Thermal Imaging of Aerospace Battery Cells

By

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Outline

- Objective
- Experimental
- Nickel Hydrogen Cell (NiH$_2$)
- Lithium-Ion Cell (Li-Ion)
- Conclusions
Objective

Understand the thermal characteristics of cylindrical aerospace battery cell by studying the surface thermal profiles.
Experimental

• Cells
  – Eagle Picher 50Ah rabbit-ear (cylindrical) Nickel Hydrogen (NiH$_2$) cell
  – Saft 40 Ah cylindrical Lithium-Ion (Li-ion) cell
• ThermCAM S60    FLIR Systems
• Charge and Discharge with Passive cooling
  – C/2 rate
    • Charge to thermal limit of 35°C
    • Allow cell to cool
    • Discharge to 1.0V
Experimental: Brief Background on I.R. Camera

- The camera is working on the principle of Blackbody Radiation and works from 7.5\(\mu\)m to 13\(\mu\)m wavelengths.
- Light is from 0.40\(\mu\)m to 0.70 \(\mu\)m.
- The object under investigation needs to have constant and known emissivity. (preferably > 0.7)
  - Metals are variable from 0.045 to \(\sim\)0.07.
  - Cell was covered with Kapton tape \(\sim\)0.86, checked with thermistor.

All measured Temperatures are Surface Temperatures.
Experimental: Block Diagram

- Battery
- Thermal Camera
- Power Supply
- Data Collection
- Computer
- IR Data Collection
NiH₂ Cell: Thermal Image during Charge @ C/2

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<th>Current</th>
<th>T/Top</th>
<th>T/Middle</th>
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During Overcharge
NiH$_2$ Cell:
Thermal Image
during
Discharge
@ C/2
Towards End of Discharge
NiH₂ Cell: Thermal data as obtained from IR Camera Over Full Charge

Temperature (°C)

End of Charge

10 Minute (Overshoot)
NiH$_2$ Cell: Popping Noted during Charge (Indicated by Circle)

Short and Defined Surface Feature

Towards start of overcharge
NiH$_2$ Cell: Popping Noted (Indicated by Circle)

Defuse Interior Feature

Towards end of overcharge.
NiH$_2$ Cell: Thermal Explanation of Popping

Equal Energy Over Thermal Gradient

Fast and Sharp

Distance from Surface

Slow and Diffuse

Distance from Surface
NiH$_2$ Cell: Popping in Differential Temp. Mode

Popping-Going Hot Spot 2

Post-Popping Return to Ambient Spot 1

Middle of Overcharge
NiH$_2$ Cell: Popping in Differential Temp Mode. Plot Over Time (Charging)

Note: Each plot has multiple steps of heating.
NiH₂ Cell: Popping Depicted as Circles

Count of pops varies from ~10 to >44

Pattern at end of charging
NiH$_2$ Cell: Catalytic Wall-wick Strip are Similar to popping pattern during Overcharge.
NiH₂ Cell: Battery Temperature Profile
Vertical Crosscut
Charge

Max Temp 40.2°C
Min Temp 27.3°C
Delta 12.9°C

During Overcharge
NiH₂ Cell: Battery Temperature Profile
Horizontal Crosscut

Charge

Max Temp 40.3°C
Min Temp 36.6°C
Delta 3.7°C

Catalytic Strip
NiH₂ Cell: Battery Temperature Profile
Horizontal Crosscut

Discharge After Cell was allowed to return to Ambient

Max Temp 36.6°C
Min Temp 27.4°C
Delta 9.2°C
NiH₂ Cell: Summary

- Surface Thermal profile have been studied for 50 Ah NiH₂ Cell under
  - Charge (C/2 to Thermal Limit of 35°C) and
  - Discharge (C/2 to Min Voltage of 1.0V)

- Cell Thermal Gradients
  - Middle of stack to top or bottom is about 12.9°C
  - Bottom is the coldest
  - Top to bottom is about 1°C
  - Across stack is about 4°C
NiH₂ Cell:
Summary - Continued

– Popping is demonstrated on the catalytic wall-wick strip and at the bottom section of the cell stack; Destructive Physical Analysis of the cell confirmed the signatures
– Thermal Overshoot (After Charge Stopped) indicates cell interior is at least 4°C hotter than the pressure vessel cylindrical surface
Li-Ion Cell: Thermal Image during Charge @ C/2
Li-Ion Cell:
Thermal Image during Discharge @ C/2
Li-Ion Cell:
Battery Temperature Profile
Vertical Crosscut

Max Temp 28.9°C
Min Temp 28.0°C*
Delta 0.9°C

*Low Temperature is at Tie-Wrap

During Charge
Li-Ion Cell:
Battery Temperature Profile
Horizontal Crosscut

Max Temp 29.3°C
Min Temp 28.8°C
Delta 0.5°C

During Charge
Li-Ion Cell: Summary

- Surface Thermal profiles have been studied for 40 Ah Lithium-Ion Cell
- Charge (C/2 charge to Voltage Limit of 4.1V with Taper)
- Discharge (C/2 to Min. Voltage of 3V)
- Less than 1°C thermal gradient on the cell vessel surface
- Significantly lower heat generation in Li-Ion cell compared to NiH$_2$ cell
  - May be due to a favorable charge method used for Li-Ion cell
Conclusions:

- Surface Thermal Profiles of Eagle Picher rabbit-ear 50Ah NiH₂ and of Saft 40 Ah Li-ion cylindrical cells have been studied using ThermCAM S60 FLIR Systems.
- Popping Phenomenon in NiH₂ cell is demonstrated.
- Temperature gradient in NiH₂ is slightly higher than normally considered — for example, Middle of stack to top or bottom is about 12.9°C compared to <7°C (may be due to passive cooling).
- Less than 1°C thermal gradient on the Li-Ion cell vessel surface.
- Significantly lower heat generation in Li-Ion cell compared to NiH₂ cell — May be due to a favorable charge method used for Li-Ion cell.