Burp Charging Nickel Metal Hydride Cells

by

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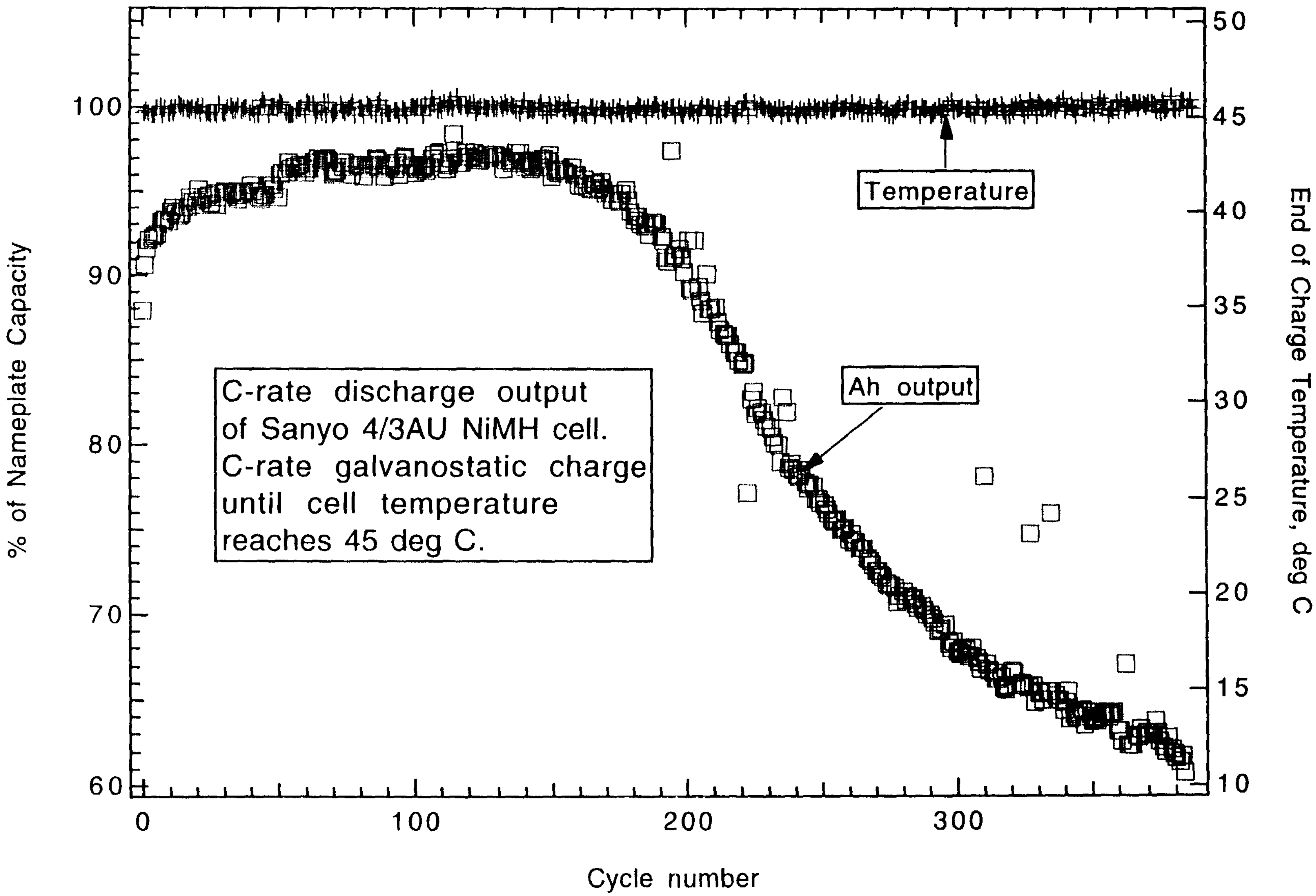
% of Nameplate Capacity
100
90
80
70
60
End of Charge Temperature, deg C
50
45
40
35
30
25
20
15
10
Cycle number
0
100
200
300
Temperature
Ah output
C-rate discharge output of Sanyo 4/3AU NiMH cell. C-rate galvanostatic charge until cell temperature reaches 45 deg C.

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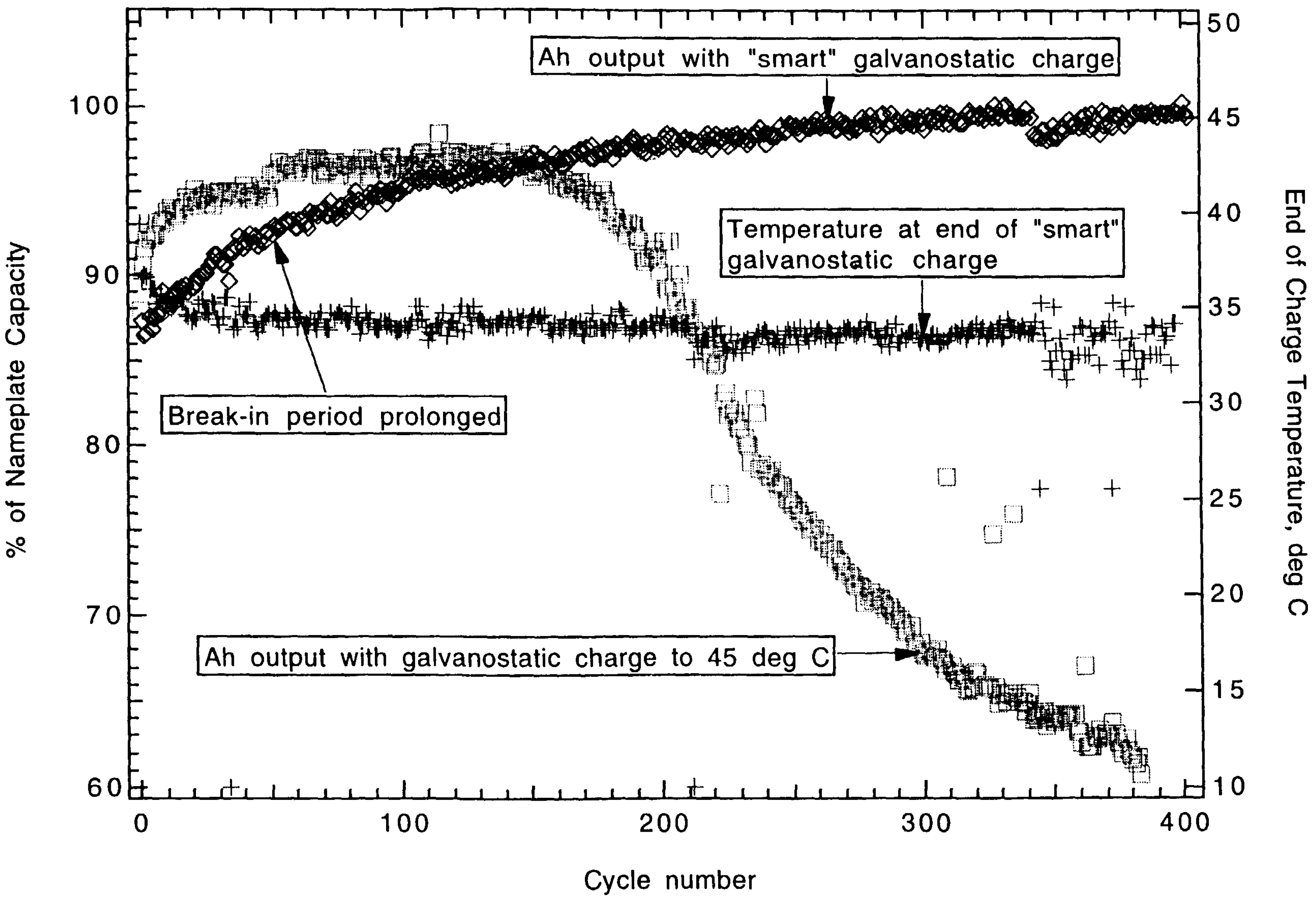
∂V/∂t = -X or ∂T/∂/t = Y



