Lithium Ion Thermal Runaway
Less than 2 Wh Lithium Ion Batteries

Presented to: International Aircraft Systems Fire Protection Working Group
By: Matthew Karp
Date: November 1, 2017
Scope of Test

• RTCA SC-225 committee working on developing document DO-311A
  • Document contains Minimum Operational Performance Standards (MOPS) for rechargeable lithium battery systems
• Proposed to exempt battery cells that are < 2Wh from testing standards
  • provided they are certified to existing UL and IEC standards
• Comments were received that the exemption level should be raised to as high as 5 Wh
• Tests were conducted to determine if the exemption level should be raised
Scope of Test

- Tests were conducted with lithium ion rechargeable 3.7V 500mAh (1.85Wh) polymer pouch cells and button cells at 100% SOC.
- The cells were forced into thermal runaway using the overheat method at 20°C/min.
- Tests were conducted in a 21.7L pressure vessel where a pressure transducer and thermocouple were used to quantify the gas release from each lithium battery cell.
- The gases were collected and analyzed for percent hydrogen, carbon monoxide, carbon dioxide, oxygen, and total hydrocarbon content (THC).
- The maximum temperature rise and peak pressure rise were annotated.
Test Equipment

• Experiments were conducted in a 21.7 liter stainless steel pressure vessel
• Gas chromatography (GC) with thermal conductivity detector (TCD) to measure H2
• Paramagnetic sensor (pO2) to measure CO/O2
• Non-dispersive infrared radiation to measure CO2
• Flame ionization detector (FID) to measure total hydrocarbon content (THC)
Test Procedure

• The pressure vessel is vacuumed to less than 0.1 psia

• The pressure vessel is filled to 14.7 psia with nitrogen gas
  • Nitrogen gas is used because of its inert properties and to prevent interference with the gas analyzers

• The battery is forced into thermal runaway by overheating and the vent gases are released

• More nitrogen is added to the pressure vessel until the pressure reaches 18 psia, this creates a positive pressure to feed into gas analyzers

• The samples are analyzed for gas composition
Test Procedure

• The battery cells were placed on top of a flexible heater

• Heated at 20°C/min until thermal runaway is induced
  • The temperature heating rate was controlled by a Proportional-Integral-Derivative (PID) controller

• Temperature was measured at the side of the pouch cell and on top of the button cell
Pouch Thermocouple Location

• Thermocouples were placed at two separate locations

• The locations
  • On top
  • On the side
Pouch Maximum Temperature

- The maximum temperature at the side of the pouch cell is hotter than on top of the pouch cell
  - Vent gas vents out of the sides
- The average maximum temperature are:
  - Side 621±25°C
  - Top 412±24°C
- The average thermal runaway onset temperature is 135±13°C
Pouch Vent Gas Volume

• The average vent gas volume is 0.76±0.03L
Pouch Pressure Rise

• The pressure is measured inside of a 21.7L pressure vessel.
  • Note: The measured pressure is inversely proportional to the pressure vessels volume.
• The average maximum pressure is
  • 17.1±0.1 psia
• The average percent pressure rise is
  • 15.1±0.6%
• The gas concentrations used for the calculation of the lower flammability limit (LFL) were measured and averaged. The results are tabulated.

• The LFL can be calculated using Le Chatelier’s Mixing Rule.

• The calculated LFL is 8.5% vol battery gas in air.

