Thermal Characterization of Plastic Lithium Ion Cells

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Presentation Outline

- Objective
- Cell Description and Ah Capacity
- Heat Capacity Testing
- Heat Generation under Various Charge/Discharge Cycles
- Infra-Red Thermal Imaging
- Summary and Conclusions

Objective

- The objective of NREL's effort was to measure the thermal characteristics of plastic lithium ion cells based on Bellcore's technology.
- NREL determined the heat generation of the cells with a calorimeter and IR imaged the cells to determine hot spots or points of concern. The data was used to thermally model a battery pack for an EV or HEV vehicle.

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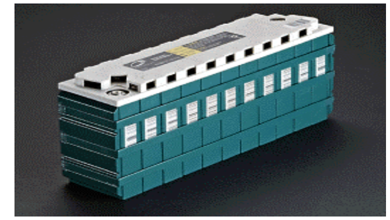
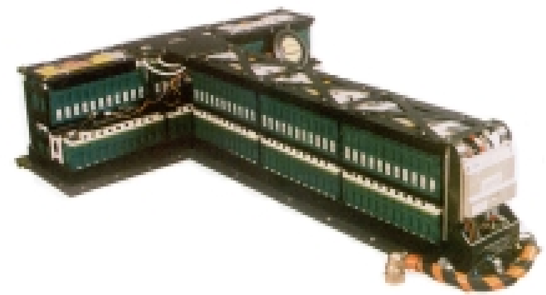
Battery Temperature is Important



- Temperature affects battery:
  - Operation of the electrochemical system
  - Round trip efficiency and charge acceptance
  - Power and energy
  - Safety and reliability
  - Life and life cycle cost



Battery temperature affects vehicle performance, reliability, safety, and life cycle cost

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NREL has used various tools in working with vehicle and battery manufacturers on BTM

- Thermal analysis

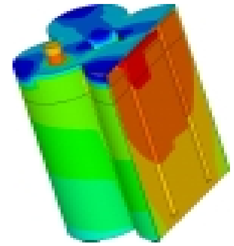
  Thermal imaging

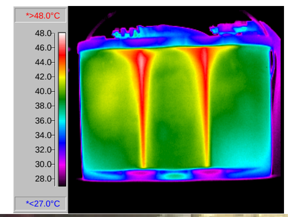
- Fluid and heat transfer experiments

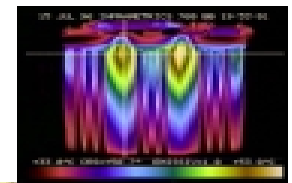
  Thermal characterization

- Battery modeling

  Battery Pack and Vehicle Testing







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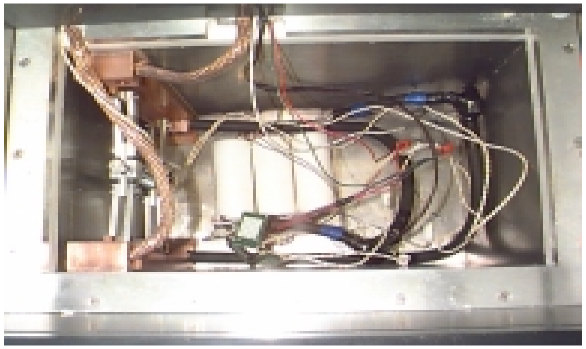
Battery Calorimeter for Thermal Characterization

- We use a single-ended, large conduction calorimeter to measure **heat capacity** and **heat generation** at various rates, temperatures, and SOCs

- Cavity dimensions: 21 cm x 20 cm x 39 cm (WxHxL)
- Heat rate detection: 0.015 W to 100 W
- Minimum detectable heat effect: 15 J (at 25ºC)
- Baseline stability: ± 10 mW
- Temperature range: -30ºC to 60ºC (±0.001°C)



Calorimeter Cavity

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Plastic Lithium Ion Cell

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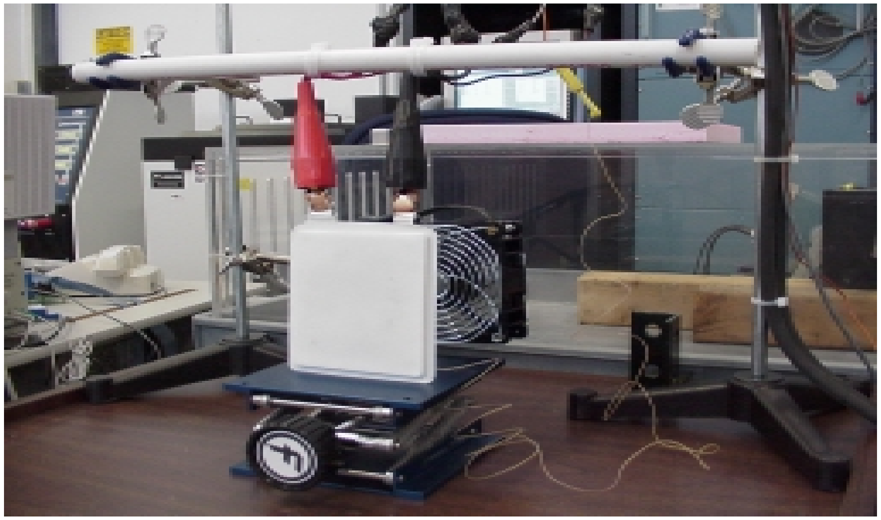
Specification of Manganese and Cobalt Cells