Ah output with "smart" galvanostatic charge
Temperature at end of "smart" galvanostatic charge
Break-in period prolonged
Ah output with galvanostatic charge to 45 deg C
% of Nameplate Capacity
100
90
80
70
60
End of Charge Temperature, deg C
50
45
40
35
30
25
20
15
10
0
100
200
300
400
Cycle number

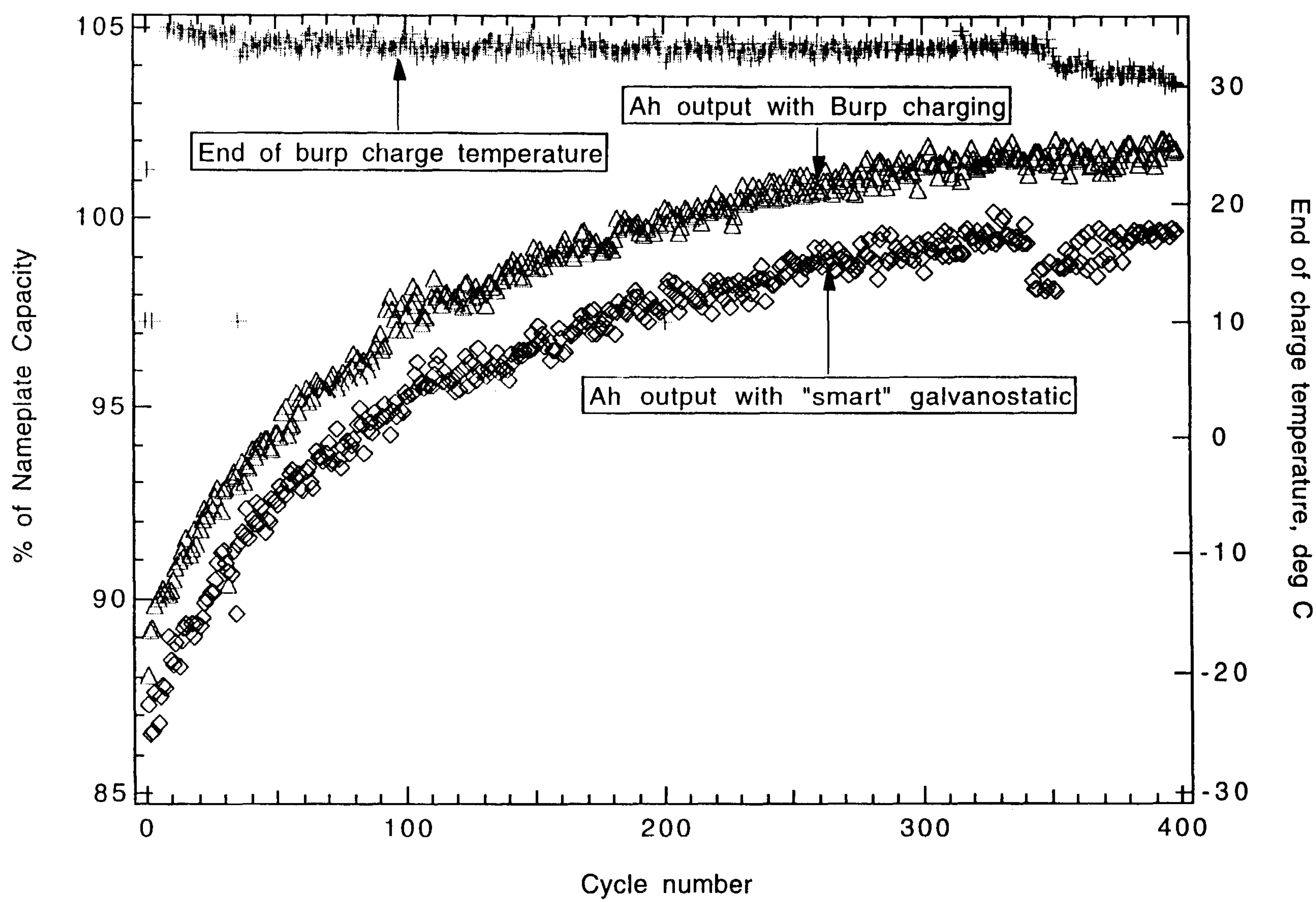
Some methods for improving cell peformance

- Smart termination
  - negative voltage slope, $\partial V/\partial t < 0$
  - rise in temperature, $\partial T/\partial t = Y$
- Charge current waveform changes
  - relaxation, $I = 0$
  - discharge burp, $I < 0$

Areas of improvement remaining

- can break-in period to maximum capacity be accelerated?
- can discharge capacity be increased without compromising cycle life?
- can charge heat be reduced further?

