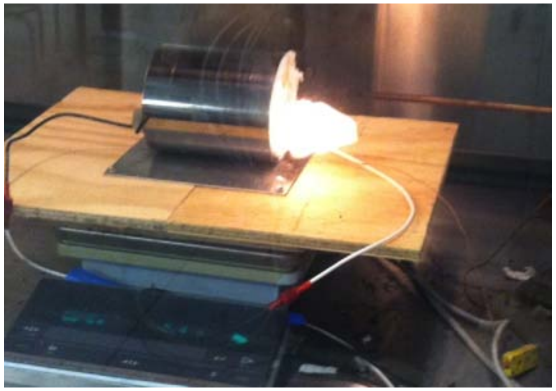


Thermal Runaway Energy Measurements

18650 Li-Ion Battery

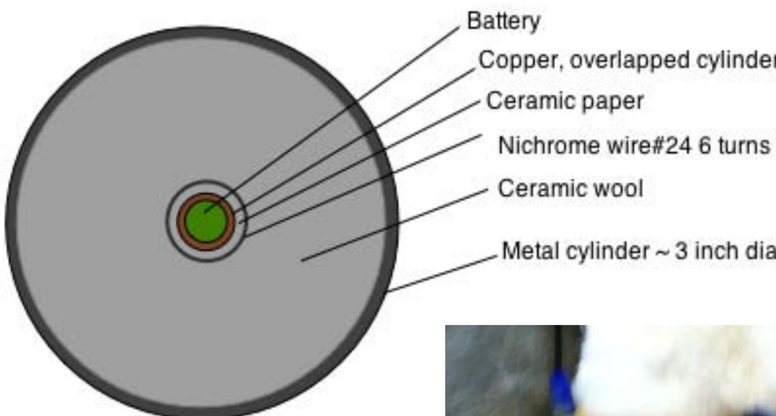


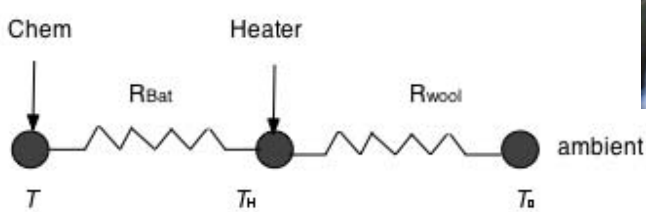
- Build calorimeter with known heat input
- 18650 characteristics
  - 2.6 Ah @ 3.7 V or 34.6 kJ of electric power available
  - Separator softens at 130ºC and melts > 150ºC
  - PRV @ ~ 200 psi: white vapor emitted
  - ~ 250 ºC onset of runaway, jump to ~ 800ºC in seconds
  - Gases emitted: CO_2, CO, H_2, CH_4, other HC
  - Solids emitted: Cu, Graphite, Molten Al
- Chemical – Electrical mechanisms not discerned



