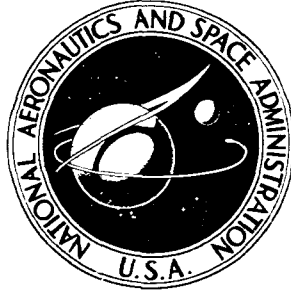


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MEMORANDUM**



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**NEW SEPARATORS FOR NICKEL-ZINC BATTERIES**

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16. Abstract Flexible separators consisting of a substrate coated with a mixture of a polymer and organic and inorganic additives were cycle tested in nickel-zinc cells. By substituting a rubber-based resin for polyphenylene oxide (PPO) in the standard inorganic-organic separator, major improvements in both cell life and flexibility can be made. Substituting newsprint for asbestos as the substrate shows promise for use on the zinc electrode and reduces separator cost. The importance of ample electrolyte in the cells is noted. Cycle lives and the characteristics of these flexible, low-cost separators are compared with those of a standard microporous polypropylene separator.			
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# NEW SEPARATORS FOR NICKEL-ZINC BATTERIES

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## SUMMARY

Because of its energy density, the nickel-zinc (Ni/Zn) alkaline secondary battery has potential for replacing the lead-acid battery in a number of terrestrial applications. However, cycle life of present Ni/Zn batteries must be improved. The separator is recognized as a major element in achieving this goal.

The NASA inorganic-organic (I/O) separator developed for silver-zinc (Ag/Zn) cells was evaluated in the Ni/Zn system. These separators consist of an asbestos substrate coated with polymer-containing organic and inorganic additives. They appear to operate as microporous separators. Nickel-zinc cells with the original I/O separator had cycle lives exceeding published cycle life data by a factor of 2. At 50-percent depth of discharge, three cycles per day, these cells achieved an average of 400 cycles. Insufficient electrolyte probably resulted in premature failure.

Because of the brittle character of the I/O separator, a more flexible separator was needed to eliminate separator cracking resulting from handling. Flexibility was attained by reformulating the original I/O coating. An even more flexible separator was developed from a thermoplastic rubber containing plasticizer and fillers coated onto a substrate. In laboratory-built cells, these separators achieved about 800 cycles.

Cycle test results and the costs of these improved separators compare well with results from a more-expensive, commercial, microporous polypropylene film. This microporous separator has shown cycle lives ranging from 300 cycles in electrolyte-starved cells to greater than 1150 cycles in electrolyte-flooded cells.

The principal failure mode of Ni-Zn cells with separators described herein has been warping of the nickel electrode and its eventual contact with the zinc electrode. Insufficient electrolyte and inadequate absorber material on the nickel electrode probably led to this mode of failure. Failures from the expected zinc dendrite or zinc nodule shorting were infrequent.

## INTRODUCTION

Because of its energy density the nickel-zinc (Ni/Zn) secondary alkaline battery has potential for replacing the lead-acid battery in a number of terrestrial applications such as electric vehicles. However, extending cycle life beyond the published life expectancy of 150 cycles (ref. 1) of moderate use and reducing the cost of cell components are necessary before the Ni/Zn system can compete effectively with established lead-acid-battery technology.

Recognizing that separators are a key to extending zinc battery life, separator development for the Ni/Zn battery at the NASA Lewis Research Center began with cell test evaluation of the inorganic-organic separator used in the Ag/Zn battery. The forerunner of the inorganic-organic separator was originally developed and patented by Astropower Corporation (ref. 2). NASA supported the testing and evaluation of the separator in Ag/Zn cells and later obtained a license to make and use the separator in alkaline batteries for government applications. The preparation, physical properties, and other characteristics have been described in detail elsewhere (refs. 3 and 4). Briefly, the Astropower separator is an envelope constructed from 0.0254-centimeter (10-mil), fuel-cell-grade asbestos impregnated with 2-weight-percent polyphenylene oxide (PPO) and manually dip-coated twice on the outside with a slurry. The coated separator dry thickness is ~0.038 centimeter (15 mils). The slurry consists of a PPO-chloroform solution containing an organic additive (a polymeric polyester) and inorganic fillers (pigmentary potassium titanate and calcia-doped zirconia).