Modifying the current waveform shown effective with NiCd cells


End of burp charge temperature
Ah output with Burp charging
Ah output with "smart" galvanostatic
% of Nameplate Capacity
End of charge temperature, deg C
Cycle number
105
100
95
90
85
30
20
10
0
-10
-20
-30
0
100
200
300
400

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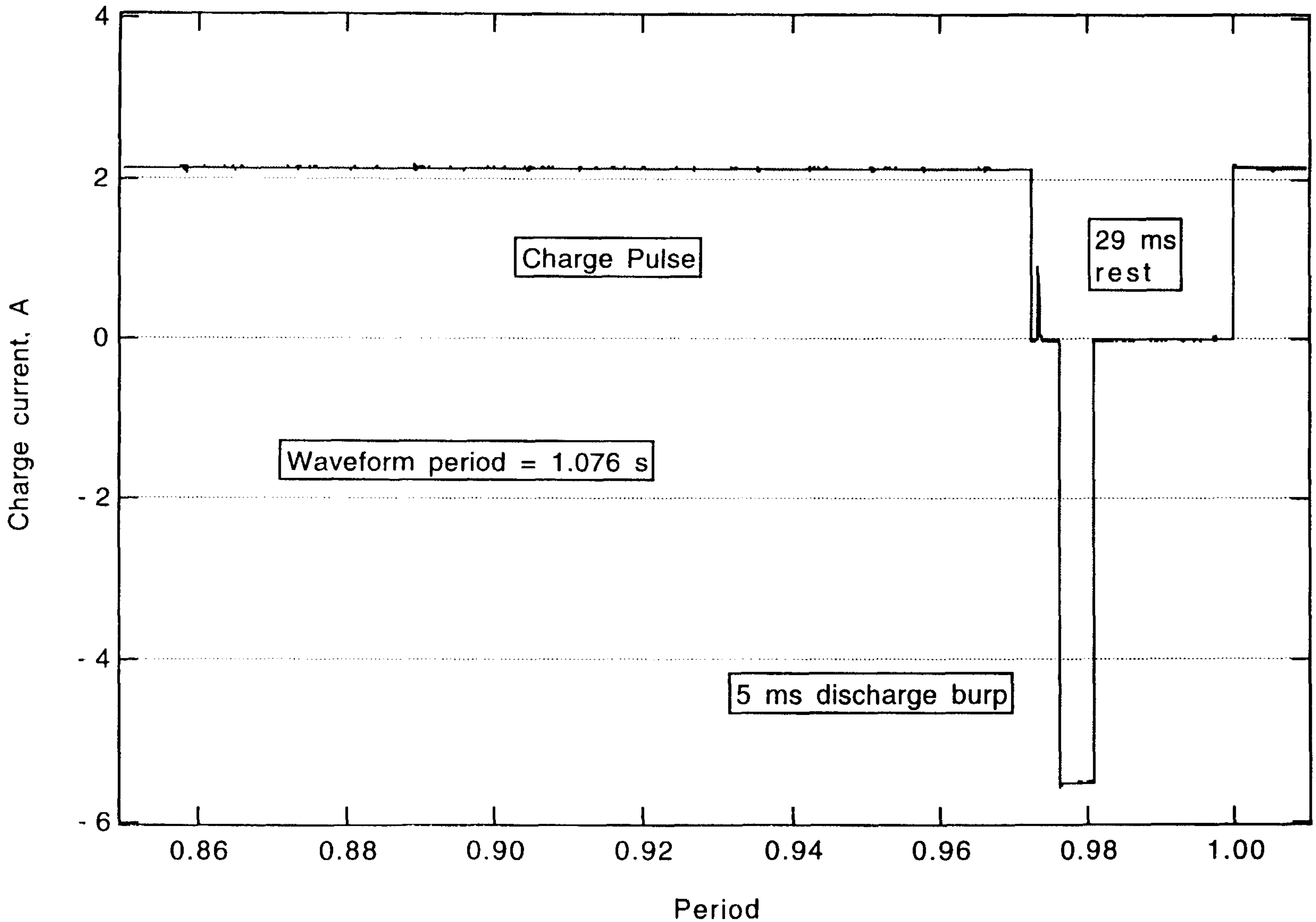
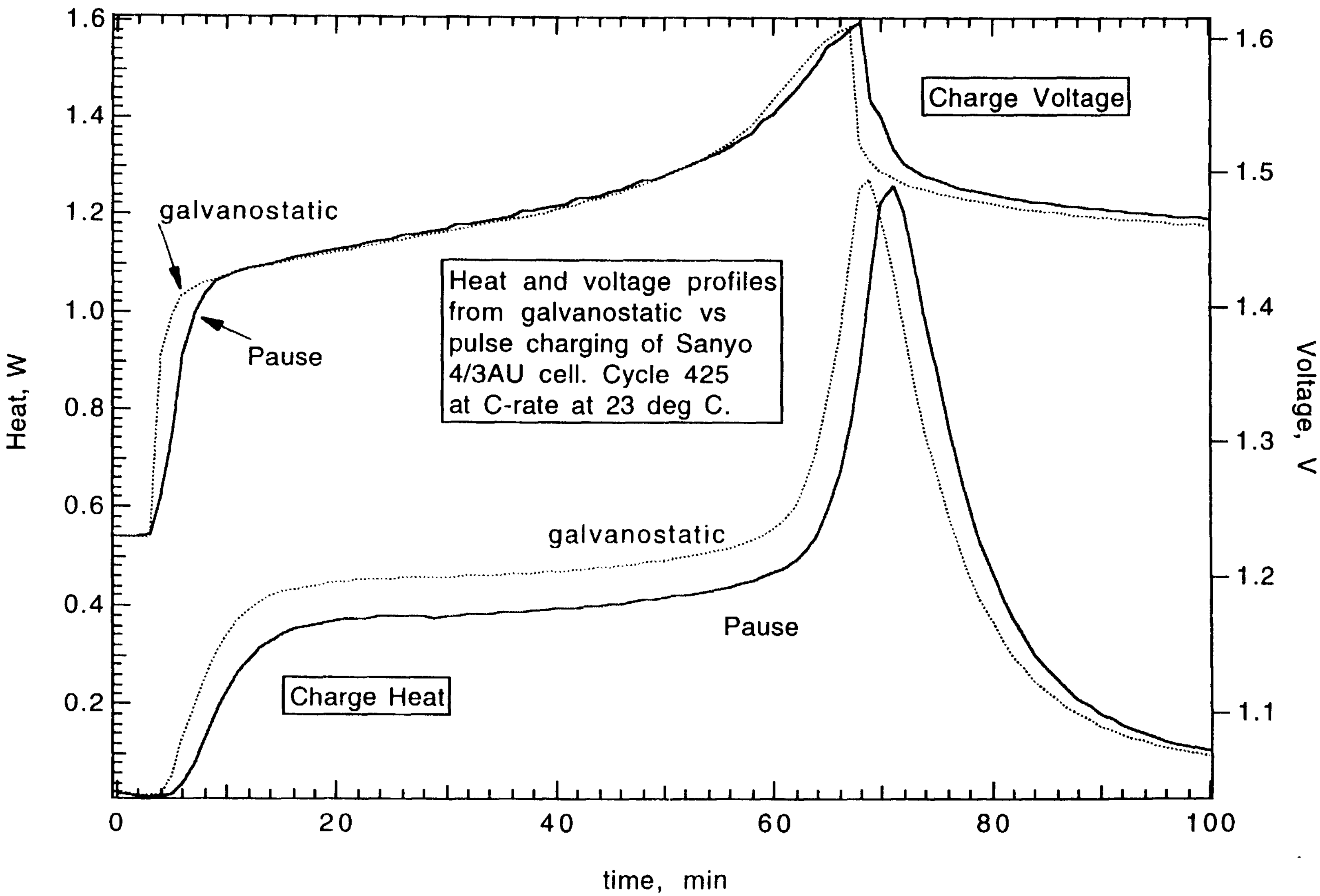
What is Burp Charging?



