

The Design of VRLA Batteries for Successful Operation in a High-rate, Partial-state-of-charge Regime

The Advanced Lead–acid Battery Consortium

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ACKNOWLEDGMENTS

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Types of Hybrid Electric Automobile

	Micro-	Mild-	Medium	Full
EV Drive				★
Motor assist		★	★ ★	★ ★ ★
Regen. braking	★	★	★ ★	★ ★ ★
Engine stop	★	★	★	★
Battery voltage	12	36	144	>200
Battery capacity (Ah)	50 - 60	15 - 20	6 - 8	6

HEV Power-assist Performance Requirements

	USABC Minimum P-A goals	NiMH use in Honda Insight
Maximum wt (kg)	40	~30*
Power out (10s) kW	25kW (625W/kg)	14 kW (467W/kg)
Power in (10s) kW	20kW (500W/kg)	7 kW (233W/kg)
Energy available in HRPSoC (Wh)	300 (7.5Wh/kg)	450 (15 Wh/kg)
(% of Total Cap'y)	~33%(of 900Wh)	~50%(of 900Wh)
% of Capacity used in cycle test (25Wh)	2.8%	?
Cycle life	300,000	?
Production Price (\$)	500	1017^

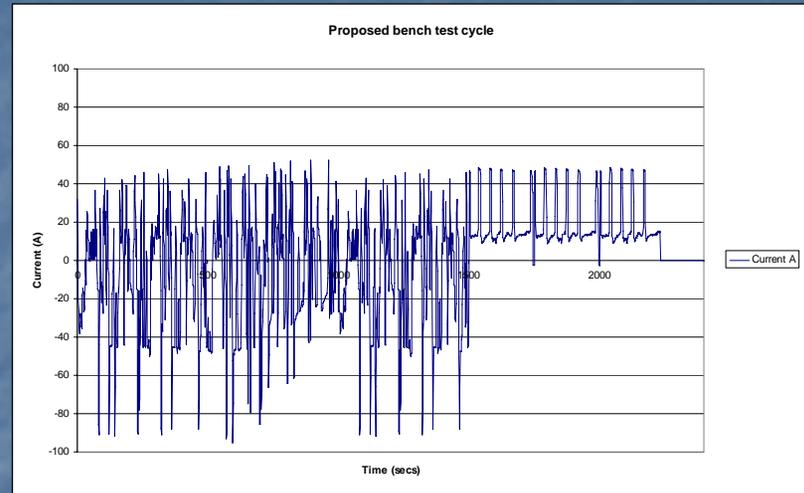
* Inc. BMS., ^ U.C. Davis report, 2003.



Real-world HEV Battery Duty

Current pulses through
30 minutes driving - 2 to 5% of
capacity discharged at up to
15C and charged at up to 8C.

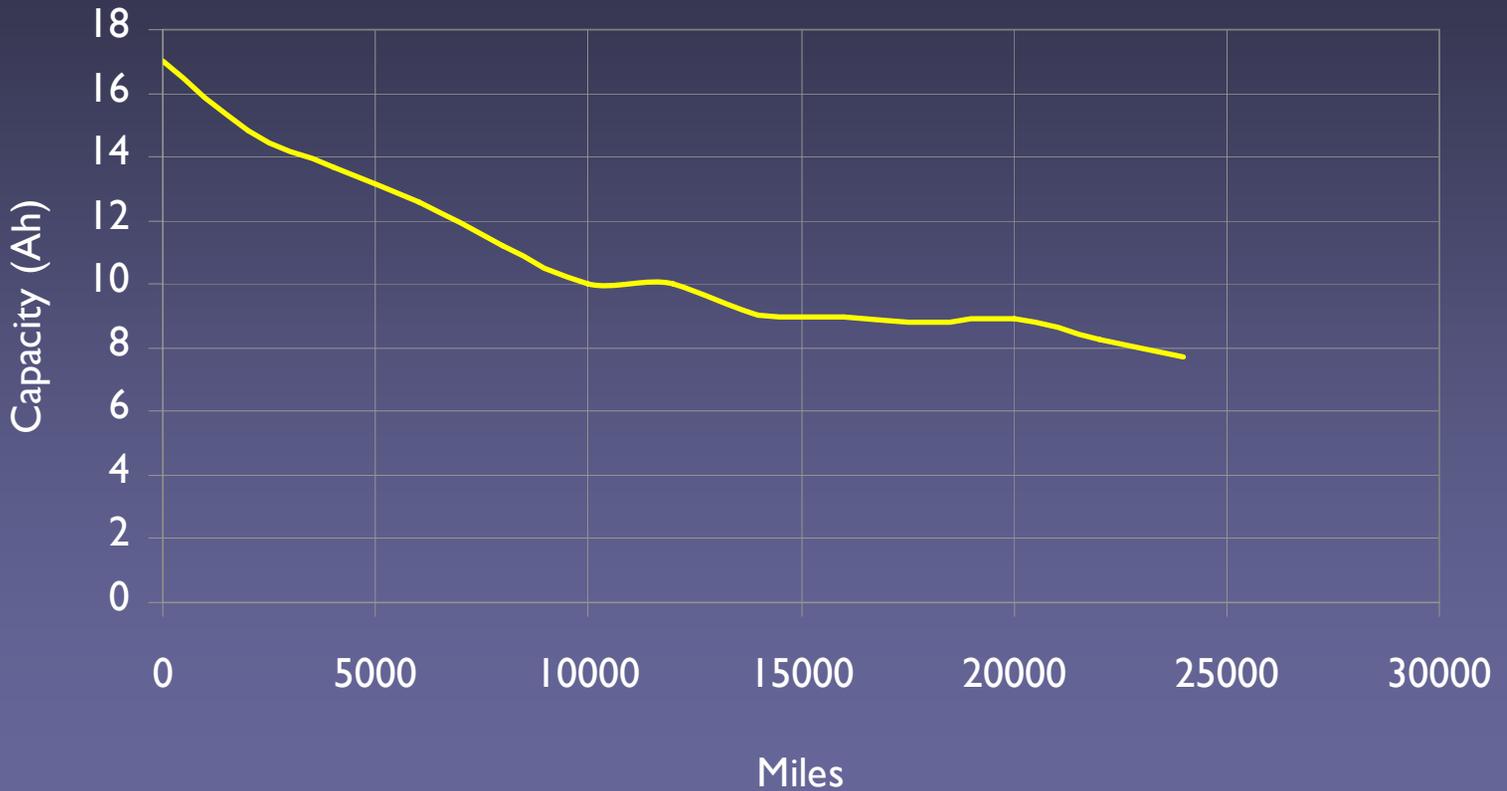
Charge removal and return
during the same period



Characteristics of high-rate partial-state-of-charge operation

1. High rate - up to 15 C discharge and 8 C charge
2. Long periods without approaching top-of-charge
3. Very large number of (small) cycles - 300,000 rather than $< 1,000$