<table>
<thead>
<tr>
<th>Gas Specie</th>
<th>Averaged Gas Concentration, %vol</th>
<th>LFL, %vol</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon dioxide</td>
<td>25.3±0.7</td>
<td>0</td>
</tr>
<tr>
<td>carbon monoxide</td>
<td>20.0±6.2</td>
<td>12.5</td>
</tr>
<tr>
<td>ethane</td>
<td>0.6±0.1</td>
<td>3.00</td>
</tr>
<tr>
<td>ethylene</td>
<td>7.3±0.8</td>
<td>3.10</td>
</tr>
<tr>
<td>hydrogen</td>
<td>24.0±2.5</td>
<td>4.95</td>
</tr>
<tr>
<td>methane</td>
<td>3.1±0.3</td>
<td>5.30</td>
</tr>
<tr>
<td>propane</td>
<td>0.2±0.02</td>
<td>2.10</td>
</tr>
<tr>
<td>propylene</td>
<td>1.6±0.4</td>
<td>2.40</td>
</tr>
<tr>
<td>oxygen</td>
<td>6.0±2.7</td>
<td>NA</td>
</tr>
<tr>
<td>THC</td>
<td>18.7±1.0</td>
<td>NA</td>
</tr>
</tbody>
</table>
• The thermocouple was placed on top of the button cell and wrapped with fiberglass tape to ensure good contact.
The two tested button cells had drastically different maximum temperature.

Variations in thermal runaway reactions has also been observed in 18650 cells.

This is often observed with a delay in thermal runaway reaction as represented by the black vertical lines.

The delayed reaction allows time for the electrolyte to evaporate away from the cell.
Button Cell Significant Values

- **Maximum Pressure, psia**
  - Peak Pressure, PSia:
    - 17.6
    - 17.3
  - % Pressure Rise:
    - 18.2%
    - 15.8%

- **Percent Pressure Rise**
  - 20.0%

- **Max Temp, °C**
  - 750
  - 387
  - 630

- **Vent Gas Volume, L**
  - 1.0
  - 0.82
  - 0.76
The gas concentrations used for the calculation of the lower flammability limit (LFL) were measured and averaged. The results are tabulated. The LFL can be calculated using Le Chatelier’s Mixing Rule. The calculated LFL is 8.2% vol battery gas in air.

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<td>0</td>
</tr>
<tr>
<td>carbon monoxide</td>
<td>25.0±3.7</td>
<td>12.5</td>
</tr>
<tr>
<td>ethane</td>
<td>0.5±0.04</td>
<td>3.00</td>
</tr>
<tr>
<td>ethylene</td>
<td>8.4±0.4</td>
<td>3.10</td>
</tr>
<tr>
<td>hydrogen</td>
<td>23.8±1.9</td>
<td>4.95</td>
</tr>
<tr>
<td>methane</td>
<td>2.7±0.2</td>
<td>5.30</td>
</tr>
<tr>
<td>propane</td>
<td>0.1±0.01</td>
<td>2.10</td>
</tr>
<tr>
<td>propylene</td>
<td>2.0±0.2</td>
<td>2.40</td>
</tr>
<tr>
<td>oxygen</td>
<td>5.1±3.0</td>
<td>NA</td>
</tr>
<tr>
<td>THC</td>
<td>17.9±1.7</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Pouch Cell</td>
<td>Button Cell</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>25.3±0.7%</td>
<td>23.4±0.8%</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>20.0±6.2%</td>
<td>25.0±3.7%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>24±2.5%</td>
<td>23.8±1.9%</td>
</tr>
<tr>
<td>Percent Pressure Rise</td>
<td>15.1±1.13%</td>
<td>17.0±2.3%</td>
</tr>
<tr>
<td>Maximum Pressure</td>
<td>17.1±0.1%</td>
<td>17.4±0.3psia</td>
</tr>
<tr>
<td>Off Gas Volume</td>
<td>0.76±0.03L</td>
<td>0.79±0.06L</td>
</tr>
<tr>
<td>Maximum Temperature</td>
<td>621±50°C</td>
<td>508±238°C</td>
</tr>
<tr>
<td>Calculated LFL</td>
<td>8.5%</td>
<td>8.2%</td>
</tr>
</tbody>
</table>
Conclusion

• While there may be examples of safer cells of higher capacity, there are also cells at or near the 2 Wh level that could pose a threat to aircraft safety.

• Based on the testing, the committee decided to maintain the 2Whr limit and not to extend the exemption level.
Contact Information

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