Methods to study effects of relaxation and burp discharge

	Charge Waveform	Termination Method $\partial T/\partial t = X$	$\partial V/\partial t = -Y$	$\partial^2 V/\partial t^2 = 0$
Galvanostatic	Constant current	x	x	
Pause	Constant current with short relaxation periods	x	x	x
Burp	Constant current with relaxation periods and discharge burps	x	x	x

Calorimetric Results



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Effects of interrupting the galvanostatic charge

- Lowers Ah input rate by 2.7%
- Total Ah input lowered by 4%, while Ah output unchanged
- Overvoltages essentially the same
- Charge heat rate, W, reduced throughout the charge *
- Total charge heat, J, lowered by 8% *
- Rise in cell temperature (T_{final} - T_{init}) not affected *

* evaluated at 425th cycle

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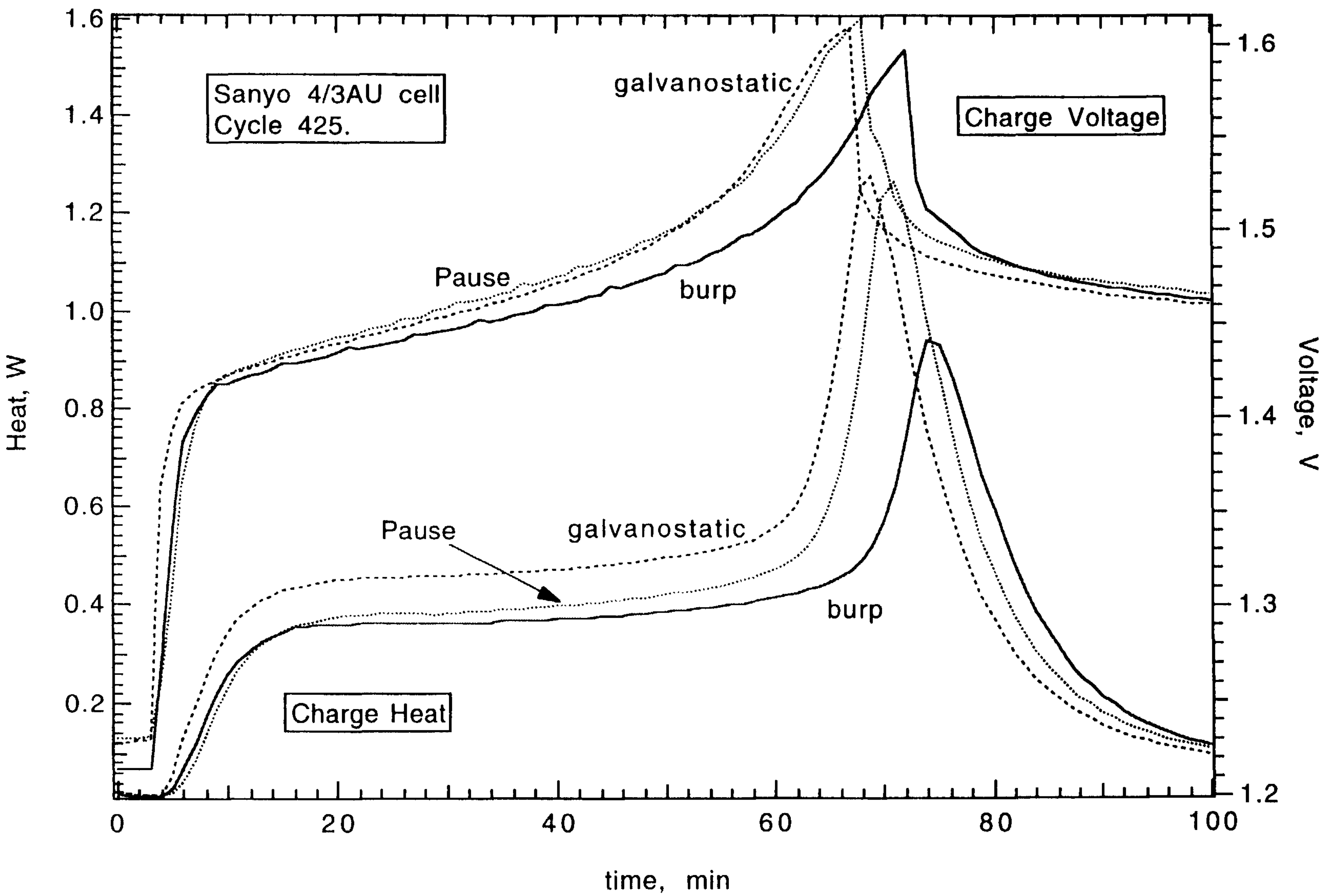