Battery Capacity in HEV Duty



Discharge



&



When current is limited by diffusion,

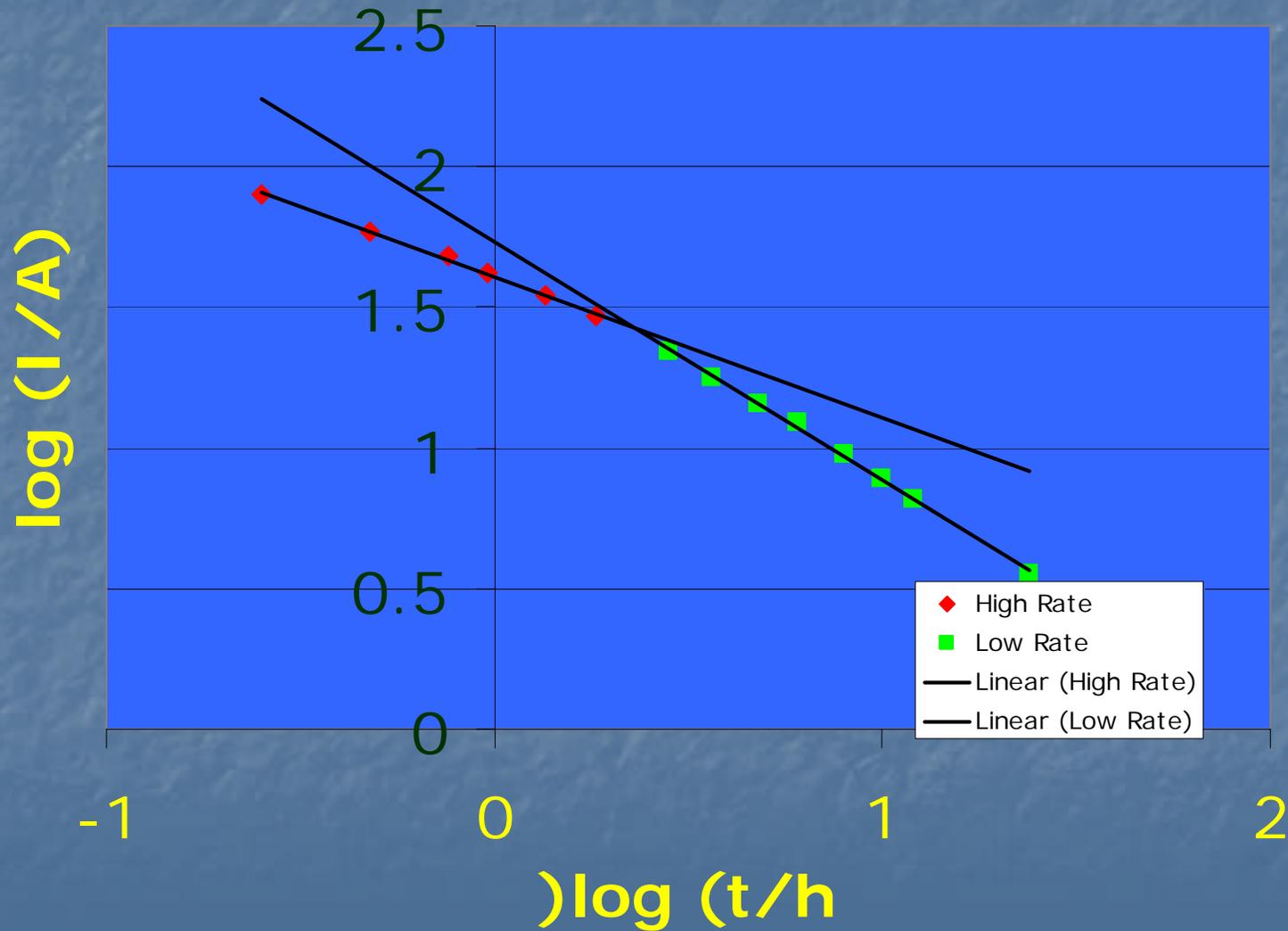
$$\text{Flux, } S = -D_i \delta c_i / \delta x, \quad \Delta x^2 = 2Dt$$

Peukert $I^n \cdot t = k$ At low current $n = 1$

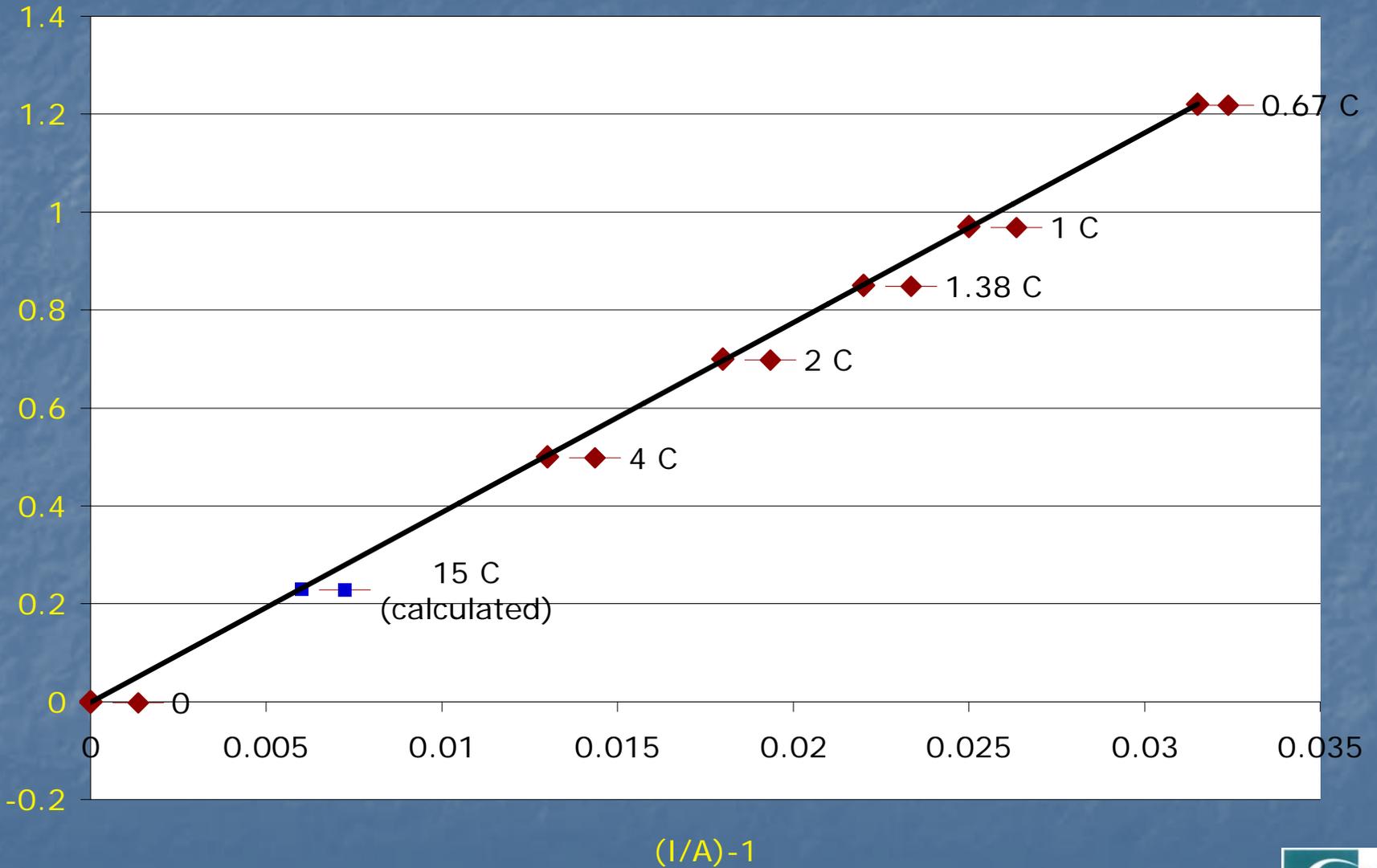
At high current (diffusion control) $n = 2$

$$I = k' t^{-0.5}$$

Peukert Plot High/Low Rate



High Rate Peukert Plot (data from JPS 9 (1983) 19)



