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26% Potassium Hydroxide Electrolyte for Long-Term Nickel–Hydrogen Geosynchronous Missions

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Nickel–hydrogen battery cells using 26% potassium hydroxide (KOH) electrolyte instead of the conventional 31% KOH have previously demonstrated longer life for low Earth orbit missions. However, the life increase has also been determined to be valid for high depth of discharge missions using nickel–hydrogen cells of similar design for 80% depth of discharge for 15 years or more in geosynchronous orbit. To use 26% KOH for geosynchronous applications, it was necessary to completely characterize the cells. Testing included initial capacity, storage, charge efficiency vs charge rate and temperature, cold temperature tolerance to −16°C, trickle charge efficiency, and self-discharge characterization. Results showed that the electrical performance differences between 31–26% KOH are minimal, and that the 26% KOH cells can be used to replace 31% KOH cells on geosynchronous spacecraft without change to either the battery or spacecraft configuration. In addition, data from long-term real-time synchronous testing have been reviewed, and an additional four cells with 26% KOH electrolyte have been placed in an accelerated synchronous test. These cells are capable of 80% depth of discharge for 15 years in synchronous orbit, including support for the additional demands of electric ion propulsion.

Introduction

THE use of 26% potassium hydroxide (KOH) electrolyte has been proposed for many years. Despite the obvious benefits,[1–6] use of 26% KOH electrolyte has been impeded by the lack of characterization data demonstrating its effectiveness for synchronous orbit use. This article describes the test results for six 160 A-h nickel–hydrogen cells activated with 26% KOH electrolyte. The results are then compared with similar data from cells activated with 31% KOH electrolyte. Cell performance characteristics measured are capacity, voltage on charge and on discharge, self-discharge, charge efficiency, low-temperature tolerance, transfer orbit performance, and storage.

Test Articles

The six-cell test program used single-stack, 160 A-h (576,000 C) cells, 11.43 cm (4.5 in.) diam. The cell[7] construction (Fig. 1) was back-to-back,[8] with a single layer of Zircar separator rather than the recirculating design with two layers of separator described in the reference. The positive electrodes are electrochemically impregnated using the alcohol[9] process. The 26% KOH was vacuum impregnated into the cells with the positive electrodes at approximately 60% state of charge.

Test Program

All six of the cells were activated with 26% KOH, and were activated and acceptance tested simultaneously with a lot of 30 flight cells containing 31% KOH. Two of the 26% KOH cells were centrifuged at 8 *g* for 30 min during the activation process to remove excess electrolyte. All of the cells received nickel electrode precharge[10] to prevent capacity losses during storage. In the figures that follow, where the plural cells are used, the plotted data represent averages; where the singular cell is used, the plotted data are for that single cell.

After activation, all of the cells were acceptance tested and characterized. Four of the cells, including both of the centrifuged cells, were subsequently subjected to characterization testing, while the other two cells were put into a storage test.

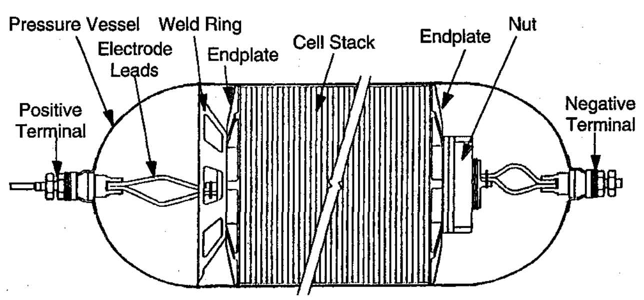
Test Results

Capacity

Production 160 A-h (576,000 C) nickel–hydrogen cells with 31% KOH range from 175 to 205 A-h (630,000–738,000 C), averaging 190 A-h (684,000 C) in capacity at 10°C. These values were obtained from a standard acceptance test (16-h charge at charge rate C/10, discharge at discharge rate C/2 to 1 V), prior to setting nickel electrode precharge. The six 26% KOH cells had capacities of 178–192 A-h (640,800–691,200 C), averaging 186 A-h (669,600 C).