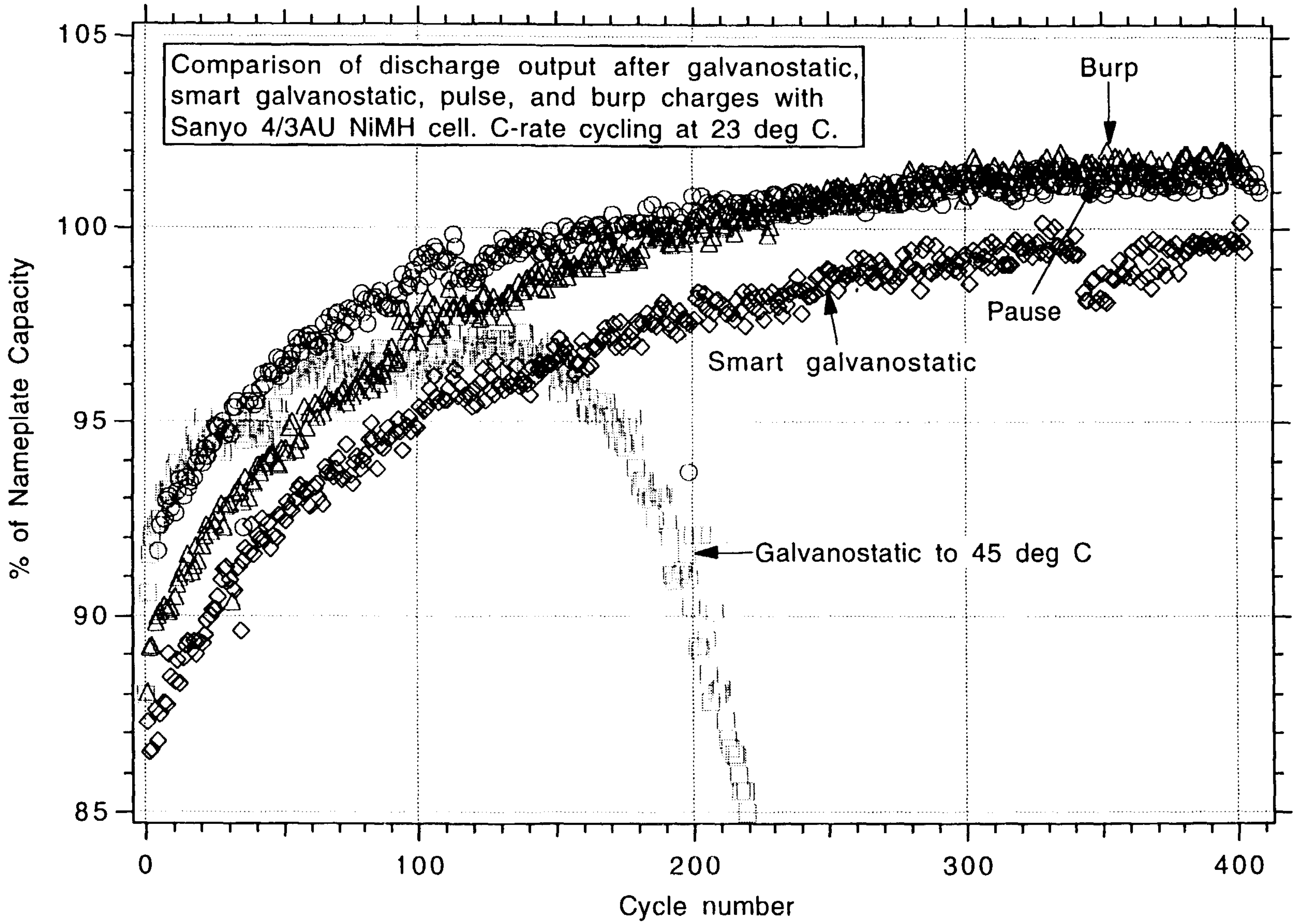

Sanyo 4/3AU cell
Cycle 425.
galvanostatic
Charge Voltage
Pause
burp
Pause
galvanostatic
burp
Charge Heat
Heat, W
Voltage, V
time, min
0
20
40
60
80
100
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1.6
1.5
1.4
1.3
1.2

Results



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Effects of adding 5 ms discharge burps

- Reduces Ah input rate by 1.1%
- Increases total Ah input and output by 5%
- Lowers charge heat rate (e.g., by an additional 6% at midcharge point) *
- Lowers rise in cell temperature by ~1 °C, despite larger Ah input *
- Reduces overvoltage throughout charge (e.g., by ~50 mV near end of charge) *

Do differences between burp vs pause charging depend on cycle number?

- break-in period shorter with pause

Is overvoltage reduction developed with cycle number?