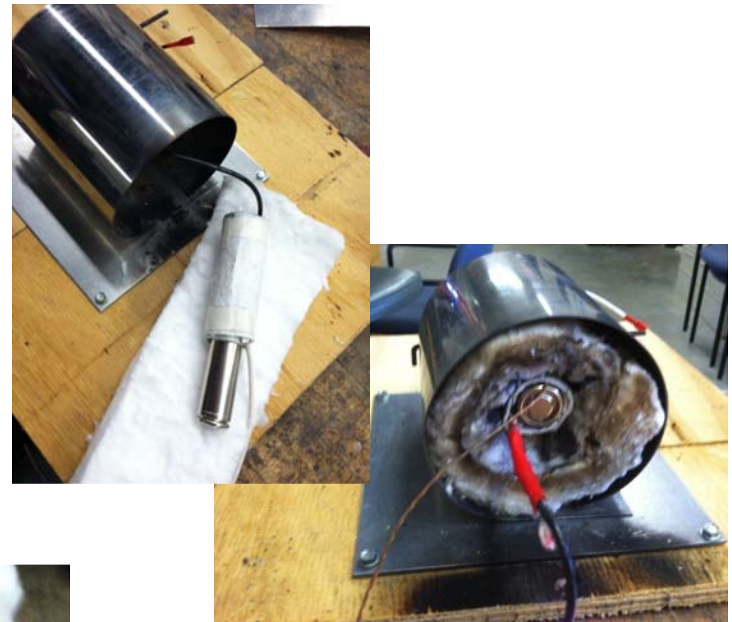
Apparatus Design

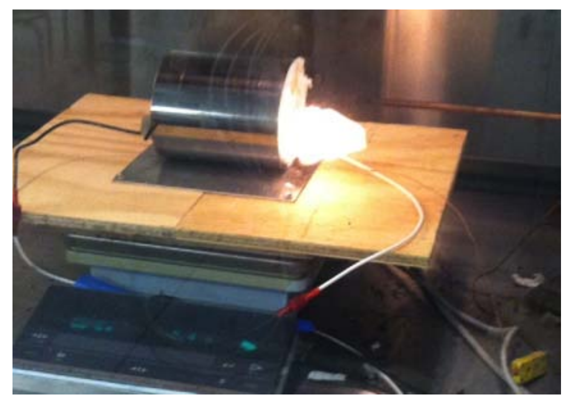
Temperature & Mass Measured





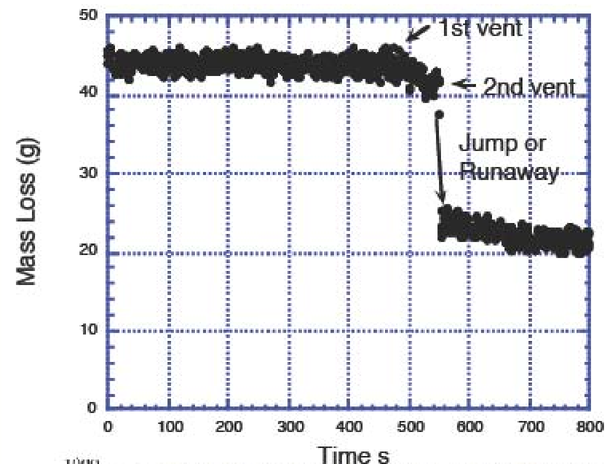
THERMAL MODEL

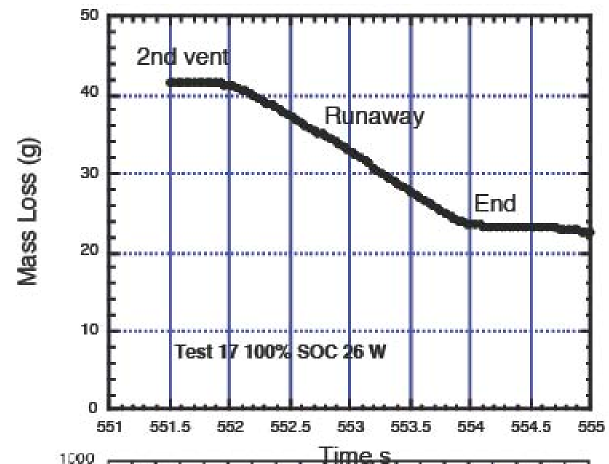


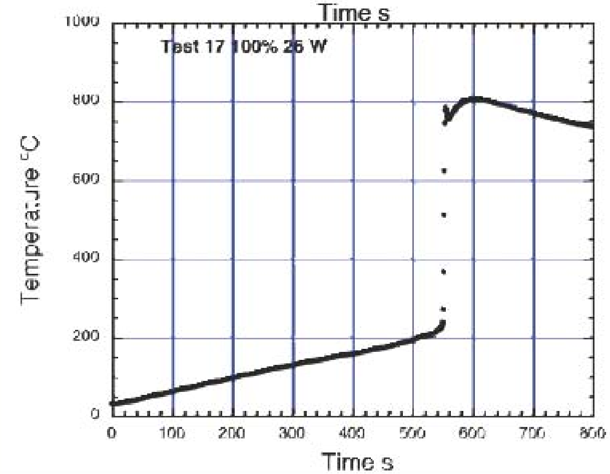


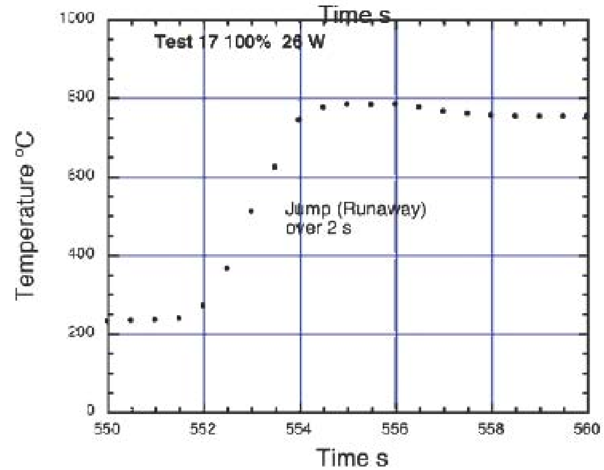
Heater: I * V = Watts

Typical Battery Thermal Runaway 100% SOC



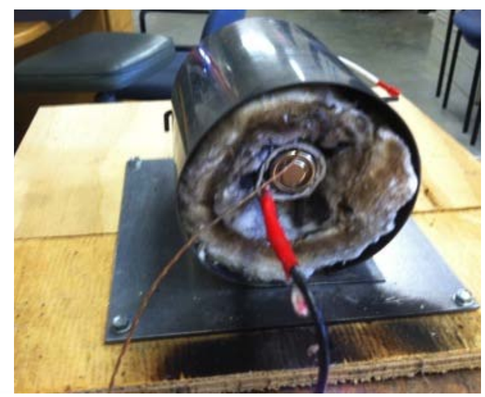




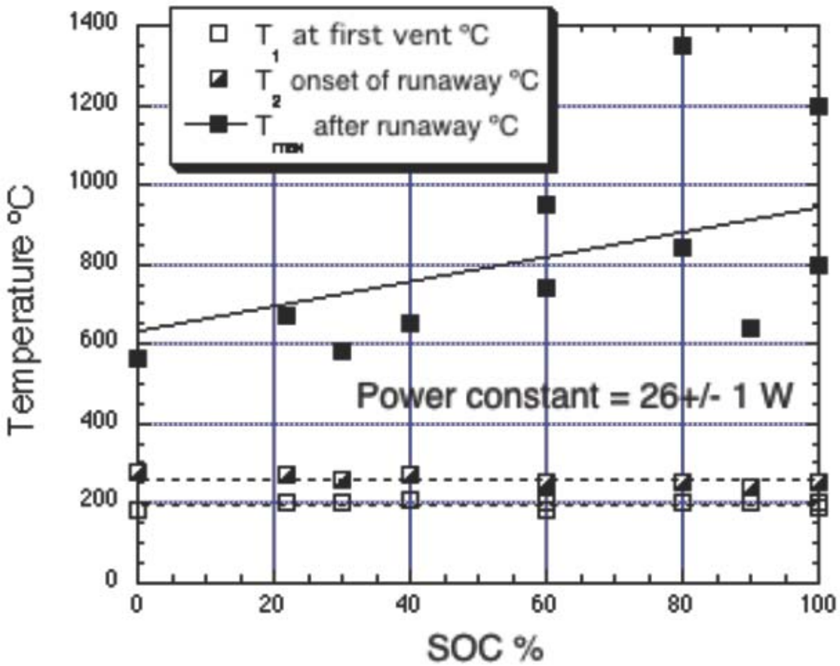


1^{st} vent @ 470 s
Lose ~ 2 - 3 g
~ 200 ºC

2^{nd} vent @ 552 s