The $LiMn_2O_4$ cell has a nominal C/5 capacity of 4.5 Ah, and the $LiCoO_2$ cell has a nominal C/5 capacity of 3.6 Ah.

General Specifications of $LiMn_2O_4$ and $LiCoO_2$ Cells

Parameter	Value
Nominal Voltage	3.8 V
Charge Time	Approx. 3 hours
Continuous Maximum Discharge Current	9 A
Operating Temperature – Charge	0 ~ +40°C
Operating Temperature – Discharge	-10 ~ +50°C
Relative Humidity Range	0 ~ 90%
Storage Temperature (<1 month)	-20 ~ +60°C
Storage Temperature (<3 months)	-20 ~ +45°C



The cells are prismatic cells that measure 105 x 125 x 5.3 mm.

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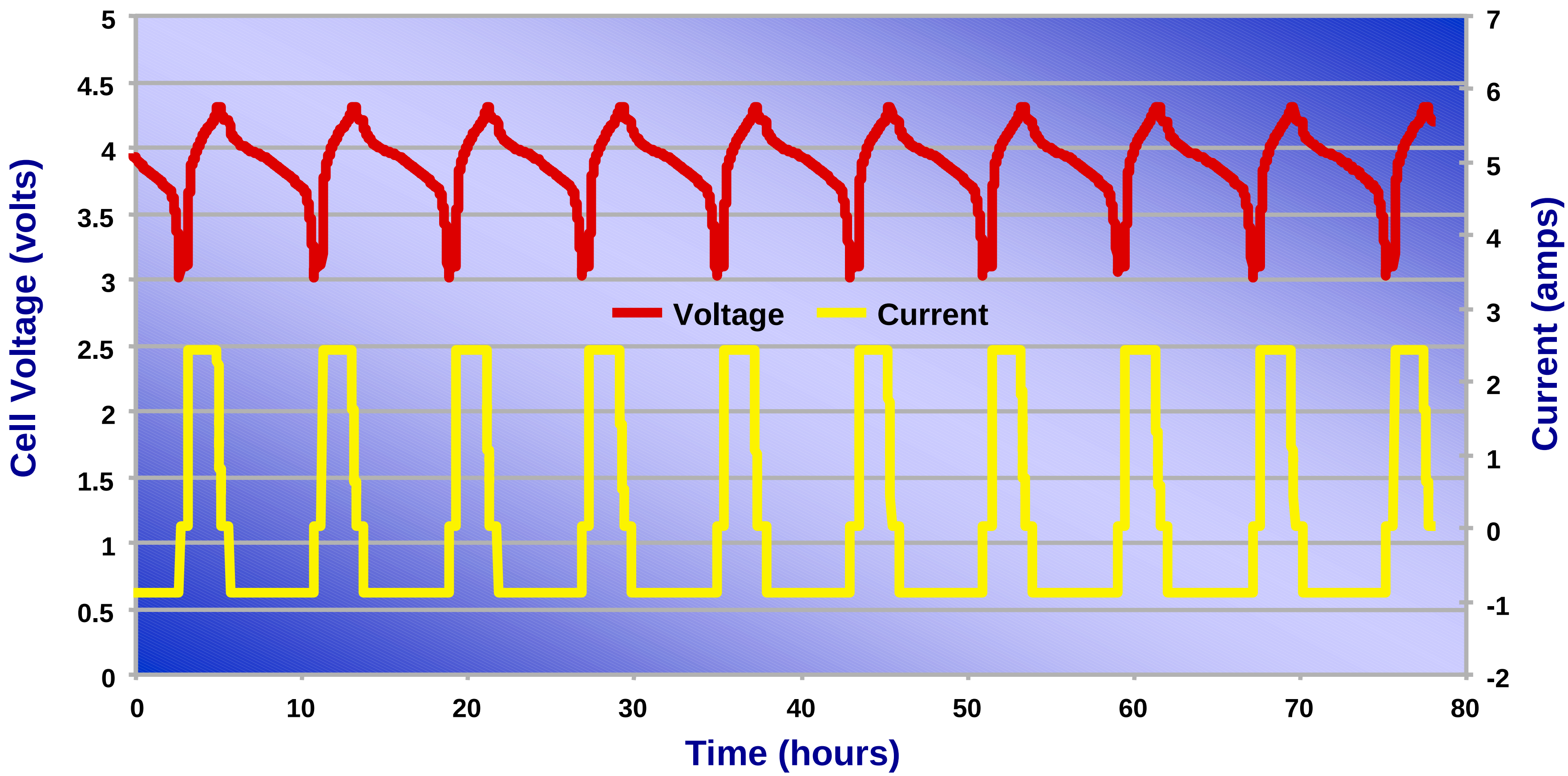
$LiMn_2O_4$ Voltage and Current During Conditioning Cycles



