

## HIGH SPECIFIC ENERGY, HIGH CAPACITY NICKEL-HYDROGEN CELL DESIGN

James R. Wheeler  
Eagle Picher Industries  
Joplin, Missouri 64801

### ABSTRACT

A 3.5 inch rabbit-ear-terminal nickel-hydrogen cell has been designed and tested to deliver high capacity at steady discharge rates up to and including a C rate. Its specific energy yield of 60.6 wh/kg is believed to be the highest yet achieved in a slurry-process nickel-hydrogen cell, and its 10°C capacity of 113.9 AH the highest capacity yet of any type in a 3.5 inch diameter size. The cell also demonstrated a pulse capability of 180 amps for 20 seconds. Specific cell parameters and performance are described. Also covered is an episode of capacity fading due to electrode swelling and its successful recovery by means of additional activation procedures.

### CELL DESCRIPTION

A development program was initiated with the objective of maximizing power and specific energy for 3.5 inch diameter nickel-hydrogen cells while still retaining the long-cycle life and ruggedness of the positive slurry electrode. Eagle-Picher designed cells to meet this objective as part of a joint project with a major aerospace company. We have now completed and tested a 100 ampere-hour cell design in two separator versions. One version has a single layer of Zircar (zirconia-fiber cloth) separator for each positive electrode (hereafter termed -3 cells), and the other version has a single asbestos separator (-5 cells), but they are otherwise identical and were made from the same lots of electrodes and other components.

The electrolyte quantity for single layer Zircar is just slightly larger than the single layer asbestos version, and this should ensure at least equal cycle life. At Eagle Picher, single-layer Zircar cells in an on-going life test have exceeded 20,000 cycles at a depth of discharge of 15%. End of discharge and charge voltages have thus far been stable.

A photograph of a sample cell (both versions are externally the same) and a table of weights and dimensions are provided by Figure 1 and Table 1. All of the cells were equipped with strain-gage pressure monitors.

The internal cell design is a dual stack with a back-to-back electrode configuration and continuous leads to rabbit-ear terminals. The rabbit-ear terminal is a feature which permits a shorter battery height and therefore a shorter thermal path when the cells are vertically mounted. Thus, the high specific energy can be further improved at the battery level by reducing the length of cell sleeve mountings and cell inter-connections. If the cells are mounted parallel to a base plate, the rabbit-ear terminals help there as well because the cells can be rotated to minimize the length of the interconnects.

The positive electrodes are slightly thicker and more porous than Eagle-Picher's standard high-bend-strength slurry plaque. They are approximately double the bend-strength of dry sinter, but only about 3/4 the strength of the standard slurry product. Bend strength may be considered a measure of the resistance of the electrode to plate swelling.

Four Zircar cells and three asbestos cells were built. The electrolyte concentration was set at about 39% in order to maximize the specific energy of the cell. It was hoped that this high concentration would not be so great as to cause the positive electrodes to swell, since it has proved compatible with the standard electrodes in the past. As we were to learn later, this was not the case.

A catalyzed wall wick is incorporated for improved thermal operation and gas management, making the cell suitable for either LEO or GEO applications. The final electrolyte levels for the two versions were about the same, with the single Zircar version holding, on average, only 1% more per cell than the single asbestos version.

The pressure vessel is Inconel 718. MEOP translates to a minimum burst safety factor of 2.5. The actual maximum pressure reached by the highest Zircar version cell under conditions of severe overcharge was 3% greater than the value for the asbestos.

## INITIAL CELL TESTING

Four Zircar-separator cells and three asbestos cells were built. After activation, the cells were tested to the customer's performance specification, which conservatively assumed a rated capacity of 90 AH. For the initial acceptance testing therefore, standard capacity charges were 9 amps for 16 hours. The discharge rate used was 68 amps. Performance data are summarized in tables 2 and 3. Average discharge voltage performance for each type of cell is shown by the curves in Figure 2. Mid-discharge values (45 minutes) are comparable to those achieved in shorter 3.5 inch cells, indicating that the internal bussing has an adequate cross-section. The voltage advantage of Zircar over asbestos is apparent, and is essentially the same for the single Zircar configuration as would be expected from a double Zircar design.