Runaway ~ 2 s
Lose ~ 17 g
T: ~ 250 ºC to ~ 800 ºC



Temperature and Mass Loss Measurements

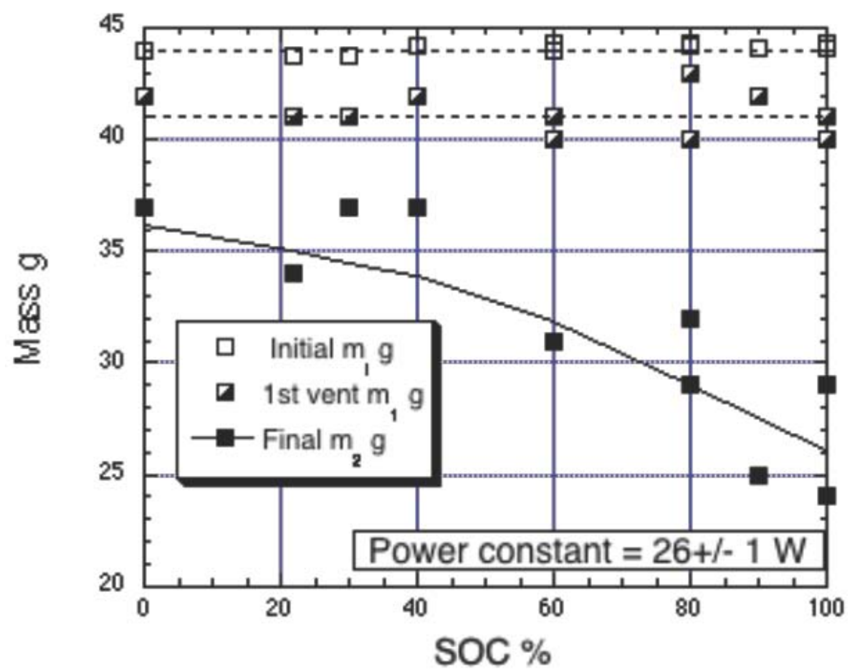


-Temperature of venting and thermal runaway onset independent of SOC

-Maximum temperature of runaway dependent on SOC

-Mass lost during 1st vent independent of SOC

-Total mass lost during runaway dependent on SOC

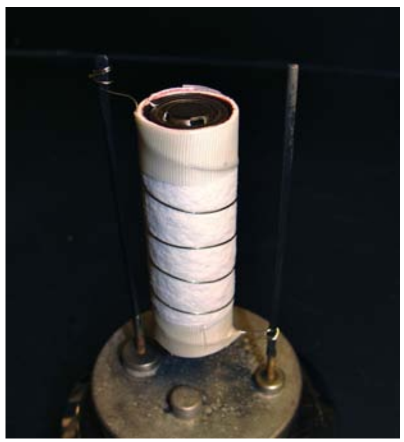


Chemical Energy Measurements

- ASTM bomb calorimeter method was modified to measure chemical energy of battery exotherm during thermal runaway