Charging Algorithm

C/2 current until 4.3 volts

Hold 4.3 volts until current <400 mA

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Discharge Capacity, Charge Return, and Columbic Efficiency of Cells

Conditioning Cycle	$LiMn_2O_4$ Cell: C/5 Discharge Capacity (Ah)	$LiMn_2O_4$ Cell: Return Capacity (Ah)	$LiMn_2O_4$ Cell: Columbic Efficiency (%)	$LiCoO_2$ Cell: C/2 Discharge Capacity (Ah)	$LiCoO_2$ Cell: Return Capacity (Ah)	$LiCoO_2$ Cell: Columbic Efficiency (%)
1	2.489	4.569	54.5	3.512	3.638	96.5
2	4.550	4.582	99.3	3.408	3.685	92.5
3	4.511	4.566	98.8	3.262	3.692	88.3
4	4.475	4.577	97.8	3.099	3.701	83.7
5	4.452	4.577	97.3	–	–	–
6	4.409	4.563	96.6	–	–	–
7	4.365	4.569	95.5	–	–	–
8	4.548	4.579	99.3	–	–	–
9	4.550	4.564	99.7	–	–	–
10	4.536	4.568	99.3	–	–	–

Equation used for Heat Capacity

$$Cp = \frac{Q}{m(Tm - Tc)}$$

Q = 1958 Joules

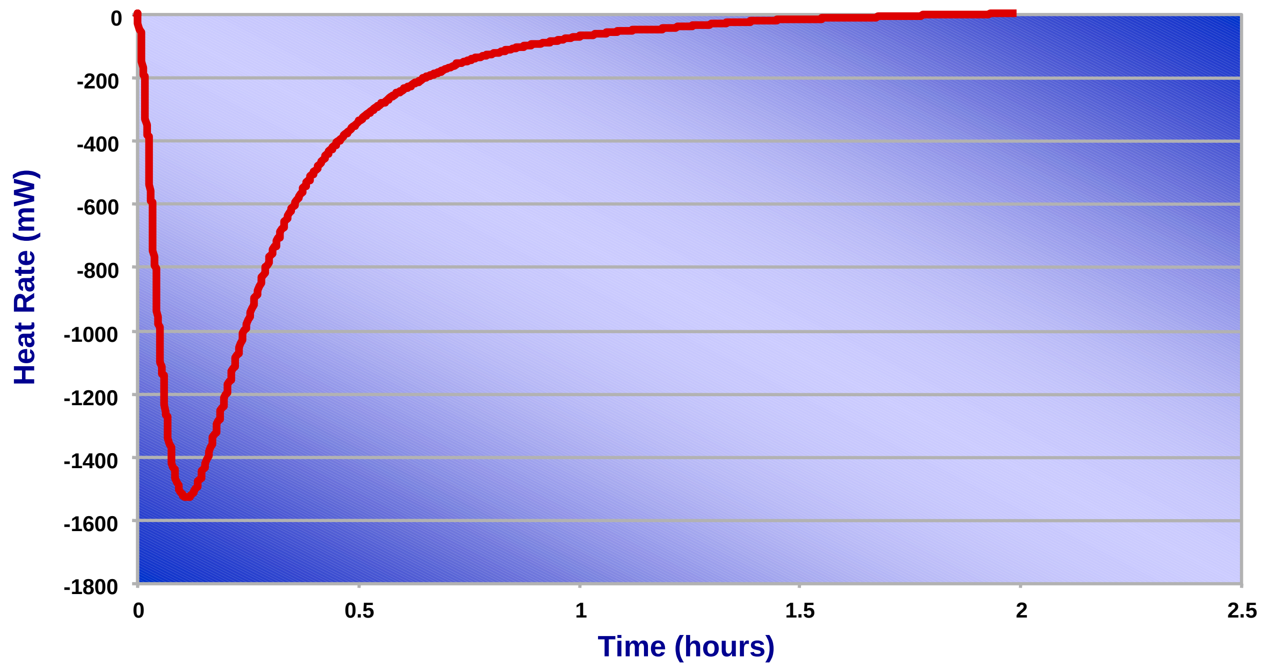
Tm = 11^{o}C

Tc = 25^{o}C

m=0.14462 kg

Cp = 1011.8 J/kg*K

Calorimeter Response for Heat Capacity Test of $LiMn_2O_2$ Cell



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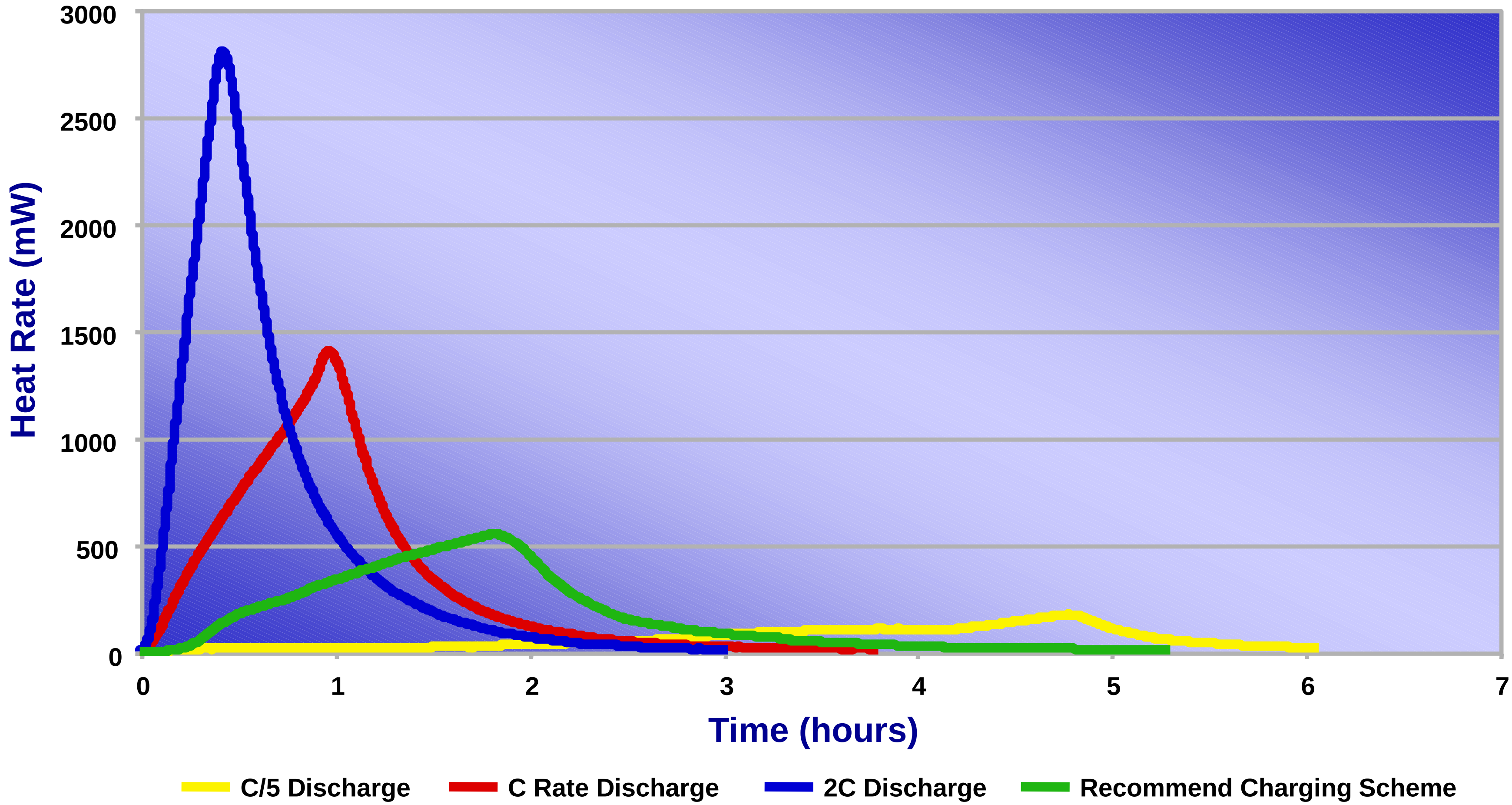
Calorimeter Response to Full Discharge Cycles and HET Recommend Charging Scheme at 25˚C



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$LiMn_2O_4$ Cell Under Full Discharge Cycles and Under the HET Recommended Charging Scheme at 25°C