Voltage Performance

Charge voltages for 26% KOH cells at C/20 (Fig. 2) are little affected by temperature except in the overcharge region (near full charge) where a temperature coefficient of −0.0028 V/°C was calculated. This coefficient is similar to that found for 31% KOH cells. Over most of the charge region the 26%



Stack Sequence: Neg Sep Pos Pos Sep Neg Gas
Neg: Negative Electrode- Teflon/Platinum/Etched Nickel Screen
Sep: Separator- Zirconia/Yttria Cloth
Pos: Positive Electrode- Nickel Hydroxide Based
Gas: Gas Distribution Screen- Polypropylene Screen

Fig. 1 Nickel–hydrogen cell.

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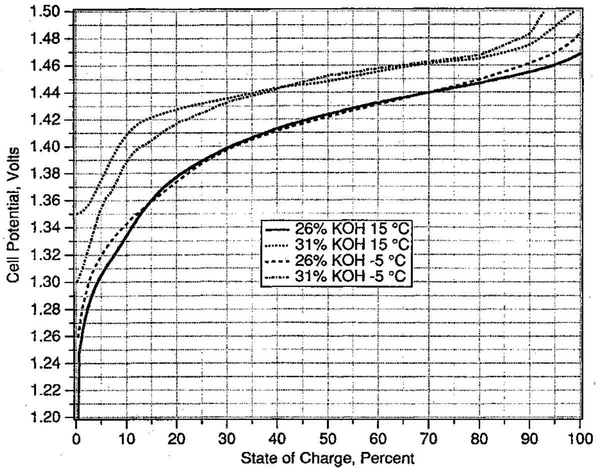

Fig. 2 Charge of 160-A-h cells at C/20 for 40 h.

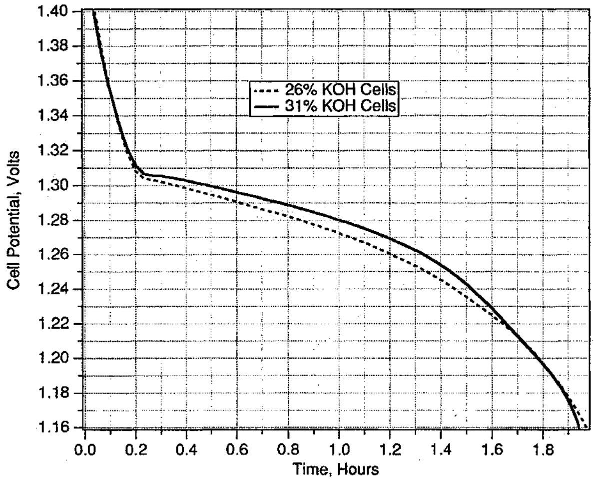

Fig. 3 Discharge of 160-A-h cells at C/2 and 10°C.

KOH cells were 20–40 mV lower in potential than 31% KOH cells. However, these slightly lower voltages seem peculiar to this test, and have not been observed in other 26% KOH test cells, or in flight cells activated and acceptance tested with 26% KOH.

Voltages at a typical geosynchronous discharge rate of 0.7 C for 26% KOH cells (Fig. 3) were found to be 10–40 mV lower than for 31% cells. The two types of cells generate about the same quantity of heat during discharge.

Charge Efficiency

Charge efficiency data for relatively new cells at C/20 rates was compared for temperatures between 5–32°C (Figs. 4–7). The charge efficiencies at 5 and 15°C were greater for the 26% cells than for the 31% cells. However, since efficiencies at those temperatures are close to 100%, the differences are not critical, but favor the use of 26% KOH cells. At 25°C, efficiencies are about the same for both cases; efficiencies at 32°C are lower for 26% KOH than for 31% KOH cells. At temperatures greater than 15°C, the effect of cell age and use (model 1 is for a nearly new cell and model 2 for a cycled cell) are large and not predictable with our current level of knowledge. The effects of age are not significant at lower temperatures and at higher charge rates, such as C/10. Data at −5°C are also included as Fig. 6, but no comparison is shown to 31% KOH because of lack of data at that temperature. Heat dissipation and charge efficiencies were calculated from voltages, current, pressure, and temperature.