- Battery heated in bomb pressurized with N_2 until thermal runaway
- Energy release calculated from temperature rise of bomb
- Baseline test was run after battery test without disturbing contents to keep mass the same
- Chemical energy from reaction at different SOC measured

Bomb Calorimeter

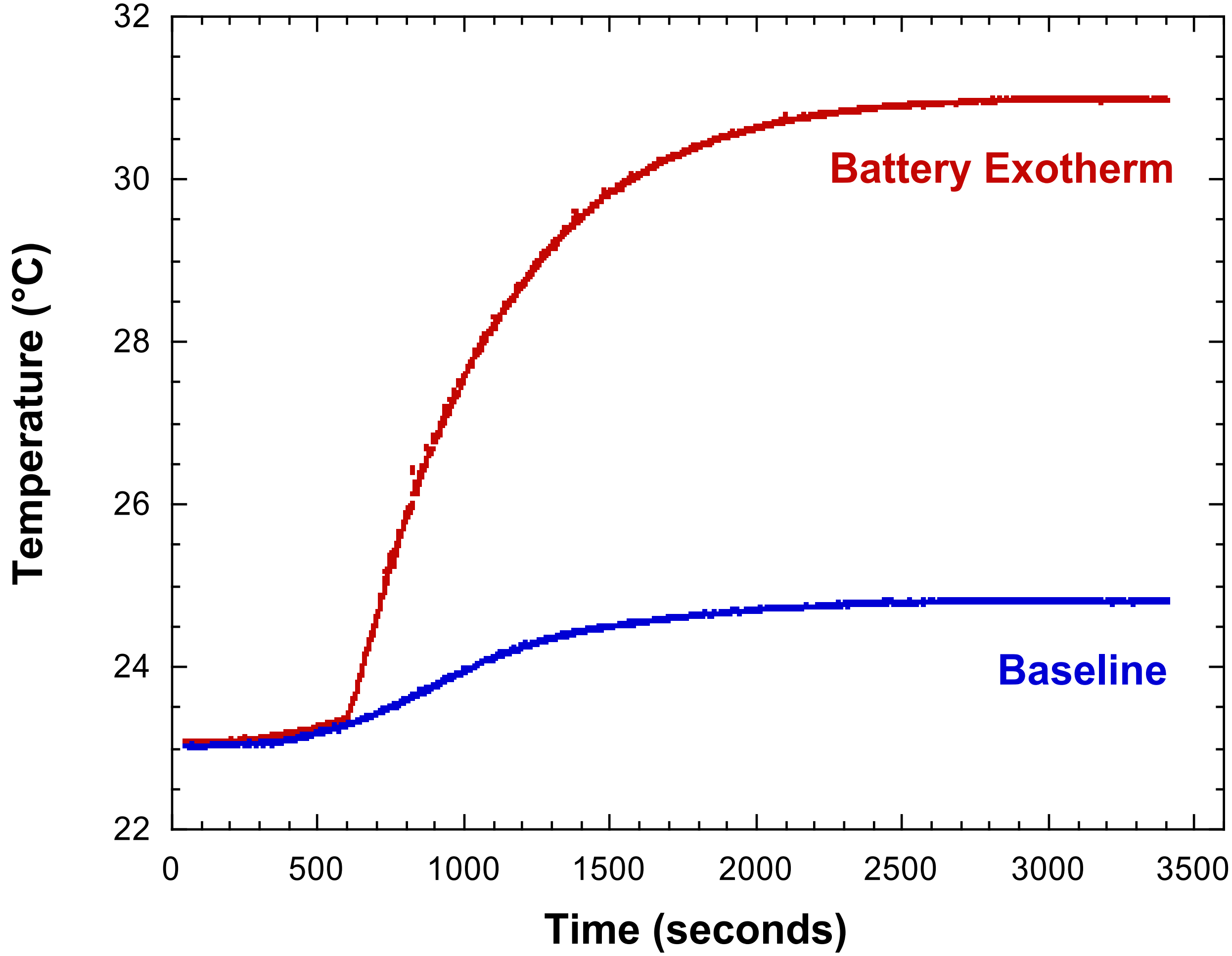
- Parr Instruments Model 1341 Plain Jacket Oxygen Bomb Calorimeter
- Voltage and current applied to force thermal runaway was the same for all tests
- Temperature data logged for all tests