Cycle	Discharge Capacity (Ah)	Charge Return (Ah)	Nominal Amperage (Amps)	Elec. Energy Input (Joules)	Elec. Energy Output (Joules)	Cal. Heat Measured (Joules)	Eff. (%)	Ave. Cell Heat Rate (W)
Constant C/5 Discharge	4.544	-	0.9	-	62985	1311	97.9	0.072
Charge after C/5 Discharge	-	4.414	See Above	64691	-	3158	95.1	0.46
Constant C/1 Discharge	4.265	-	4.5	-	56205	4531	91.9	1.33
Charge after C/1 Discharge	-	4.265	See Above	62844	-	2893	95.4	0.43
Constant 2C Discharge	3.323	-	9.0	-	42069	5923	85.9	4.45
Charge after 2C Discharge	-	3.331	See Above	49601	-	2270	95.4	0.43

$$Eff = \left[1 - \left(HeatGenerated / Energy\left(Input \ldots Output\right)\right)\right] * 100$$

$$AverageCellHeatRate = \frac{HeatGenerated}{CycleTime}$$

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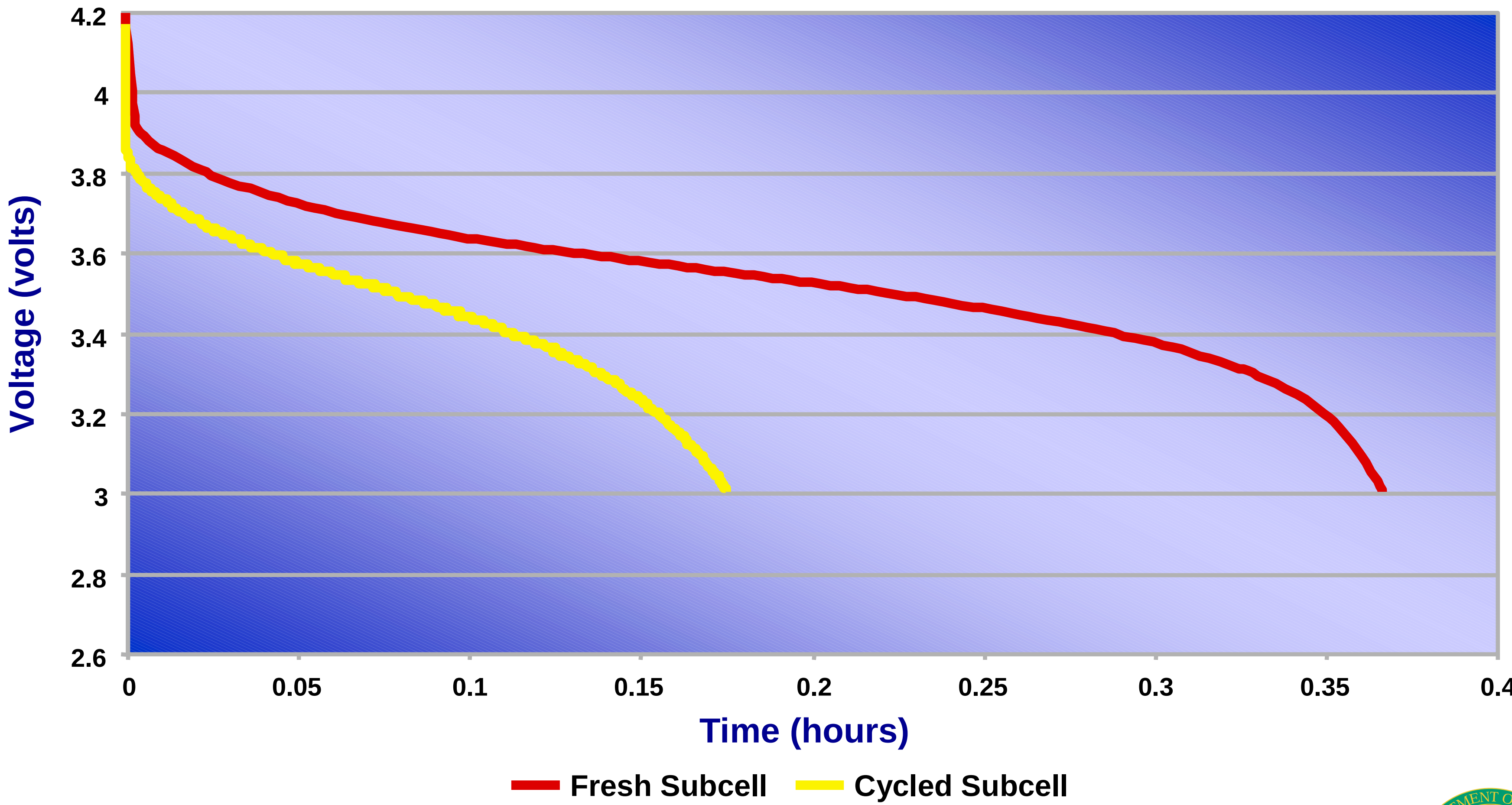
$LiMn_2O_4$ Cell Under 2C Discharge Current Before and After Cycling at 25°C