* evaluated at 425th cycle

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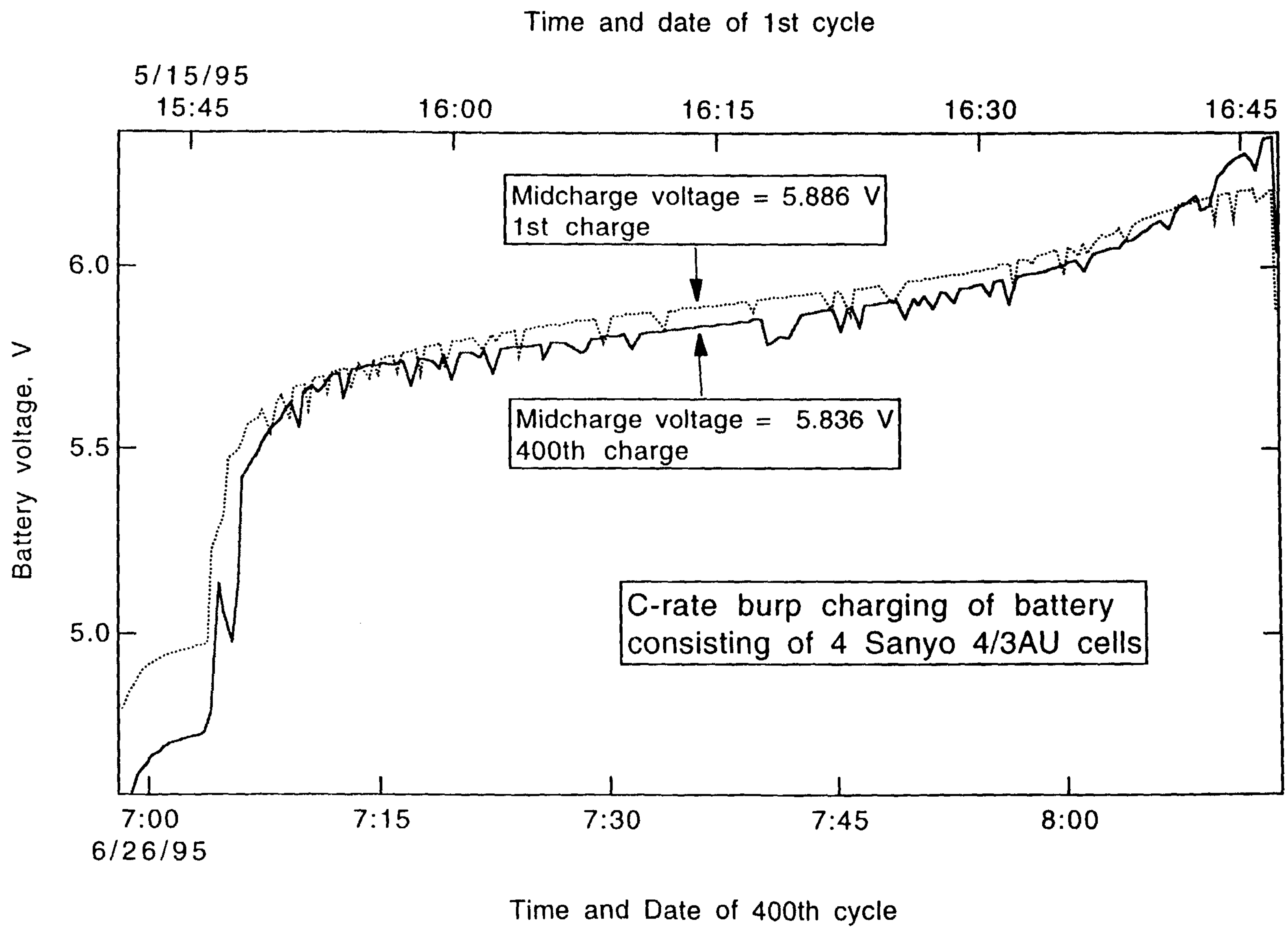

Time and date of 1st cycle
5/15/95
15:45
16:00
16:15
16:30
16:45
Midcharge voltage = 5.886 V
1st charge
Midcharge voltage = 5.836 V
400th charge
C-rate burp charging of battery
consisting of 4 Sanyo 4/3AU cells
Battery voltage, V
6.0
5.5
5.0
7:00
6/26/95
7:15
7:30
7:45
8:00
Time and Date of 400th cycle

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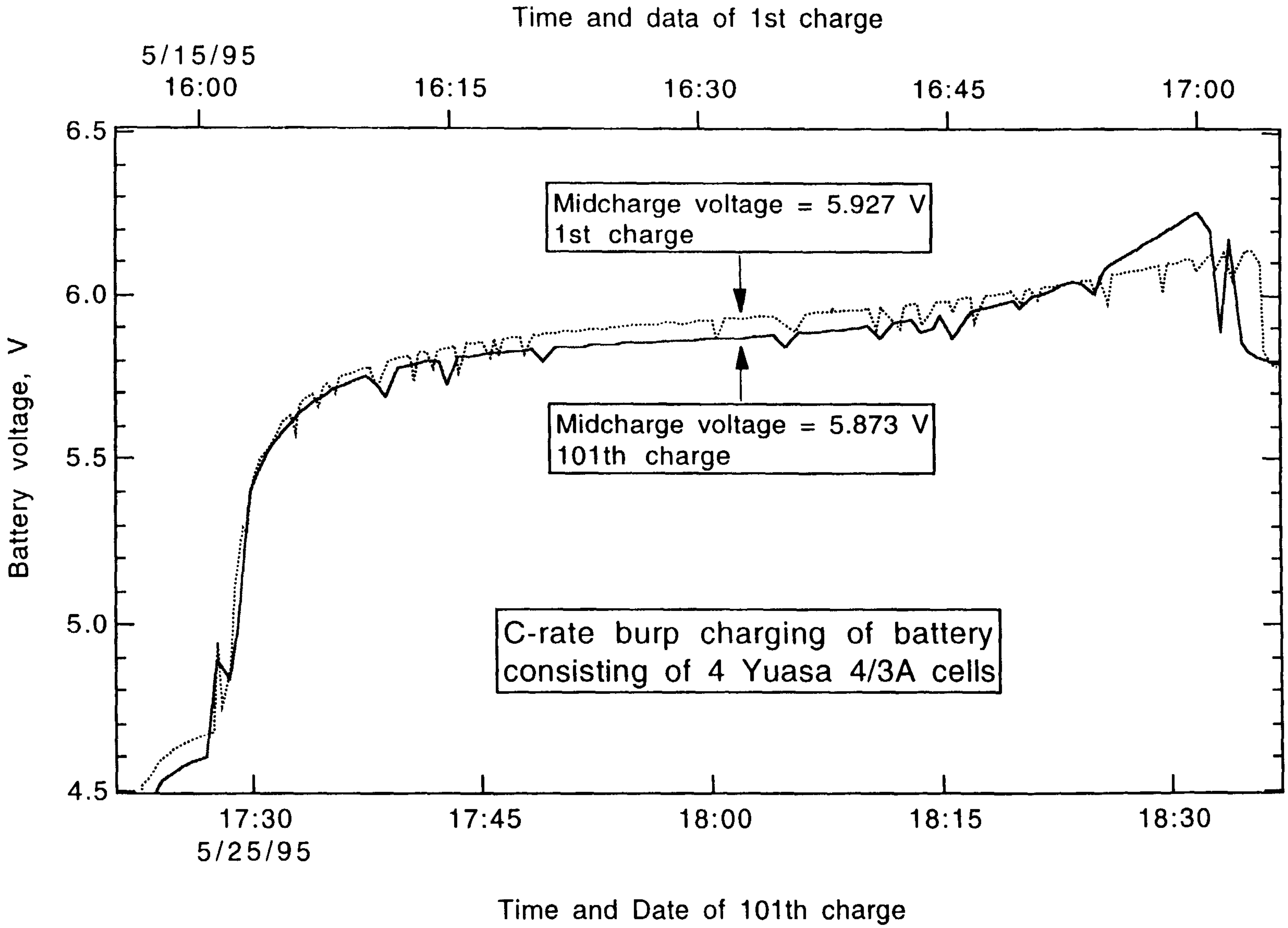
Do other NiMH cell designs exhibit similar behavior?