Mechanism & solution:

I. Grid design

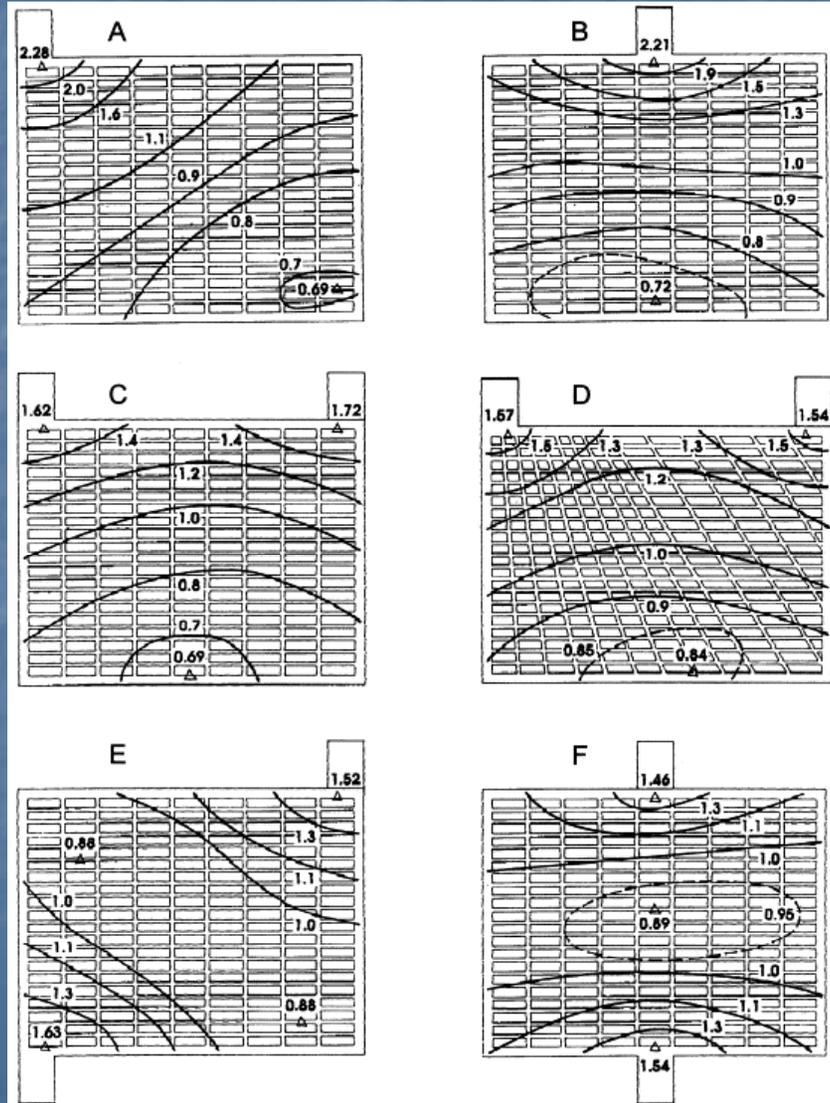
Change of failure mode of a standard VRLA (15 Ah, flat plate) cell with operating rate

	PAM Porosity %	NAM Sulfate % Top	NAM Sulfate % Bottom	Failure mode(s)
After formation	48.9	4.9	4.9	
Low-rate (C/10) deep cycle	61.4	3.4	20.0	PCL2 Strat.
Moderate rate (C/3) PSoC	58.2	4.2	38.5	PCL2 Strat.
High rate (5C) PSoC	54.1	79.6	7.4	PCL3

Soria et al., Exide Technologies, 9ELBC, Berlin, 2004



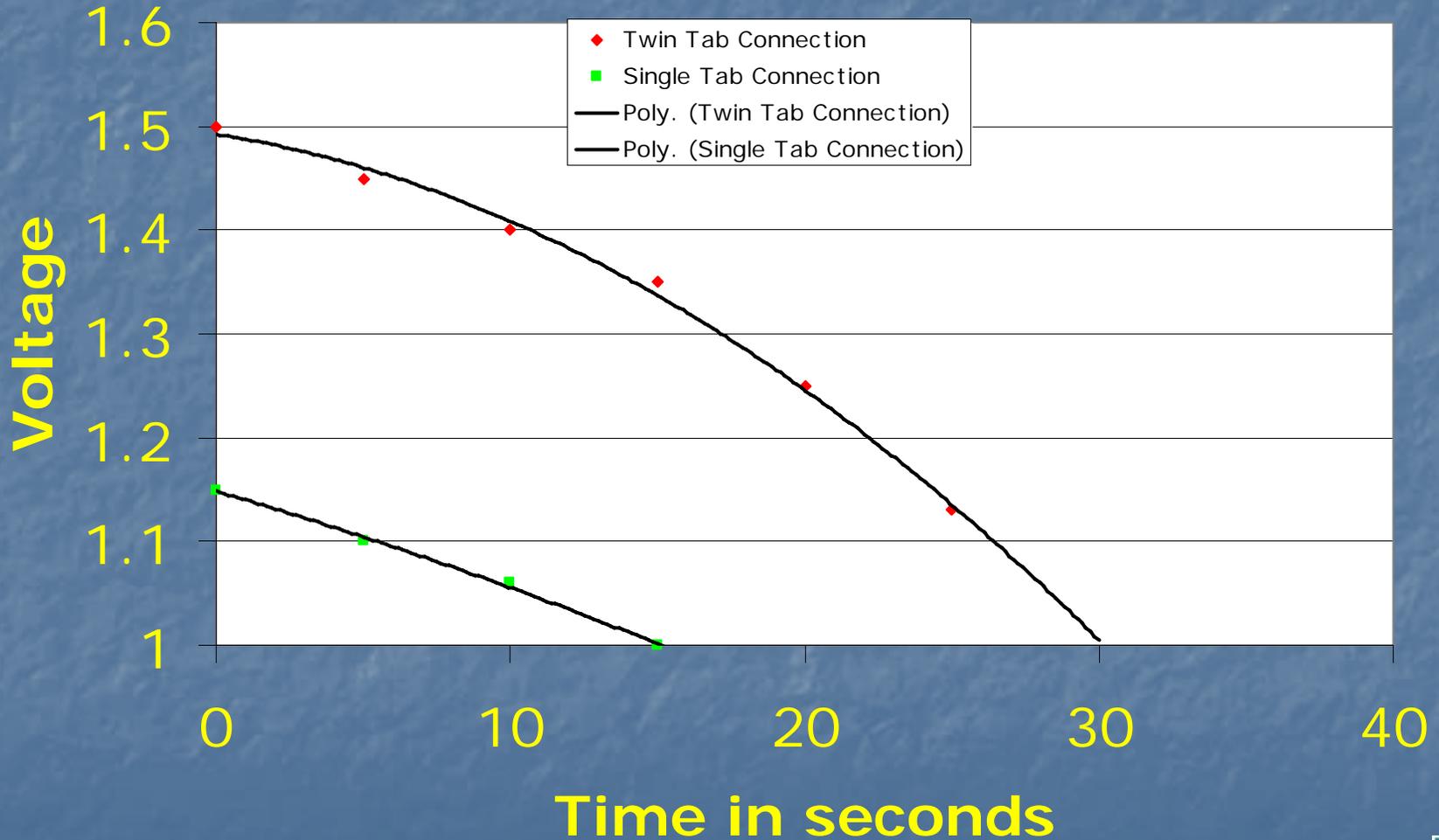
Current density contours on twin tab arrangements