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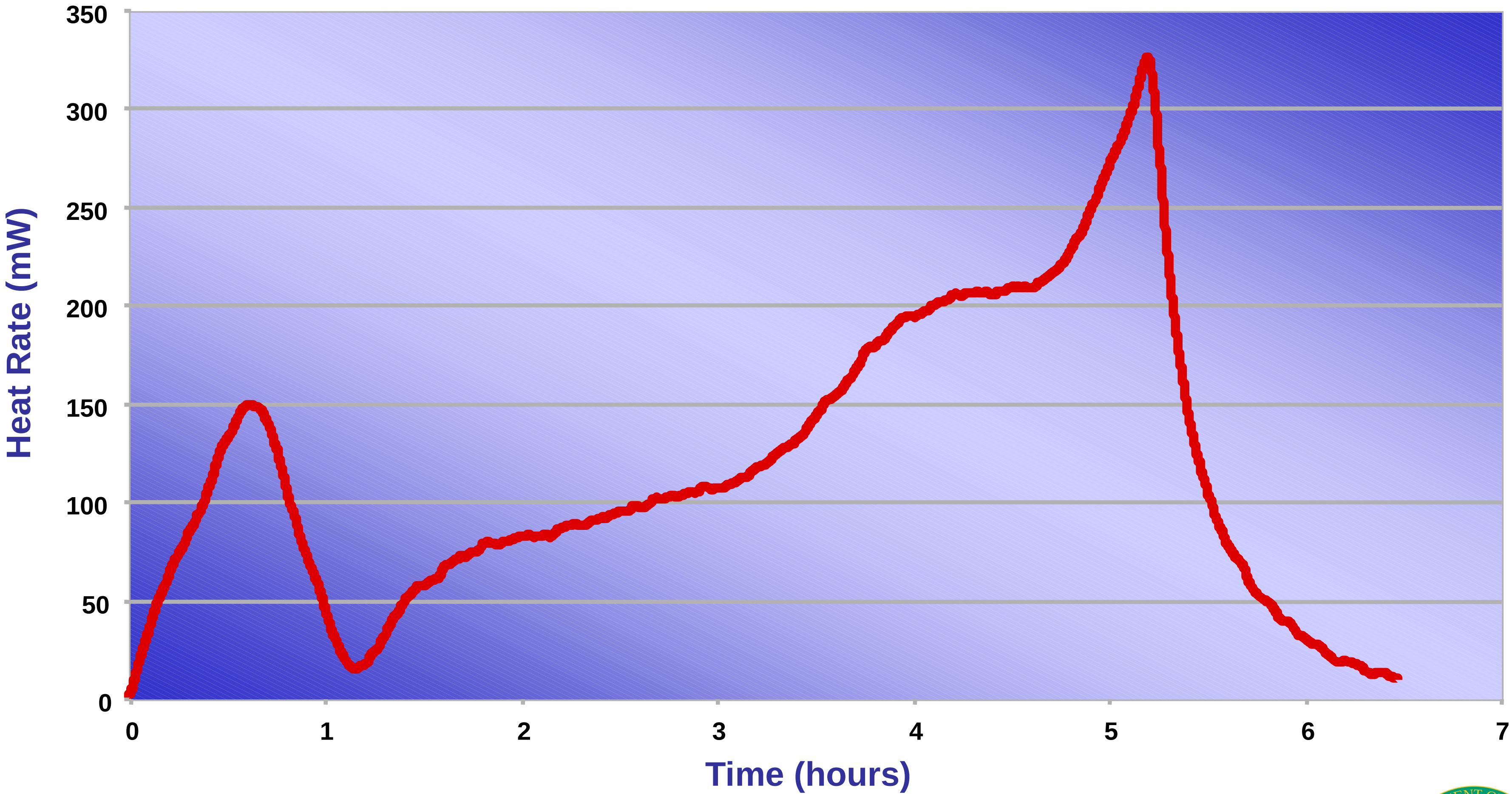
$LiCoO_2$ Cell Under Full Discharge Cycles and Under the HET Recommended Charging Scheme at 25°C

Cycle	Discharge Capacity (Ah)	Charge Return (Ah)	Nominal Amperage (amps)	Energy Input (Joules)	Energy Output (Joules)	Cal. Heat Measured (Joules)	Eff. (%)	Ave. Cell Heat Rate (W)
Constant C/5 Discharge	3.647	—	0.7	—	49263	2719	94.5	0.15
Charge after C/5 Discharge	—	3.725	See above	54254	—	4991	90.8	0.55
Constant C/1 Discharge	2.974	—	1.8	—	37019	6078	83.6	2.04
Charge after C/1 Discharge	—	3.181	See above	46601	—	4473	90.4	0.55