Performance dependent on charge method

- cycle life
- rise in cell temperature
- overvoltage
- break-in period
- etc.


Time and data of 1st charge
5/15/95
16:00
16:15
16:30
16:45
17:00
6.5
6.0
5.5
5.0
4.5
Battery voltage, V
Midcharge voltage = 5.927 V
1st charge
Midcharge voltage = 5.873 V
101th charge
C-rate burp charging of battery consisting of 4 Yuasa 4/3A cells
17:30
5/25/95
17:45
18:00
18:15
18:30
Time and Date of 101th charge

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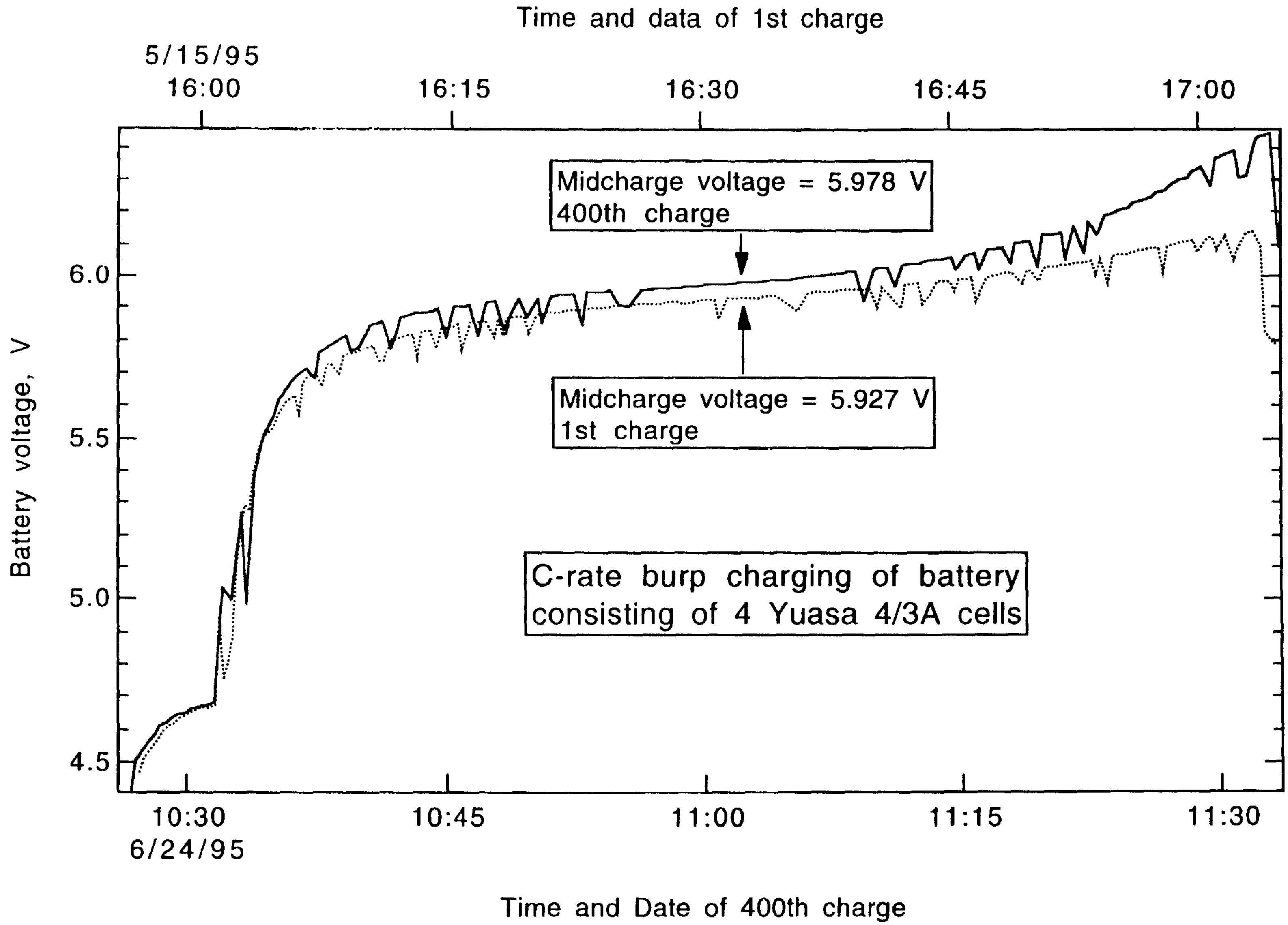
Time and data of 1st charge
5/15/95
16:00
16:15
16:30
16:45
17:00
Midcharge voltage = 5.978 V
400th charge
Midcharge voltage = 5.927 V
1st charge
C-rate burp charging of battery consisting of 4 Yuasa 4/3A cells
Battery voltage, V
6.0
5.5
5.0
4.5
10:30
6/24/95
10:45
11:00
11:15
11:30
Time and Date of 400th charge