Bomb and other components for 18650 battery tests

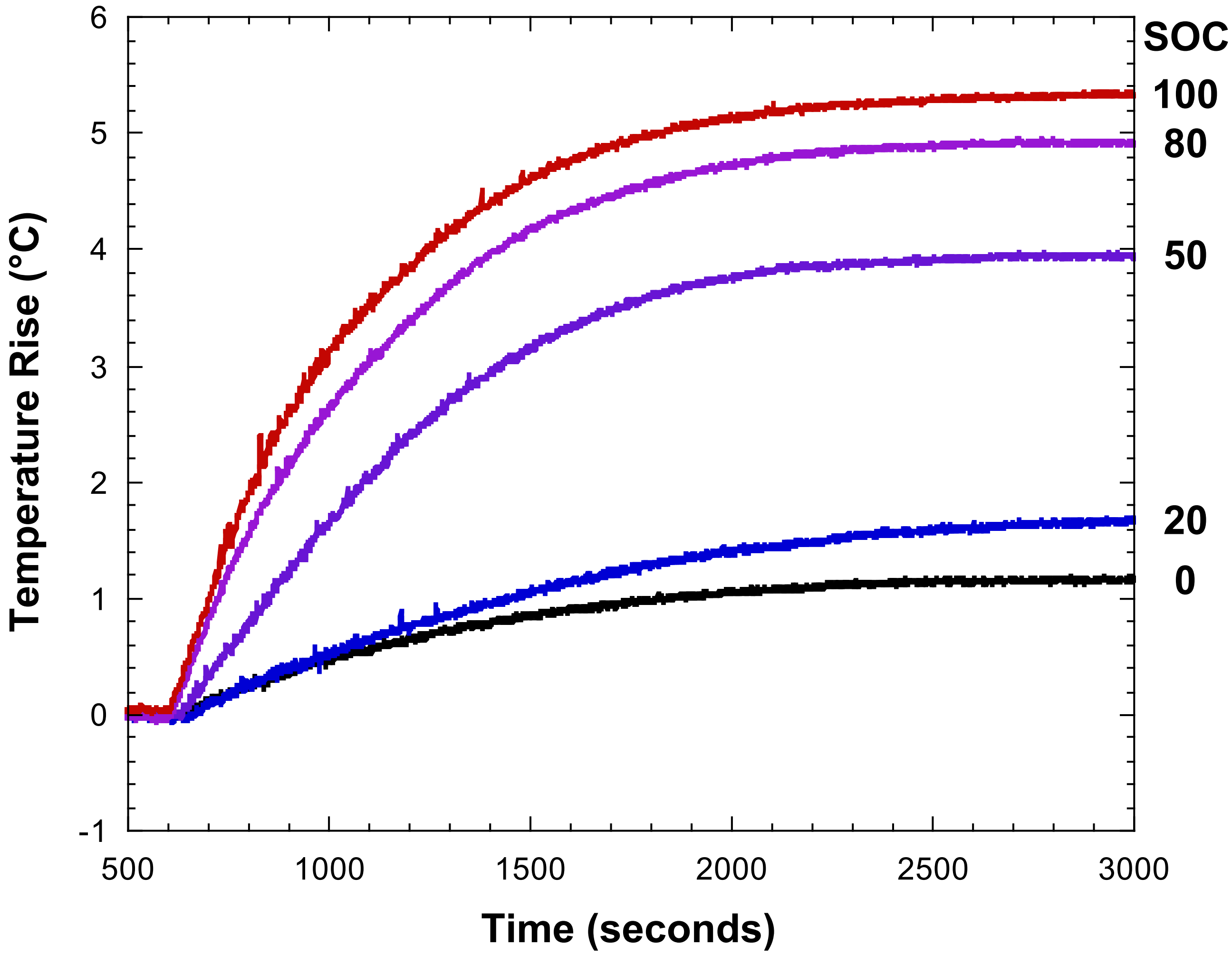
Experimental Setup

Test Data from 100% SOC



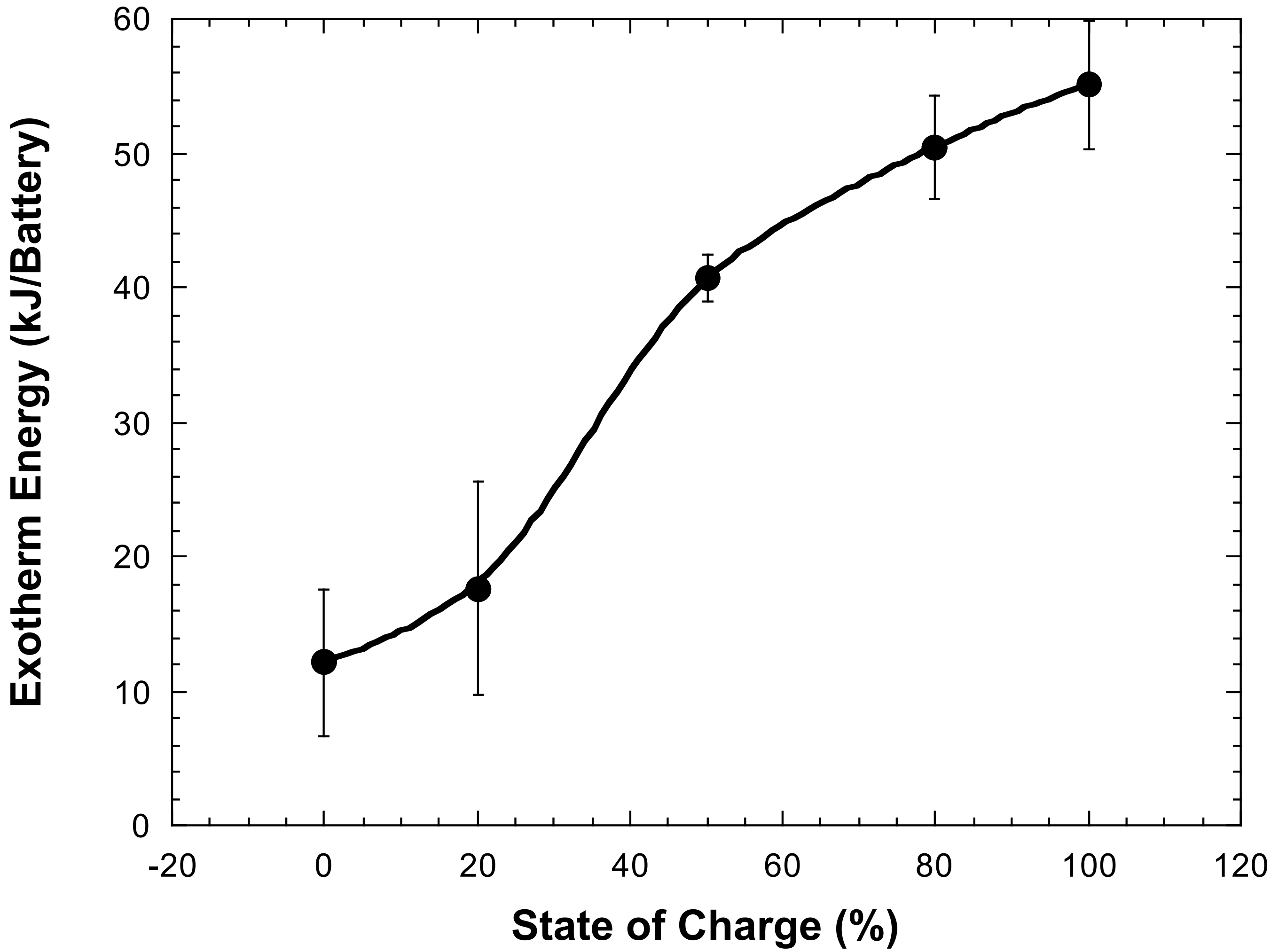