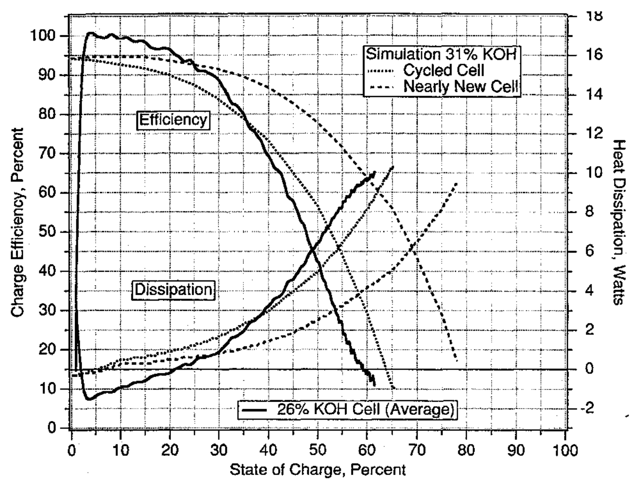

Fig. 4 Charge of 160-A-h cells at C/20 and 32°C.

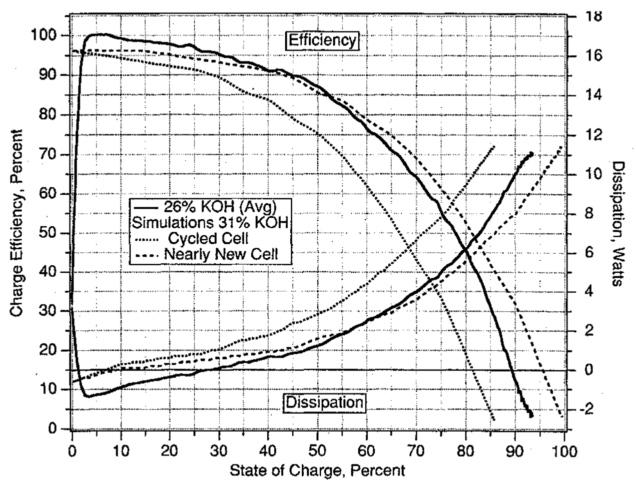

Fig. 5 Charge of 160-A-h cells at C/20 and 25°C.

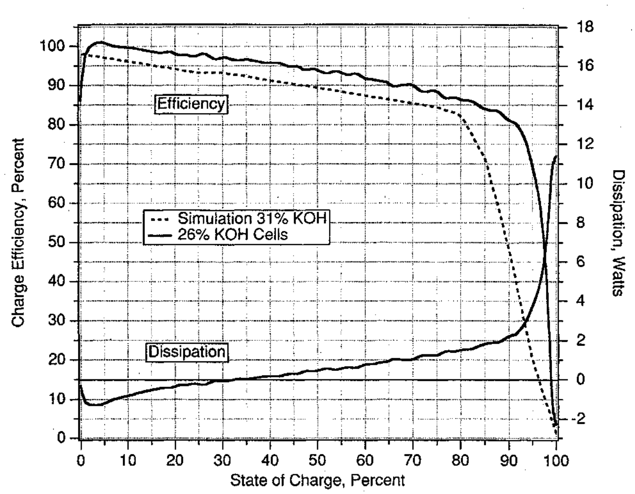

Fig. 6 Charge of 160-A-h cells at C/20 and 15°C.