Spiral Wound Cell with Dual Tabs



2V 8Ah Cell Discharged at 250A



Dual-tab spiral wound cell

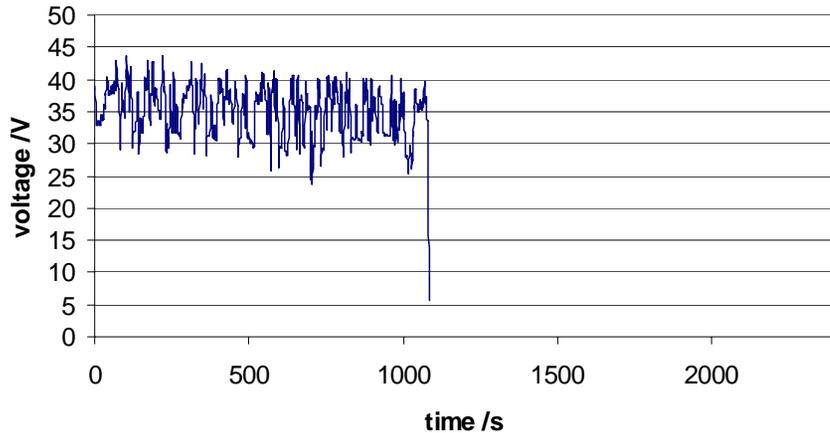
Discharges up to 28 seconds at 250 A
At 1.4 V.

Weight 578 g.

Specific power: 605 W/kg

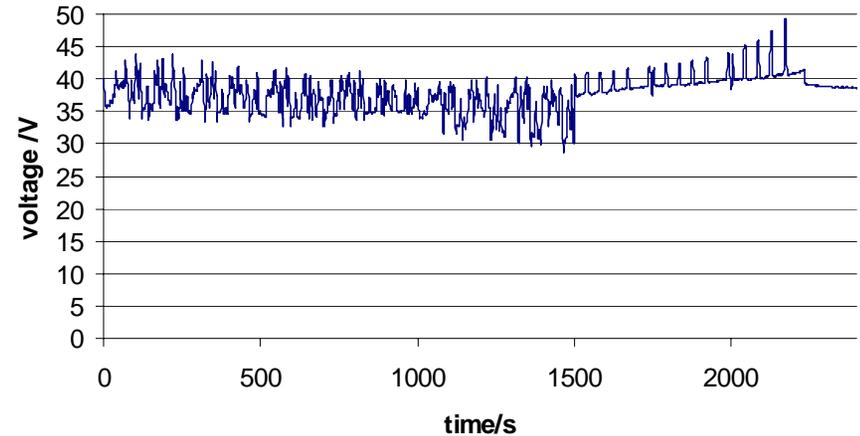
RHOLAB test procedure – cell comparison

voltage vs. time for standard cyclon pack on rholab power profile. start @ 70% SOC, 40 degrees C



Normal Cyclon 36V pack

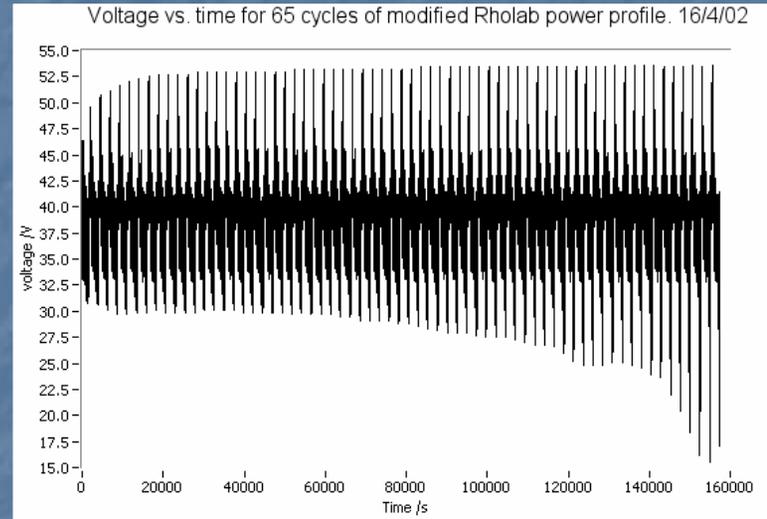
voltage vs. time for first double ended cell pack on rholab power profile. start @ 70%SOC, 40degrees C



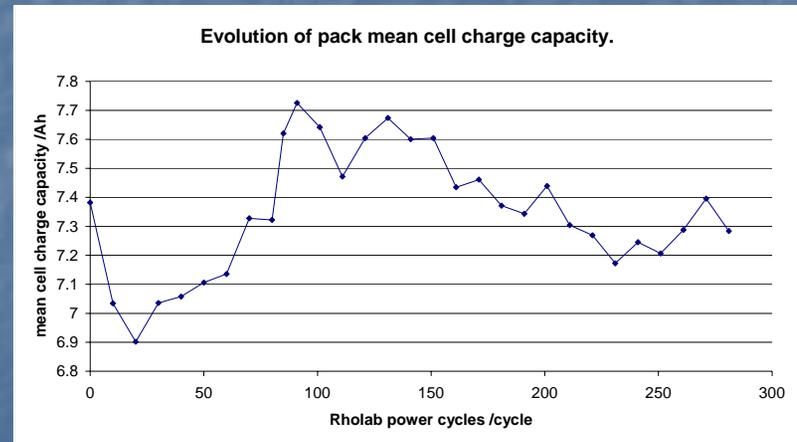
Dual-tab Cyclon 36V pack

Effect of continuous cycling (40 hours)