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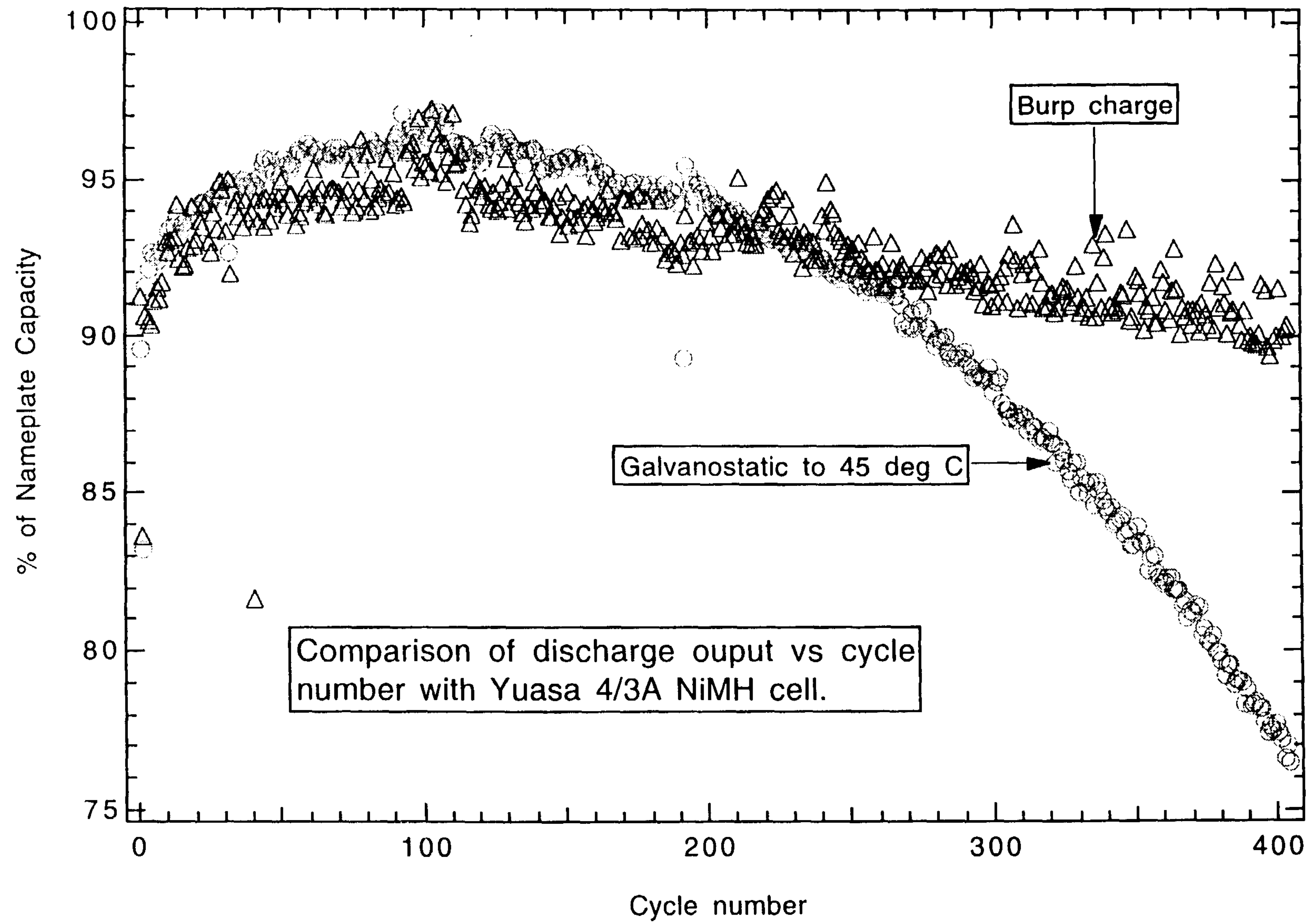
100
95
90
85
80
75
% of Nameplate Capacity
0
100
200
300
400
Cycle number
Burp charge
Galvanostatic to 45 deg C
Comparison of discharge ouput vs cycle number with Yuasa 4/3A NiMH cell.

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Conclusions

Addition of "smart" termination to simple galvanostatic charge *
- prolongs cycle life
- lengthens break-in period

Addition short relaxation periods to "smart" galvanostatic charge *
- lowers total Ah input without compromising discharge capacity
- shortens break-in period
- no effect on cycle life (to 400 cycles)

Adding very short discharge burps to the relaxation periods *
- increases total Ah input and output by same amount
- lengthens break-in period
- no effect on cycle life (to 400 cycles)

Burp charging improves cycle life with different NiMH cell designs

* Based on studies with 1 cell design

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On-going Work

- Continue cycling comparison of galvanostatic, pause, and burp charging

- Compare morphology changes of electrodes
  - particle size distribution
  - porosity

- Compare burp heat effects with other cell designs

- Develop thermal model of NiMH cell based on obtained properties
  - heat capacity
  - thermoneutral potential
  - $\partial E/\partial T$

Why does burping lower overvoltage?

Possible reasons;

- dislodges O_2 from cathode pores, preventing local current density rise
- increases or maintains electrode porosity, aiding ion transport
- results in less O_2 evolution, due to lower charge heat

SEM analysis to date of electrodes after 400 cycles is unsupportive

- particle size differences are small in negative electrode
- porosity differences not yet discernable in positive electrode

In-situ analysis of positive electrode with 7x magnification fibroscope reveals

- bubbling activity increases with SOC during charging
- differences between charge techniques are not discernable

On-going Work

- Compare galvanostatic, pulse, and burp charging with 50x magnification
  - place electrode coil from NiMH cell into a transparent KOH beaker
  - place a reference electrode (Hg/HgO) between the electrodes
  - expose a portion of positive electrode for viewing
  - control waveform with an automated waveform generator
  - mark occurrance of pulses and burps with audio signal
  - record video and audio of bubbling activity on positive during charge

First Application - EMU Helmet Interchangeable Portable (EHIP) Lights

- Battery (P/N SED39130223)
  - 15 Sanyo NiMH cells arranged 3P-5S
  - strings connected in parallel to power 6W lights for 7 hours
  - bottom glide latches allow EVA replaceability from helmet
  - Raychem polyswitches limit current to 1.5 A/cell
  - weighs 1.04 kg

- Charger (P/N QC-1001)
  - charges 4 batteries in <4 hours independently and simultaneously
  - "burp" charge control achieved by 4 ICS-1702 chips
  - uses shuttle 28 $\pm$ 4 Vdc input
  - strings connected in series (18V) during charging
  - thermistors in battery provide temperature input to charger
  - velcro mounted to mid-deck area
  - weighs 1.39 kg

- Charger has passed all certification tests

- New lights, battery, and charger first flight is STS-82 in Feb 97