Calorimeter Response to $LiCoO_2$ Cell Under C/5 Full Discharge at 25°C



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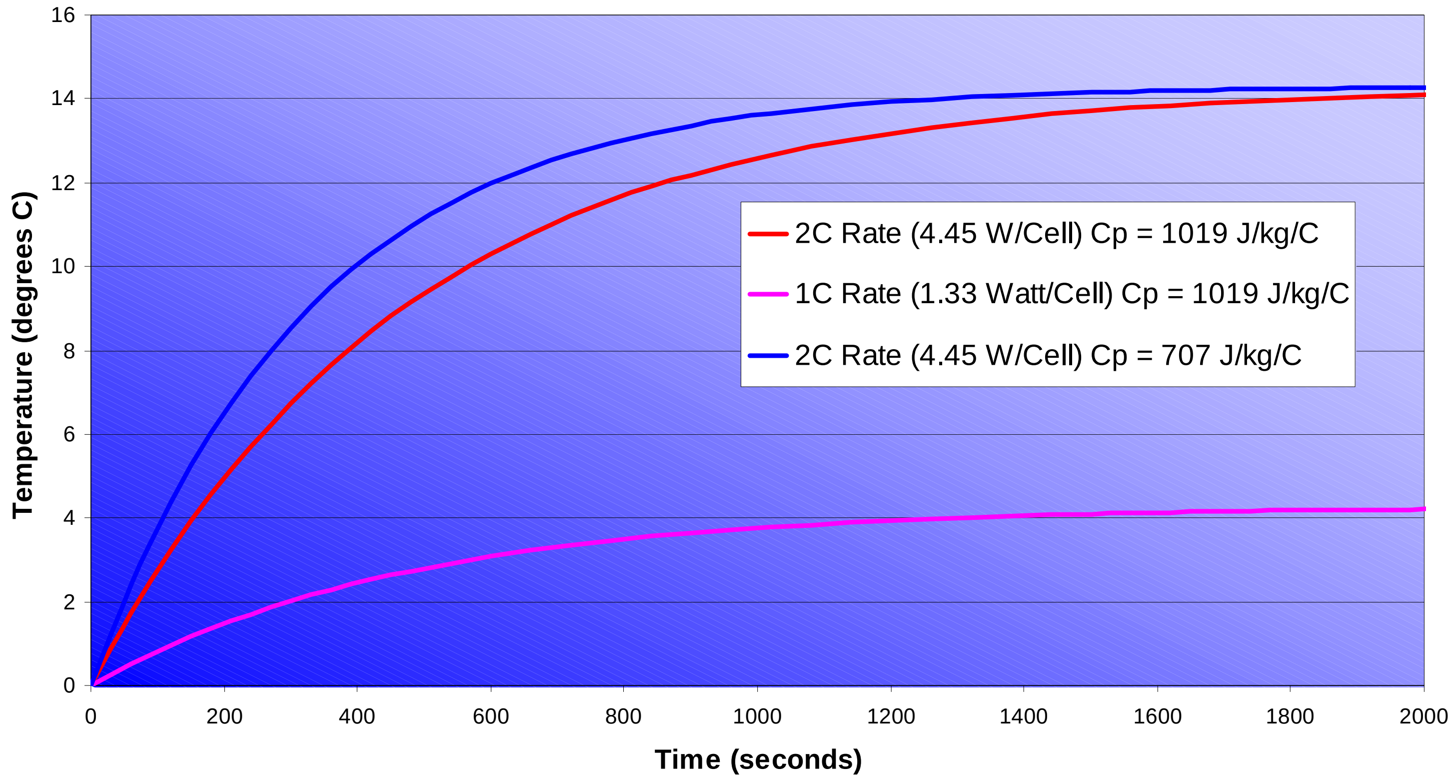
How Heat Generation and Heat Capacity Impact Module Temperature Rise