The drift of pack voltage over 65 RHOLAB cycles

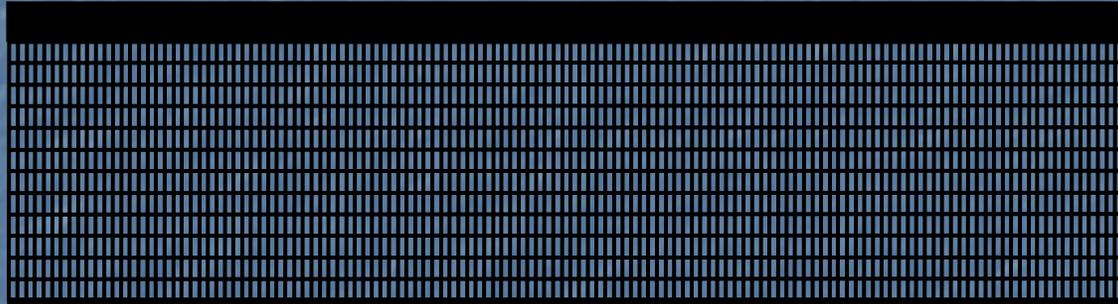


The effect of conditioning on the evolution of cell capacity

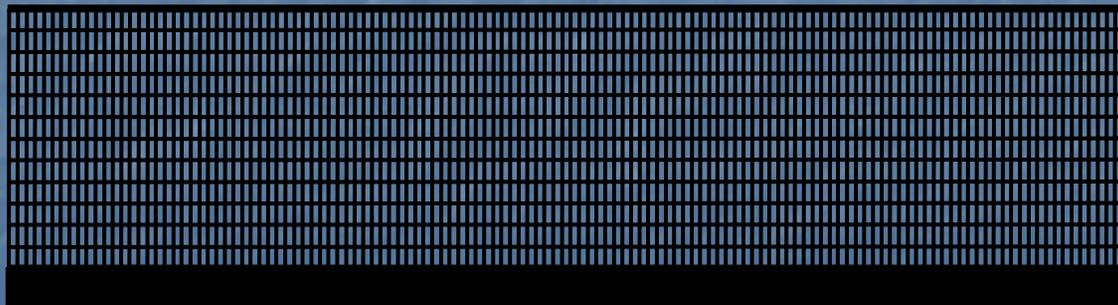


Configuration with Most Uniform Current Distribution

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+



Pasted Plates



Plates Wrapped with Separator in Case



High-rate performance of

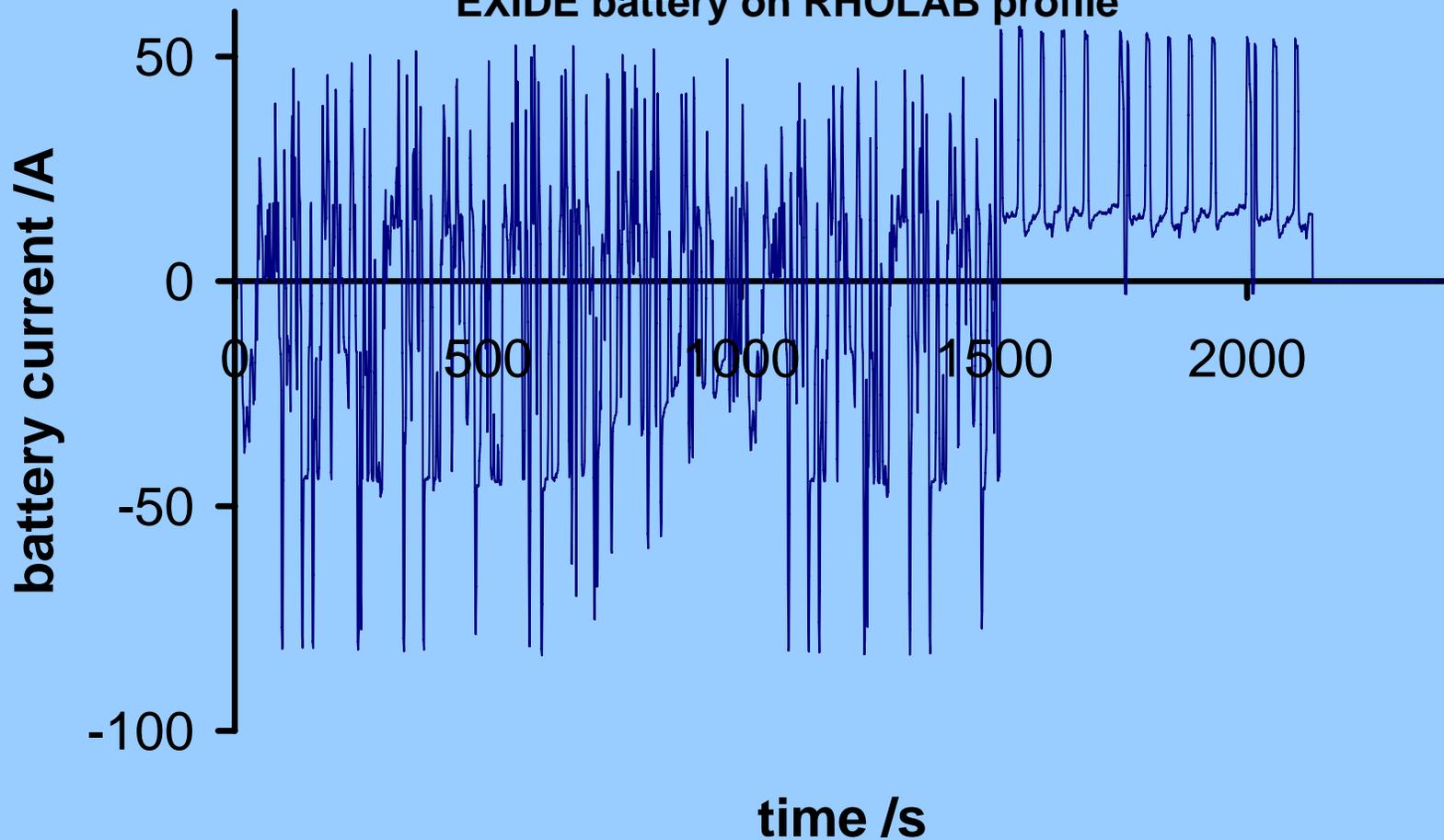
1) Conventional cells

275 A for 120 s at -18°C to 1.0 V.

2) Cells with selvage current collection

420 A for 121 s at -18°C to 1.0 V.

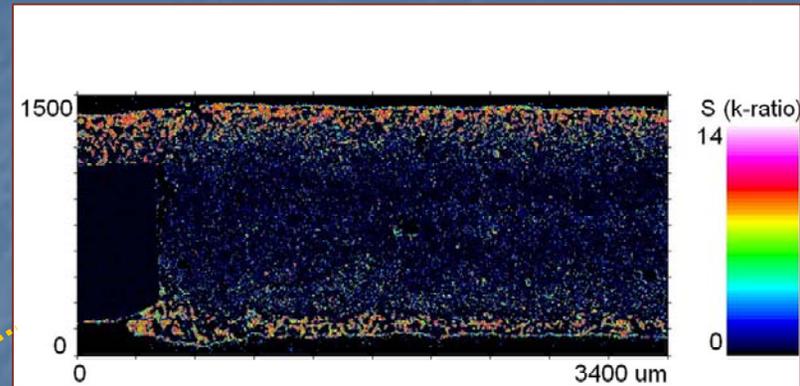
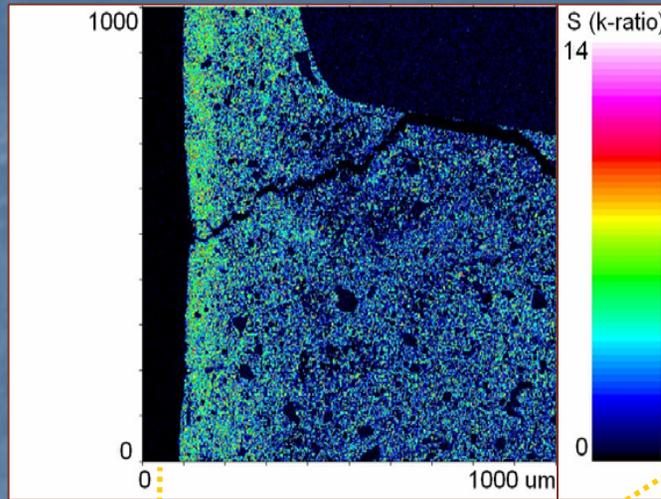
EXIDE battery on RHOLAB profile



Mechanism & Solution:

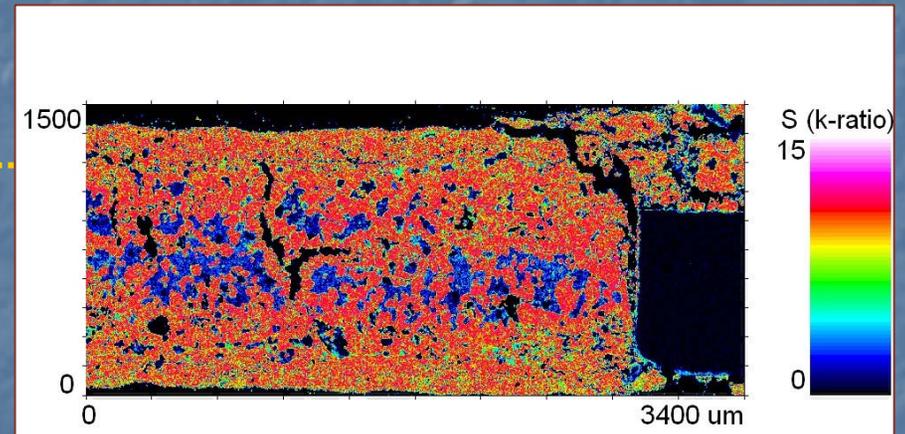
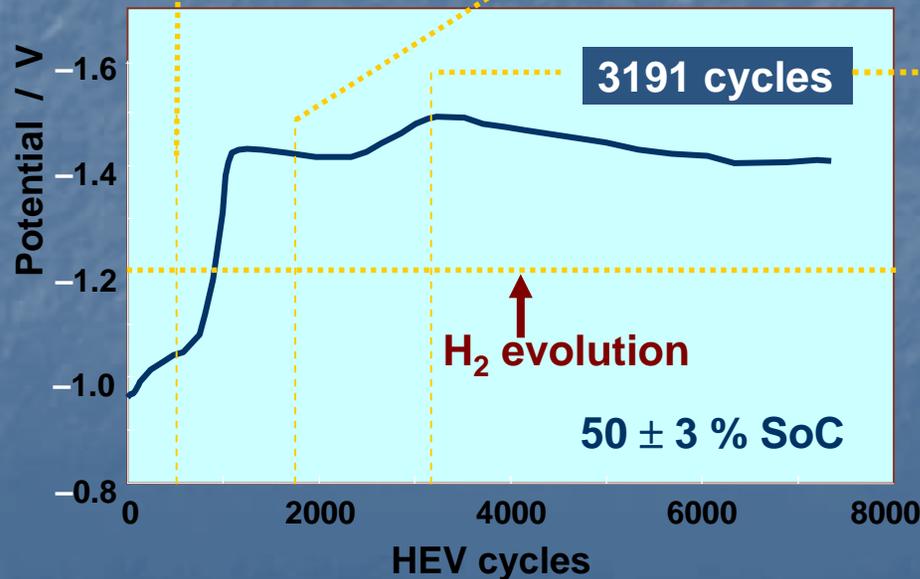
2. Expander Composition

HEV duty: sulfate build-up in negative plates – PCL-3!