Testing also included a 180 amp pulse test (See Figure 2). The pulse was conducted after a 16 hour, 9 amp charge and 15 minutes of the 68 amp discharge. Pulse duration was 20 seconds. Minimum terminal voltages reached at the end of the pulse were 1.17 V for the Zircar version cells, and 1.13 V for the asbestos cells.

The Zircar version achieved 60.1 watt-hours per kilogram at 10°C to 1.0 V at a discharge rate of 68 amps (C/1.47 for a 100AH nominal rating). (Watt-hour values were not merely estimated on mid-point voltages, but were actually measured by the automated data collection software.) In the same test the asbestos version achieved 59.0 watt-hours per kilogram. Capacities would have been greater and discharge voltage higher at a more-normal C/2 rate. They would also likely have been higher had the cells been charged closer to a true C/10 rate, i.e. at 10 amps rather than 9.

Without the strain gages, the values would be 60.6 wh/kg and 59.4 wh/kg respectively. These are believed to be the highest energy densities yet achieved at the cell level for nickel-hydrogen cells with slurry-process positive electrodes. The performance exceeds other large cells recently reported, including some 83AH cells [1] and the 90AH HST cells [2]. The evolution of size and power of slurry-type cells at Eagle-Picher is shown in Figure 3. The progression in efficiency has paralleled a rather steady increase in cell size and increasing operating pressures over the last 10 years.

Capacity retention at 10°C was measured by charging the cells for 16 hours at 9.0 amps, and, after an open circuit stand of 72 hours, discharging at 68 amps to 1.0 V. The percentages of capacity retained, when compared to the standard 10°C test, were 84.6% for Zircar, and 85.8% for asbestos. These are in the expected range for nickel-precharged cells.

## SUBSEQUENT TESTING

After initial acceptance tests 6 of the 7 cells were shipped to the customer, with one asbestos cell being retained in cold storage at Eagle Picher. At the customer's facility the cells were subjected to characterization tests with a nominal rating of 100AH. The testing included discharges at 74.5 amps and 100 amps. Counting the initial acceptance and conditioning testing, 51 full-depth cycles had been performed on the cells when, within a few cycles of the end of this period, the cells declined in capacity from an initial value of about 114 AH to about 102 AH at 10°C. The cells were returned to Eagle Picher at this point, where the low capacity condition was confirmed. There was no evidence of a second plateau in the discharge curve.

A destructive physical analysis (DPA) was performed on one of the single Zircar cells. The results showed that the positive electrodes had expanded in thickness about 12% above their initial installed thickness. This condition is consistent with the literature [3] [4] indicating a correlation of positive electrode swelling with high electrolyte concentration. Analysis of the electrolyte in the cell components confirmed the high concentration at an average of 39.31%. It showed that the electrolyte distribution was uniform among the four quadrants of the stack, but that each separator had given up about a third of its electrolyte to its corresponding positive electrode. It was therefore decided to remove the fill-tube welds, open all of the cells, and reactivate them, this time fixing concentration at a lower value of 35%.

To replace the cell destroyed in the DPA, the cell with asbestos separator that had been stored (S/N 5-3) was added to the group. Although this cell was never shipped to the customer and did not see the additional cycles, it was opened and reactivated with the other five in order to achieve the same electrolyte concentration as the others.

Following reactivation the cells were rapid-cycled at 10°C using 10 amp charges for 16 hours and high rate (78 amp) discharges, followed by a resistor-let-down to less than 0.01 volts. A chart of rapid-cycle performance is shown in figure 4. The initial performance was disappointing (about 92 AH), but with continued cycling the capacity rose steadily. After 24 full-depth cycles the capacities of the Zircar cells were again above 100 AH. Note that the discharge rate of 78 amps

was greater than the 68 amps used in the initial acceptance tests, and the charge rate was also greater by 1 amp. It can be seen that the replacement asbestos cell (S/N 5-3) was initially higher than the others and remained fairly level in capacity until about cycle 12, whereupon it appeared to rejoin the other two asbestos cells in performance. This cell however developed a leak due to the reopening process and had to be repaired. In the process of repairing a damaged fill tube, a small piece of aluminum from a fixture fell into the cell. This may affect the future performance of this cell.