Self-Discharge

A charged-stand test at 30°C was carried out (Fig. 8). Comparisons in self-discharge are most meaningful after 24 h has elapsed. It appears that the 26% KOH cells have approximately a 20% higher self-discharge rate; however, both rates are very low. If self-discharge rates at colder spacecraft temperatures, which would be much lower, follow the same trend, then a slightly higher trickle charge rate may be desirable.

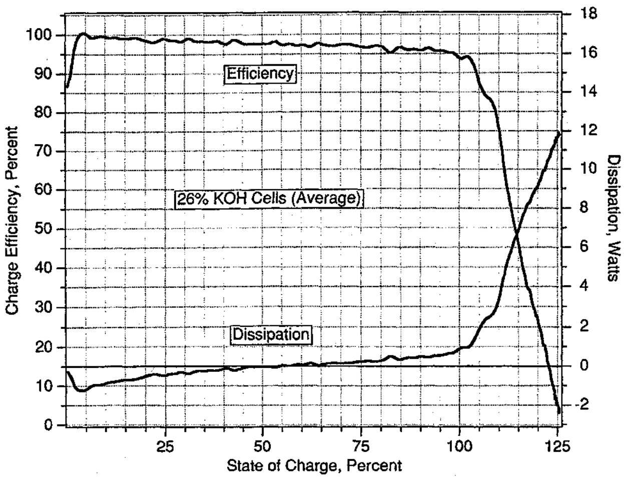

Fig. 7 Charge of 160-A-h cells at C/20 and −5°.

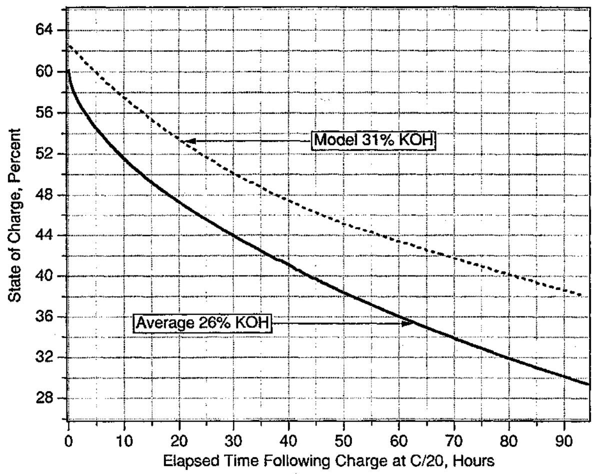

Fig. 8 Charged stand test of 160-A-h cells at 31°C.

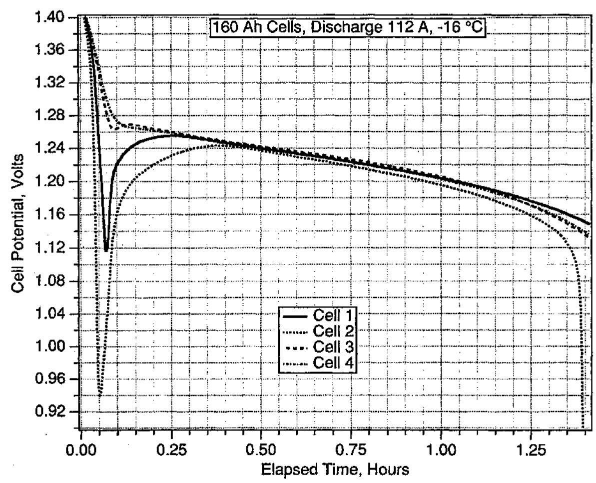

Fig. 9 Low-temperature tolerance test, 26% KOH.

Low-Temperature Tolerance

A series of five capacity tests was carried out at various low temperatures at a charge rate of C/10 and a discharge rate of 0.7 C. In prior testing, it has been established that freezing problems from low temperatures will occur during discharge rather than charge because the electrolyte at the negative electrode becomes rapidly diluted with water produced at that electrode during discharge. For 31% KOH cells, the threshold for freezing during discharge is approximately −16°C. The data for four different cells is reported in Fig. 9. At −16°C large dips in discharge voltage, characteristic of freezing, were observed. There was no indication of freezing for these cells at −10°C.