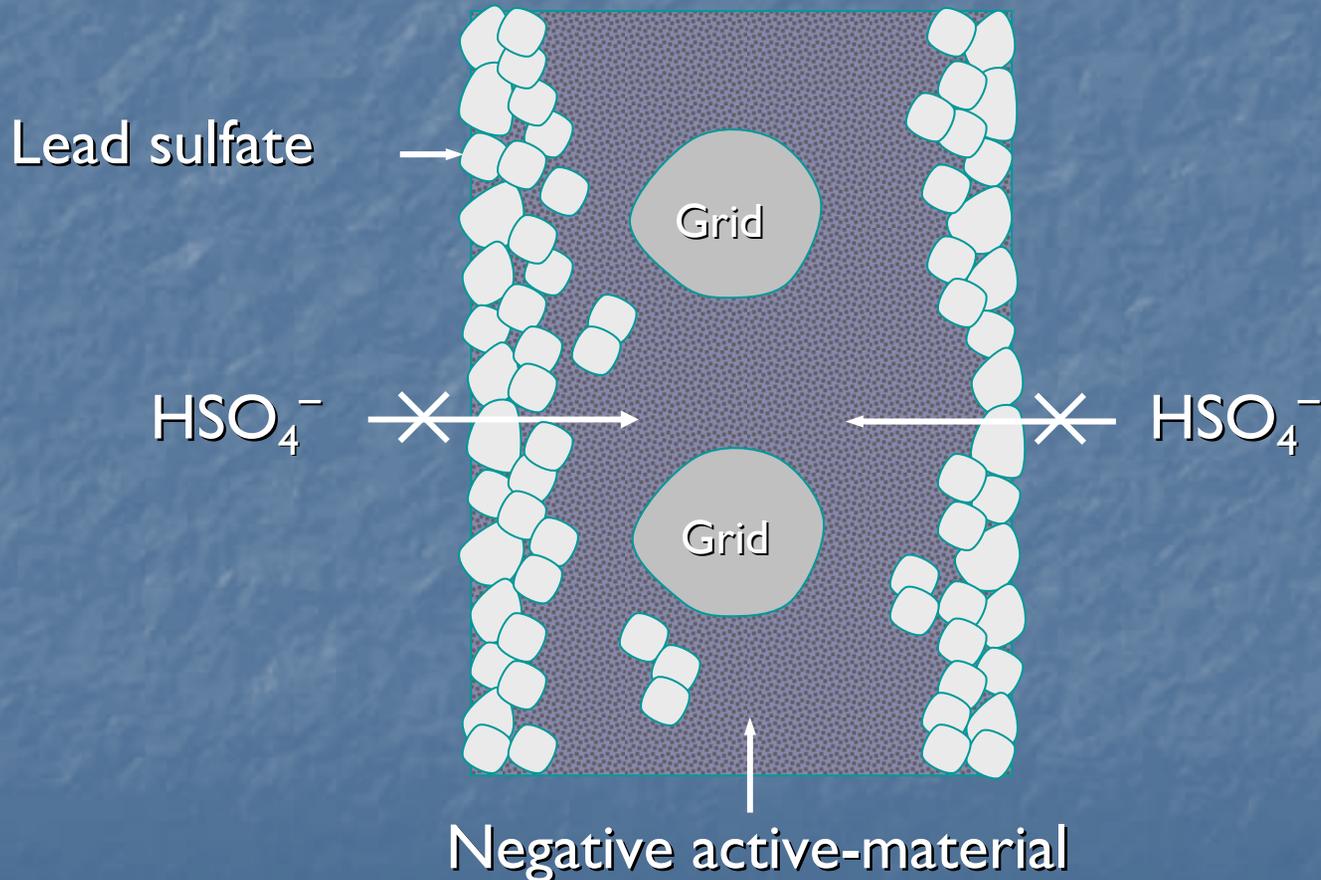


0 cycles

1735 cycles

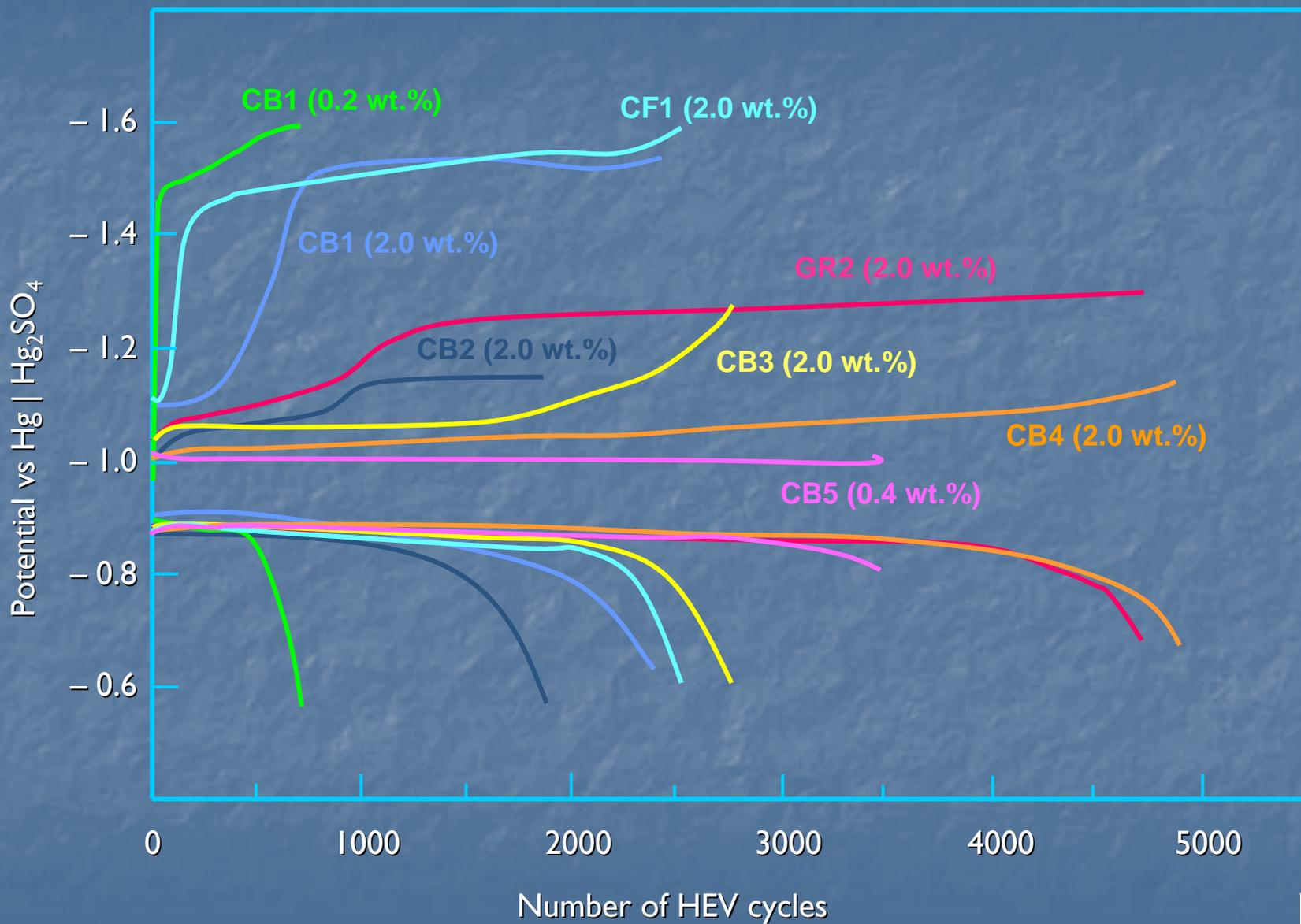


Diffusion of acid in and out of the plate is impeded by PbSO_4

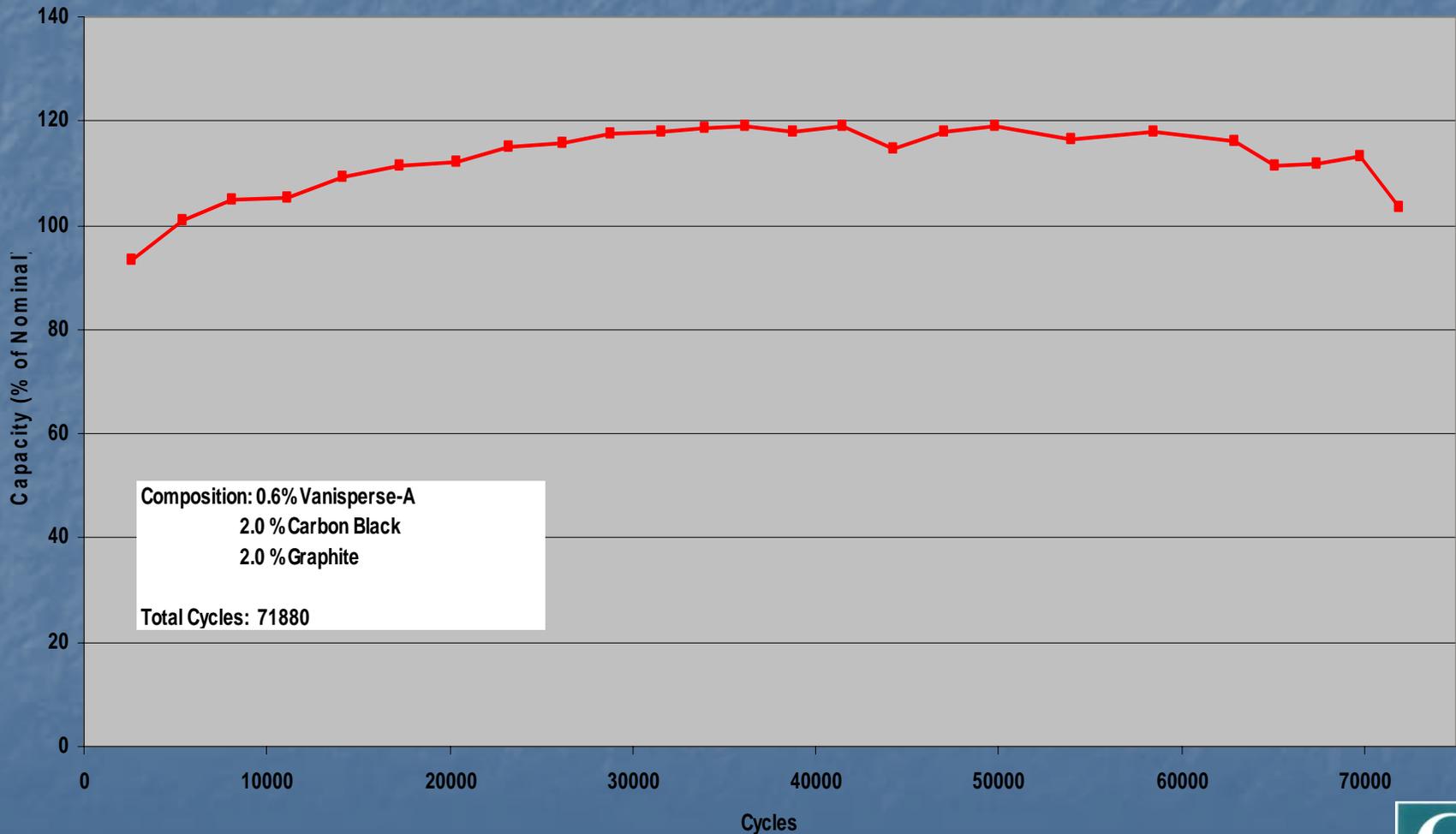


Carbon - *an element with variable properties*

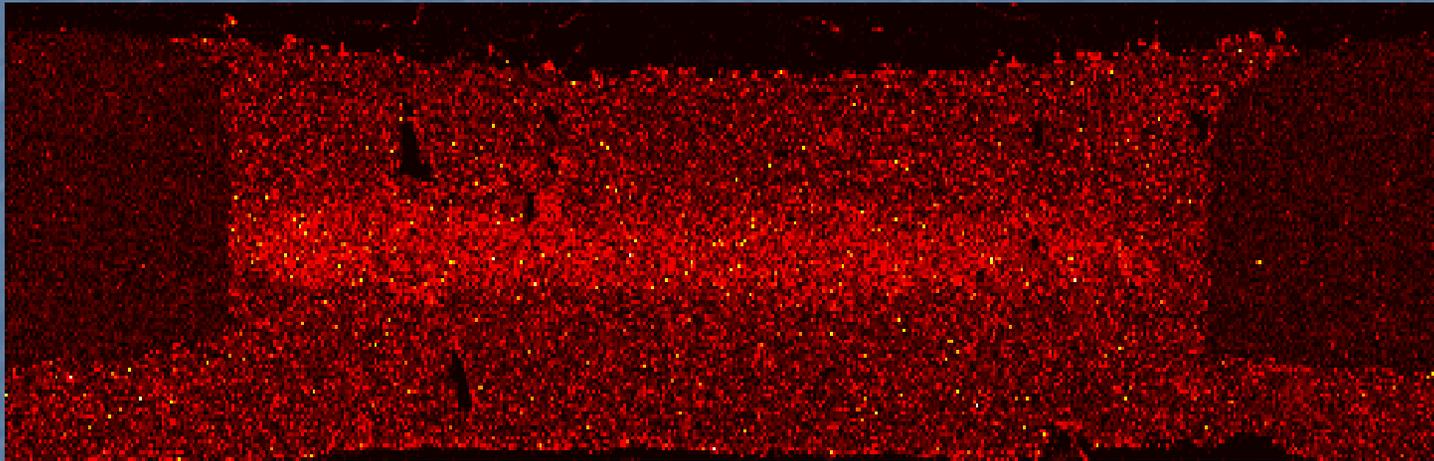
1. Ratio of sp^2 to sp^3 carbon atoms.
2. Surface groups.
3. Hexagonal/ rhombohedral stacking - faults.
4. Particle size - from Å to mm.
5. Shape.



Cycling Behavior of VRLA Cells With Enhanced Levels of Carbon Black and Graphite in the Negative Active Material



Distribution of sulfur for a cell with 2% graphite and 2% carbon black



Extension of Life Under High Rate PSoC Cycling