At cycle 16, due to small leaks in the activation plumbing on some of the cells, it was decided to reset the nickel precharge, which in effect meant adding a small amount of hydrogen. This had a positive effect on capacities. Following cycle 28, the cells were removed from the test fixtures and welded off. This involved another setting of nickel precharge similar to the last. Following pinch-off the cells were subjected to one additional 10°C rapid cycle, this time at the lower discharge rate of 74.5 amps. The capacity jumped about 5 AH after pinch-off. It is probable that this is due partly to the lower discharge rate (74.5 amps versus 78 amps) and possibly because capacities were somewhat hydrogen-limited prior to that time due to plumbing leakage. (Pinch-off involves some hydrogen addition). The cells were then subjected to an abbreviated acceptance test using 10 amp charges for 16 hours and 74.5 discharges, a lower discharge rate than for the 28 rapid cycles just completed.

Performance data for the 25 rapid cycles and the final mini-ATP are summarized in Table 4. It is clear that much of the original high-capacity performance has been restored. Charge retention at 10°C was also confirmed at 86% to 88%.

## PLANS

The cells are being returned to the customer and will be cycled to confirm the latest results. Vibration testing is also planned. Life testing is then planned for up to 15 years and will be to a GEO regime (real-time eclipse cycling to an 80% depth of discharge with shortened sun-times).

## CONCLUSIONS

By using single-layer separator and slightly thicker, slightly more-porous positive electrodes, specific energies of 3.5 inch nickel-hydrogen cells can exceed 60 watt-hours per kilogram and provide good, all-around performance, even at discharge rates of C/1.28. The use of single layer Zircar separator appears promising, but requires further validation through life-testing.

The testing demonstrates that a 3.5 inch-diameter cell can be made to yield capacities above 110 AH. This is important to spacecraft designers who are requiring larger-capacity batteries for many applications. If these higher-power requirements can be satisfied by a 3.5 inch design, thermal characteristics will be better than with a larger-diameter cell.

It was also demonstrated that a swollen-positive-electrode condition can be corrected through application of activation techniques. The long-term efficacy of this requires confirmation through cycle-testing. Such testing is planned for these cells.

## ACKNOWLEDGMENT

The professional assistance of Paul Daugherty in collecting and assessing data for this paper, and of David Cooke for cell construction and testing, are gratefully acknowledged.

1. T. M. Yang, C. W. Koehler, A. Z. Applewhite, "An 83AH Nickel Hydrogen Battery for Geosynchronous Satellite Applications," 24th IECEC Washington, D.C., Vol. 3, p. 1375
2. Jeffrey C. Brewer, Thomas H. Whitt, J. Roy Lanier, Jr., "Hubble Space Telescope Nickel-Hydrogen Batteries Testing and Flight Performance," 26th IECEC, p. 257, Vol 3
3. J. J. Smithwick, and S. W. Hall, "Validation Test of Advanced Technology for IPV Nickel-Hydrogen Flight Cells - Update," 27th Intersociety Energy Conversion Engineering Conference Proceedings, IECEC '92, San Diego, CA, 1992, Vol. 1, p.1.215
4. H. S. Lim, and S. A. Verzwyvelt, "KOH Concentration Effect on Cycle Life of Nickel Hydrogen Cells, III. Cycle Life Test," Journal of Power Sources, Vol. 22, Mar-Apr 1988, pp. 213-220

CELL DESCRIPTION	TYPE	SEPARATOR
	Single Zircar	Single Asbestos
Weight (grams)*	2279	2236
Cell Length (in) Dome to Dome	10.97	10.97
Cell Length (in) Overall	11.56	11.56
* strain gage weight subtracted (17g)		