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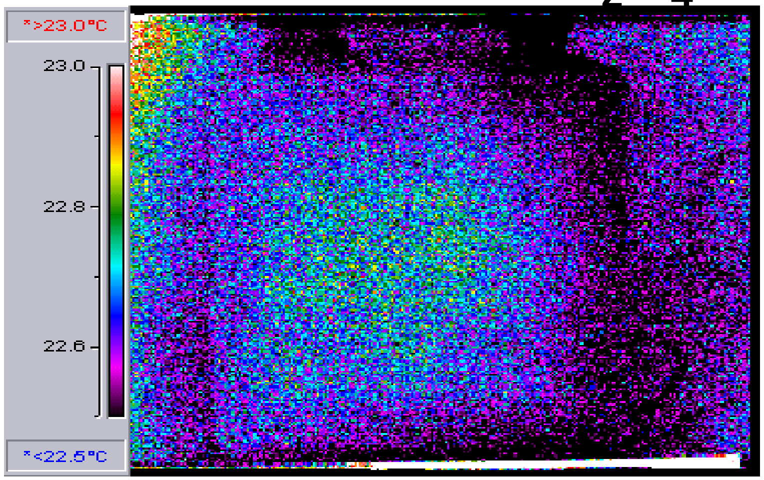
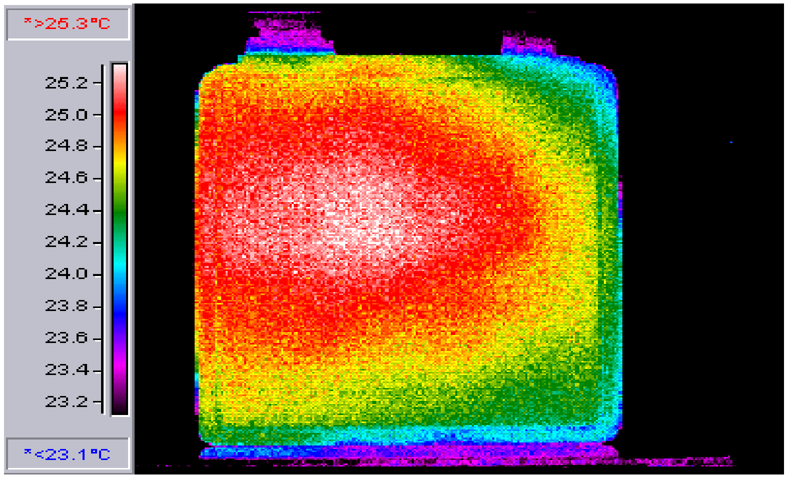
$LiMn_2O_4$ Cell Infrared Testing

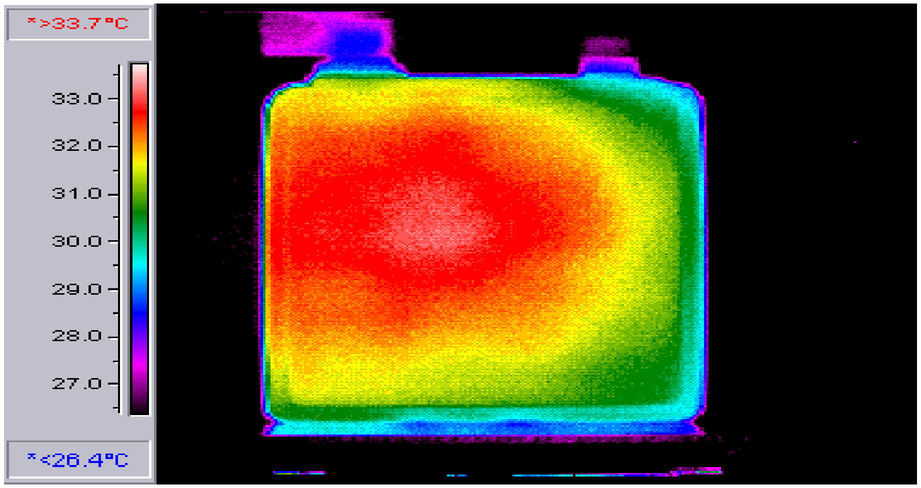


End of C/5 Discharge
Temperature Difference = neglible



End of C/1 Discharge
Temperature Difference = 2°C

Indications of localized heat underneath Positive Terminal



End of 2C Discharge
Temperature Difference = 7°C

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Physical Measurements of $LiMn_2O_4$ and $LiCoO_2$ Cells Prior to and After Testing

Cell	Initial OCV (Volts)	Final OCV (Volts)	Initial Mass (grams)	Final Mass (grams)	Initial Impedance (mΩ)	Final Impedance (mΩ)
$LiMn_2O_4$	3.968	3.918	144.62	144.63	11.0	560
$LiCoO_2$	3.702	3.796	84.59	85.15	26.1	33.0

Conclusions

- $LiMn_2O_4$ Cell
  - The columbic efficiency of the cell for the first ten full discharge cycles was around 97%.
  - The discharge efficiency at C/5 is around 98% whereas the efficiency at a 2C discharge is approximately 86%.
  - Using the HET recommended charging scheme, the charge efficiency of the was approximately 95%.
- $LiCoO_2$ Cell
  - The columbic efficiency of the cell started out at 97% but continuously dropped during repeated cycling.

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