Failure Modes: Early Gassing
Negative Sulfation
Recharge Resistance

Solutions: Carbon added to Negative
Grid Design
Pulses

the test vehicle...



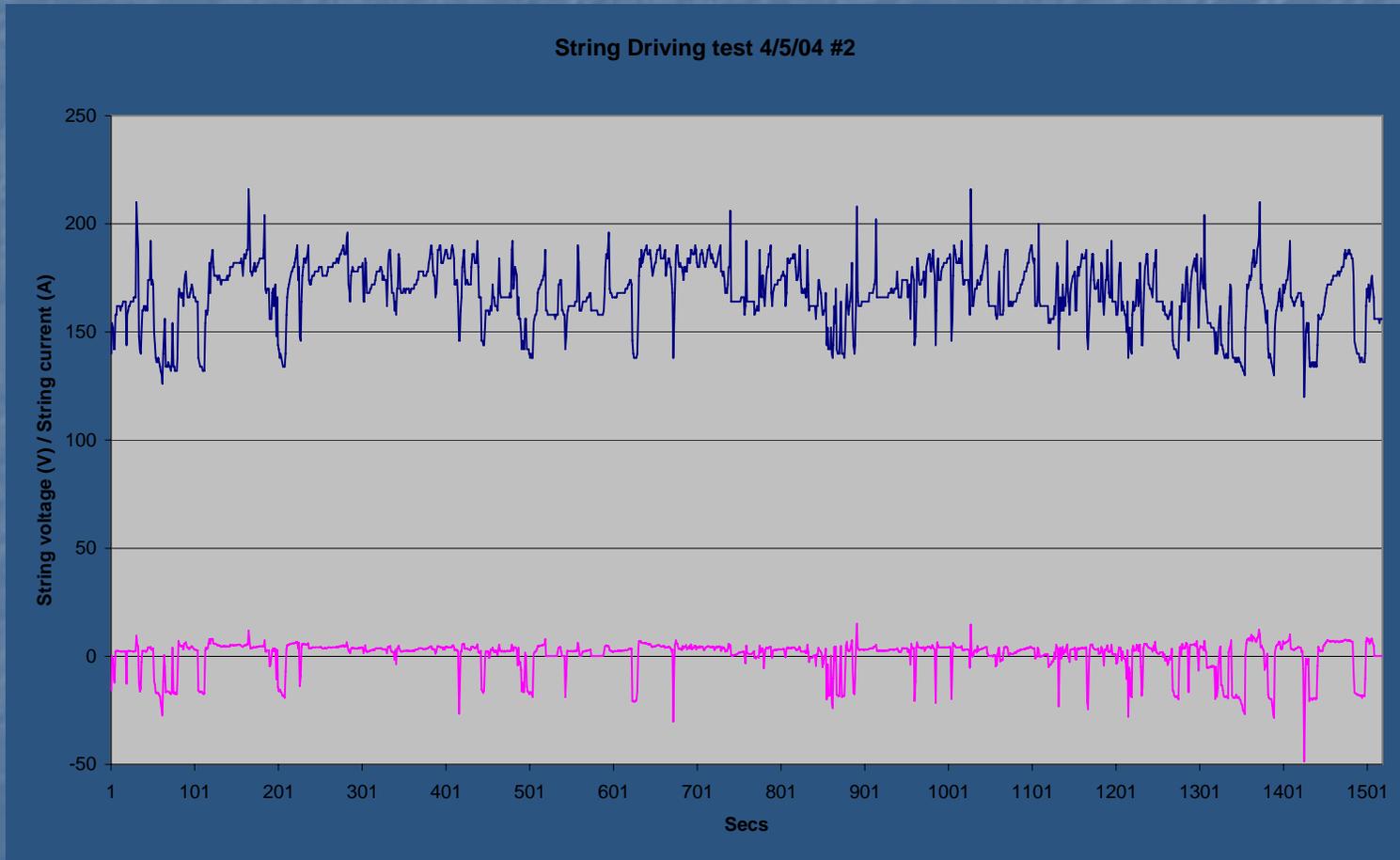
Lead–acid battery in position



Insight on road-test with its lead–acid battery



Road test data with the lead-acid battery voltage/current readings



ALABC Demonstration phase vehicles

- RHOLAB Honda 'Insight' 144 V, 8 Ah
- ISOLAB Ford 'Focus' 36 V, 25 Ah
- Project DP I.2 Ford/PSA/VW 12 V, 36 V
- Project DP I.3 Hybrid electric bus* 400+ V, 50-60 Ah
- Project DP I.6 Chevrolet 'Silverado' 36 V, 52 Ah
- Project DP I.6 Hybrid electric bus* 400+ V, 52 Ah