The lower limit recommended for flight 31% KOH cells is −10°C. At this temperature, as reported earlier, our tests show that the 26% cells function satisfactorily. There were no indications of freezing during charge as low as −19.5°C.

Transfer Orbit Tests

The critical issue is charge efficiency under the conditions of transfer orbit, which includes an average charge rate of approximately C/40 (pulsating rectified sine wave), and a temperature of 15–25°C. The results, shown in Fig. 10, indicate that 26% KOH cells and 31% KOH cells behave similarly. Charge efficiency was calculated from the rate of rise of pressure and the absolute temperature. It is assumed that, at 100% charge efficiency, the only electrochemical reaction is the generation of hydrogen. Greater than 100% charge efficiency is a result of the use of pressure differences for the calculations that increase the effect of errors in pressure measurement.

Storage

After storage at room temperature, 26% KOH cells tested satisfactorily in an acceptance test at 10°C. Capacities were 169.8 A-h (611,280 C) and 169.6 A-h (610,560 C) before storage, and 177.8 A-h (640,080 C) and 175 A-h (630,000 C) after storage for seven months. The increase in capacity was probably because of a loss of nickel precharge from slight corrosion

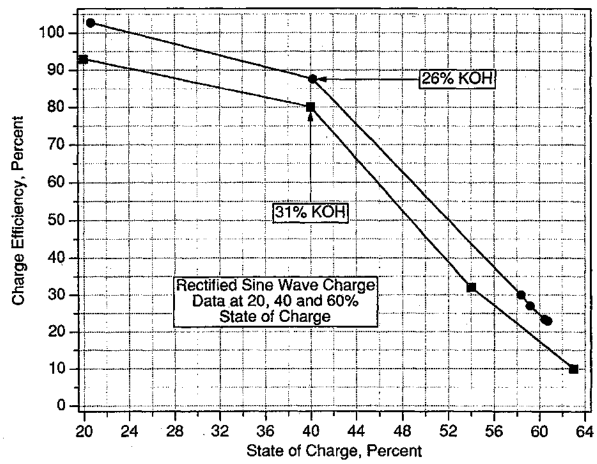

Fig. 10 Transfer orbit test of 160-A-h cells, 20°C, average charge 11.8 A, load 7.8 A.

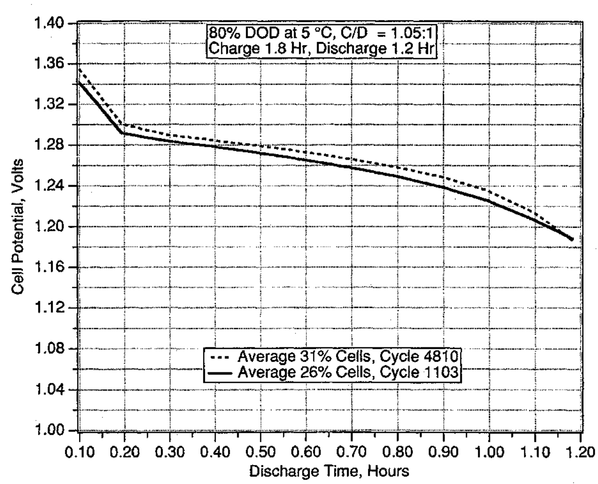

Fig. 11 Cycling test, discharge 107 A, 160-A-h cells.

of the nickel sinter in the positive electrodes. The capacity left after a 72-h charged stand test before storage was 117.2 A-h (421,920 C) and 116.9 A-h (420,840 C). After storage the capacities were 118.9 A-h (428,040 C) and 118.5 A-h (426,600 C).