Baseline from heater subtracted from battery exotherm to get temperature rise from battery only

Temperature Rise In Bomb



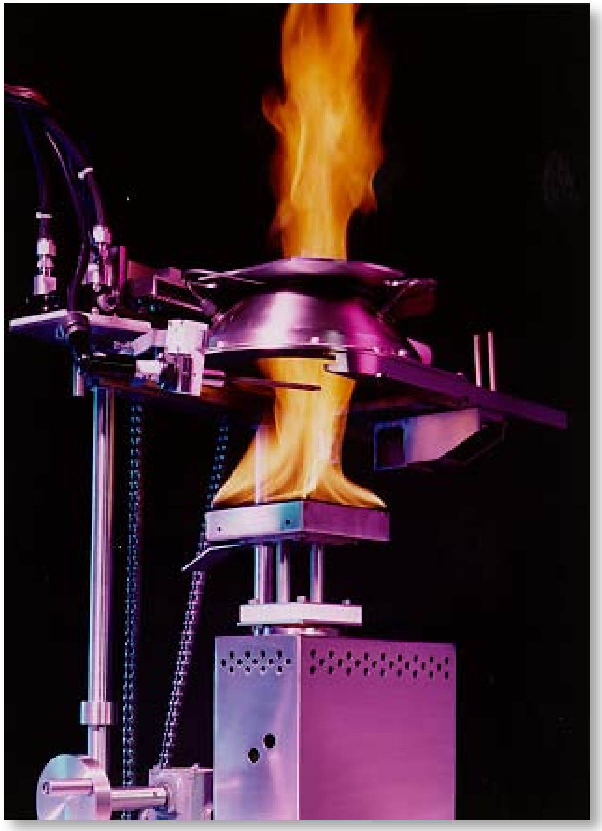
Baseline corrected temperature rise data