TABLE 1

CAPACITIES TO 1.0V (AH) AT 68 AMPS	SEPARATOR TYPE	
	Zircar	Asbestos
30°C	81.3	82.9
20°C	99.1	99.7
10°C	113.9	111.3
0°C	117.6	113.1
-10°C	115.6	108.2

TABLE 2

PERFORMANCE DATA	TYPE SEPARATOR	
	Zircar	Asbestos
<b>180 Amp Pulse, Minimum Voltages</b>	1.173	1.130
<b>WH/Kg</b>	60.1	59.0
<b>WH/Kg*</b>	60.6	59.4

\* Strain gage weight subtracted

TABLE 3

Capacities to 1.0V (AH) at 74.5 Amps (Post-Reactivation)	SEPARATOR TYPE	
	Zircar	Asbestos
30°C	77.8	81.0
10°C	107.6	101.8
0°C	117.8	109.1

TABLE 4



FIGURE 1

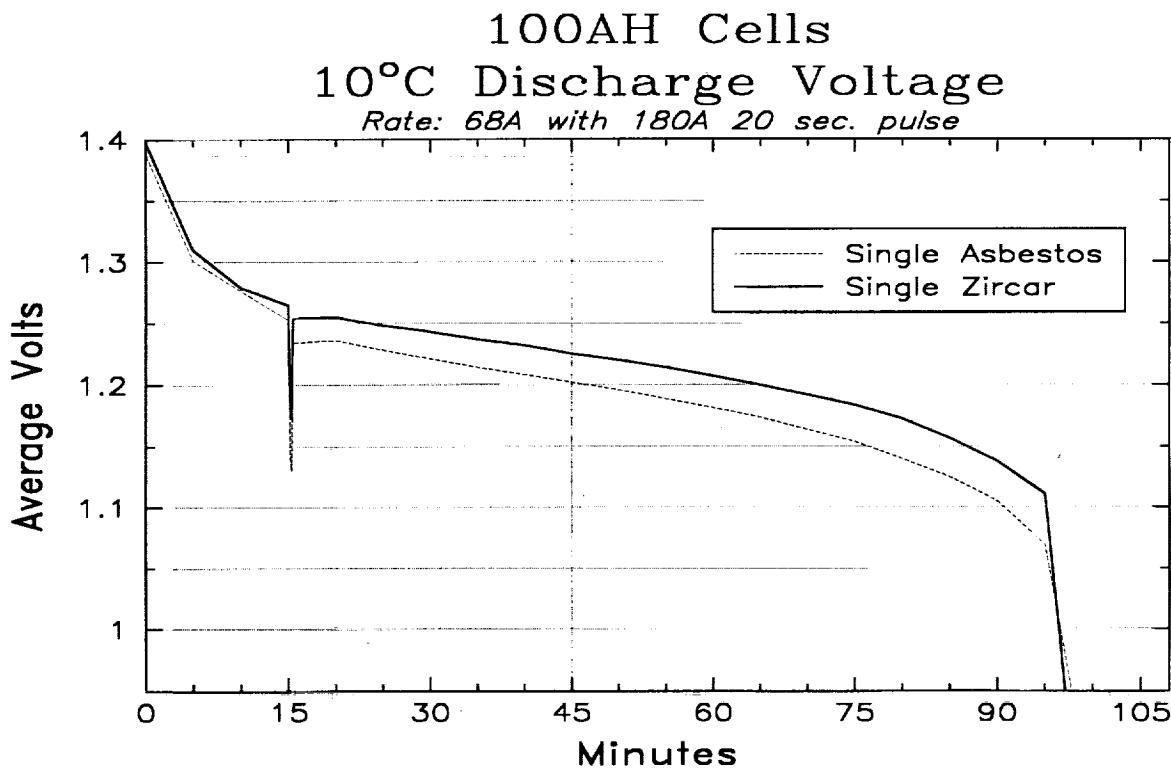


FIGURE 2

**SPECIFIC ENERGY OF EP CELLS  
WITH SLURRY SINTER POSITIVE PLATES**

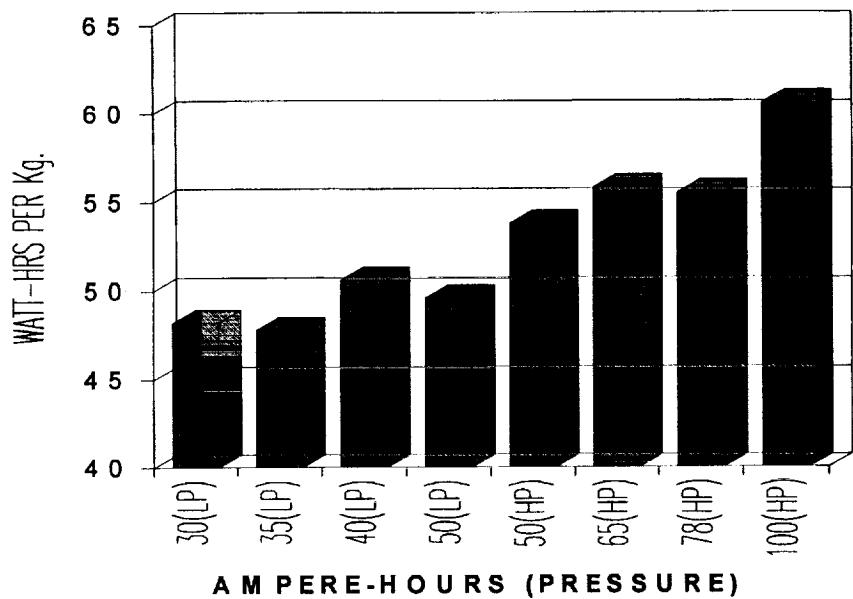


FIGURE 3

**100AH CYCLES AFTER REACTIVATION**

CYCLES AT 10°C WITH 16 HR CHARGES, 78A DISCHARGES

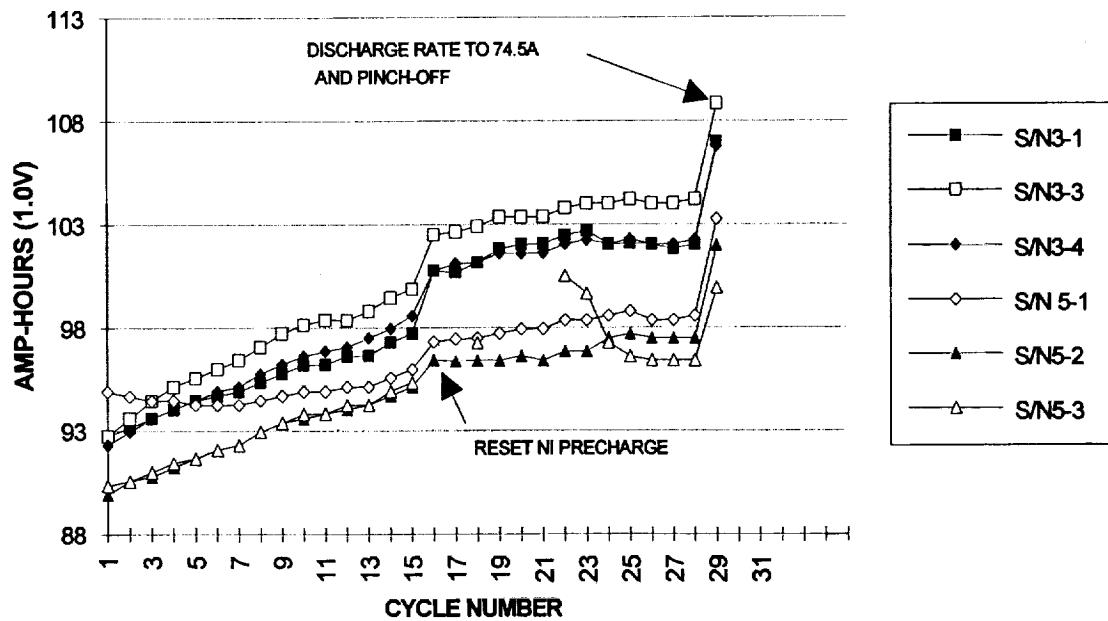


FIGURE 4