Cycling Test

The four test cells have been incorporated into a 3-h cycle test at 80% depth of discharge. Figure 11 shows a comparison of the discharge voltages of the 31 and 26% KOH cells. The 26% KOH cells have undergone 1100 cycles, and the 31% KOH cells have undergone 1700 cycles at 70% DOD, followed by 4800 cycles at 80% DOD. The cell voltages have not changed significantly during this test.

Conclusions

The capacity of 26% KOH cells, both before and after setting precharge, meets the requirements for flight cells. Cell voltages during both charge and discharge were similar to those of 31% KOH cells. As long as temperatures during charge do not significantly exceed 15°C at C/20 or 20°C at C/10, the difference in charge efficiency between the two types of cells is small. The observed difference in self-discharge rate between 26–31% KOH cells is of the same order as differences between different lots of 31% cells and is not significant. At the minimum specified temperature for operation, −10°C, cells with either concentration of KOH function properly. Under transfer orbit conditions, 26 and 31% KOH cells behave similarly. After seven months, 26% KOH cells retained capacity and did not change in self-discharge rates. While there are differences between the electrical performance of 31 and 26% KOH electrolyte cells, all of the differences are minimal, and it is our recommendation that 26% KOH be used for long-term geosynchronous missions to take advantage of the expected longer life.

References

[1]Lim, H. S., and Smithrick, J. J., "Advantage of 26% KOH Electrolyte over Conventional 31% KOH Electrolyte for Ni/H2 Cells," *Proceedings of the 28th Intersociety Energy Conversion Engineering Conference*, Vol. 1, 1993, pp. 151–156.

[2]Lim, H. S., and Verzwyvelt, S. A., "KOH Concentration Effect on the Cycle Life of Nickel-Hydrogen Cells. IV. Results of Failure Analysis," *Journal of Power Sources*, Vol. 29, 1990, p. 503.

[3]Smithrick, J. J., and Hall, S. W., "Effect of KOH Concentration on LEO Cycle Life of IPV Nickel-Hydrogen Flight Battery Cells," *Proceedings of the 25th Intersociety Energy Conversion Engineering Conference*, Vol. 3, Aug. 1990, pp. 16–21.

[4]Smithrick, J. J., and Hall, S. W., "Effect of KOH Concentration on LEO Cycle Life of IPV Nickel-Hydrogen Flight Cells—An Update," *Proceedings of the 26th Intersociety Energy Conversion Engineering Conference*, Vol. 3, Aug. 1991, p. 276.

[5]Lim, H. S., and Verzwyvelt, S. A., "KOH Concentration Effect on the Cycle Life of Nickel-Hydrogen Cells. III. Cycle Life Test," *Journal of Power Sources*, Vol. 22, 1988, p. 213.

[6]Lim, H. S., Zelter, G. R., Smithrick, J. J., and Hall, S. W., "Destructive Physical Analysis Results of Ni/H2 Cells Cycled in LEO Regime (II)," *Journal of Power Sources*, Vol. 51, 1994, p. 445.

[7]Rogers, H. H., Krause, S. J., and Levy, E., Jr., "Design of Long Life Nickel Hydrogen Cells," *Proceedings of the 28th Power Sources Symposium*, Electrochemical Society, Princeton, NJ, 1978, pp. 142–144.

[8]Dunlop, J. D., Rao, G. M., and Yi, T. Y., "NASA Handbook for Nickel-Hydrogen Batteries," NASA Reference Publ. 1314, Sept. 1993, pp. 1–15, 1–16.

[9]Pickett, D. F., Rogers, H. H., Tinker, L. A., Bleser, C., Hill, J. M., and Meador, J., "Establishment of Parameters for Production of Long Life Nickel Oxide Electrodes for Nickel-Hydrogen Cells," *Proceedings of the 15th Intersociety Energy Conversion Engineering Conference*, Vol. 3, AIAA, New York, 1980, pp. 1918–1924.

[10]Stadnick, S. J., and Rogers, H. H., U.S. Patent 4,683,178, July 28, 1987.