Battery Chemical Exotherm Energy



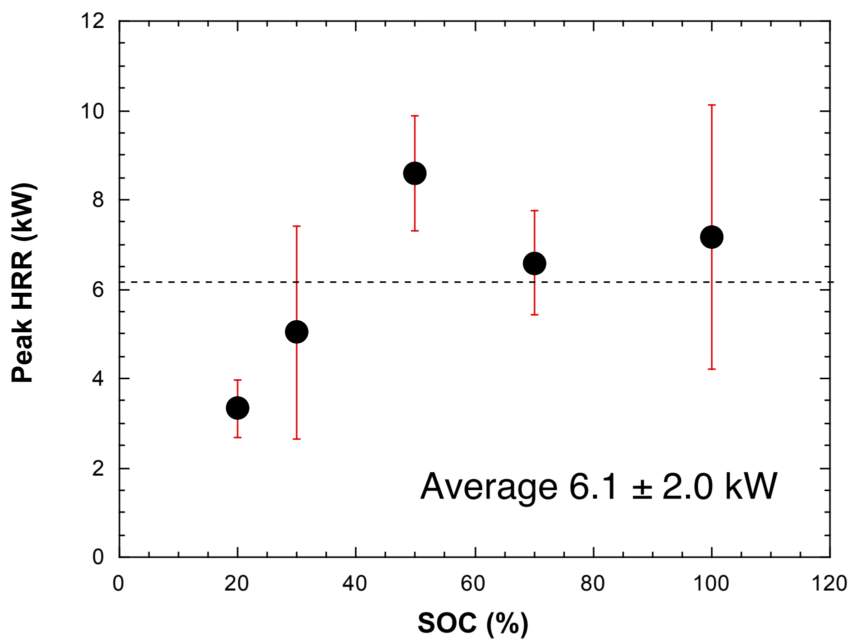
Cone Calorimeter

- ASTM E1354
  - Peak HRR
  - Total HR
  - Time to Ignition
  - Time to Peak

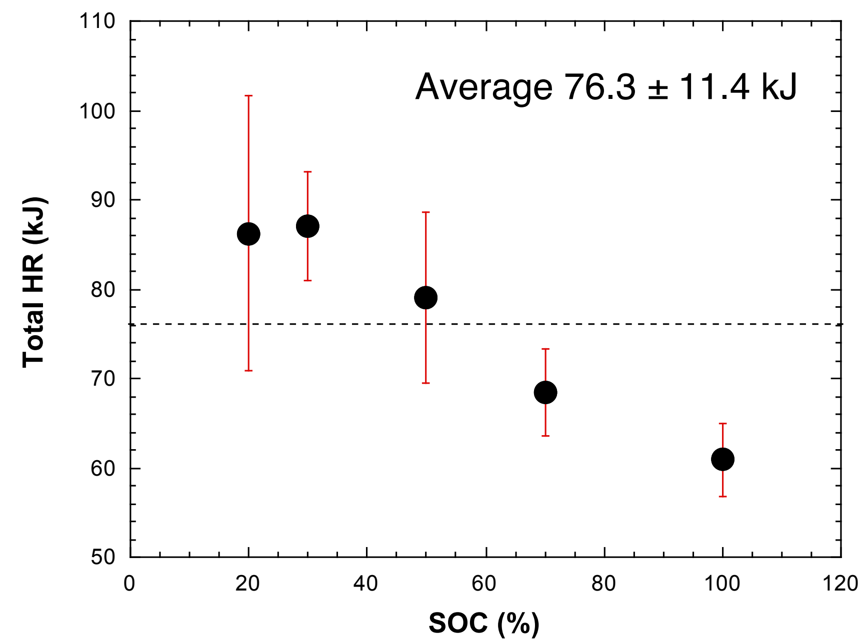


Cone Calorimeter 50 kW/m² - Varying SOC

Peak HRR

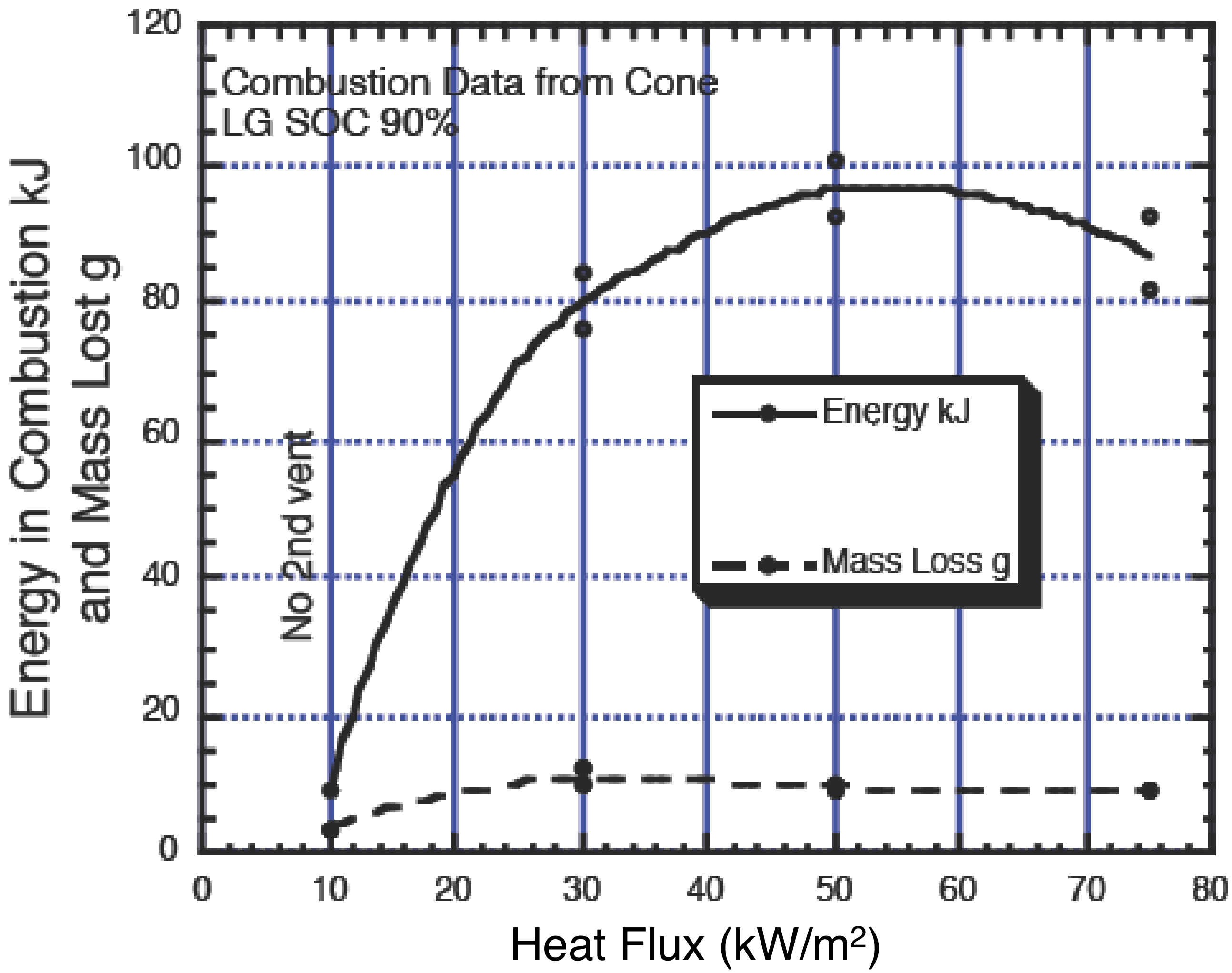


Total HR



- **Peak and total heat release independent of SOC**
- **Combustion products evolved do not change**
- **Chemical heat release not detected in cone calorimeter**

Cone Calorimeter 90% SOC - Varying Heat Flux



Total heat release and mass lost independent of heat flux

Findings

- For 18650 Li ion battery with 34.6 kJ electric power and 44 g
- Runaway results most dependent on SOC
  - Tests at 0% and at 0.5 V display limited or no runaway
  - Mass loss increases from about 8 to 19 g with increasing SOC
  - Exothermic runaway energy increases from 10 to 60 kJ with SOC (Bomb)
  - Combustion energy doesn’t vary much with SOC and heat flux (Cone data)
  - Temperatures of battery and exit debris increase from about 600 to 1000ºC with SOC
  - Duration of runaway ~ 2 s
  - Duration of flaming ~ 10 s
  - Duration of hot battery ~ 100+ s

Acknowledgement

- Thank you to Steve Summer, FAA, for supplying and charging the batteries