NASA Lewis has since modified the Astropower separator, making it more flexible, less expensive, and equivalent in cell performance. In addition, coating the asbestos by using continuous-production factory equipment has been demonstrated. The Lewis-produced separator materials embodying any or all of these changes have been termed I/O (inorganic-organic) separators. The I/O separator bags are made by glueing together two pieces (coated side out) with epoxy cement. The I/O separators reveal a microporous structure when examined with a scanning electron microscope (SEM).

The Ni/Zn cell was tested with a commercial microporous polypropylene membrane as well as with the improved, low-cost, flexible I/O separators specifically developed for the Ni/Zn system. The Ni/Zn cells, constructed in the laboratory and incorporating these experimental separators, exhibited cycle lives that exceeded published cycle-life data by factors of two to three (refs. 1 and 5). Cells described in reference 1 are commercial products. Cells described in reference 5 represent a contract development effort. This report presents cycle-life data for the Astropower and Astropower-formula I/O separators, the commercial microporous polypropylene film, and some improved flexible I/O separators, as tested in laboratory-built cells. This was an initial evaluation of these separators in the Ni/Zn system and also involved the influence of cell operation under electrolyte-starved or -flooded conditions. The failure mode of these cells

is described. The compositions of the improved, flexible, I/O coatings applied to the asbestos substrate are discussed. Separator costs for the asbestos substrate and low-cost substrates, such as newsprint, are compared.

## DETAILS OF CELL TESTS

The results of cell tests reported herein must be qualified. Most of the data for each separator material are based on a single set of three cells that were constructed in the laboratory according to laboratory methods. Some coating materials were produced and applied to the substrates by using laboratory equipment. These materials are so identified in the text. Cells were constructed from a commercial, sintered nickel electrode and a zinc electrode designed by NASA originally for Ag/Zn cells. With this zinc electrode, the ratio of negative to positive plate capacity was estimated at 3 or 4.

The cells had a capacity of 5.5 ampere-hours based on the nickel electrodes used. Charge currents were adjusted so that the cells normally received about a 5-percent overcharge based on their actual capacity.

The cycle regime consisted of three cycles per day at 50-percent depth of discharge. Each cycle was composed of 6 hours of charge and 1.9 hours of discharge with an open-circuit stand of approximately 20 minutes each day.

When cell performance reached a point where the voltage at the end of the discharge period dropped to less than 1 volt, the cells were removed from the cycling equipment for reconditioning. The reconditioning consisted of a complete discharge and then measurement of the remaining capacity by several formation cycles at a charge current of 0.2 ampere to 6-ampere-hour capacity (~10-percent overcharge) and a discharge current of 1 ampere down to 1 volt. The remaining capacity was determined from the ampere-hour output divided by 5.5 ampere-hours. To check for shorts, cells were discharge completely and then charged to 1 ampere-hour at 0.2 ampere. The cells were placed on open circuit, and the cell voltage was monitored for 3 to 7 days. Cells (not shorted) were then charged at 0.2 ampere to 7.2 to 7.5 ampere-hours in an attempt to restore some of the negative reserve. The charged cells were then returned to the cycling equipment.

Details of cell construction are given in the tables, which present cell test results.

## EXPERIMENTAL RESULTS AND DISCUSSION

Initial separator tests in Ni/Zn cells were conducted in cells fabricated according to Ag/Zn cell construction techniques. As the test results show, the separator testing also involved learning electrolyte and interseparator (absorber) requirements for the nickel electrode. The initial operation of some Ni/Zn cells in an electrolyte-starved condition

appears to be a principal cause of their poor performance and premature failure as compared with cells that contained ample electrolyte and a more hydrophilic absorber material on the nickel electrodes.

### Celgard in Nickel-Zinc Batteries

Celgard<sup>1</sup> is a 0.00254-centimeter (1-mil) thick microporous polypropylene (PP) film that has a porosity of 38 percent and a pore density of  $1 \times 10^{10}$  pores per square centimeter. The oblong pore size estimated from SEM photographs is 400 Å by 4000 Å. The grade used for these cell tests was Celgard 2400W, which contains a wetting agent. This material provided an excellent opportunity to evaluate a truly microporous separator in combination with several absorber materials in the Ni/Zn battery application. The data in table I represent one set of three cells containing nonwoven, polypropylene, heat-sealed bags on both the negative and positive electrodes and three wraps of Celgard on the negative electrode. These cells were filled with 45-wt % KOH instead of 35-wt % KOH and were operated for 120 cycles in an electrolyte-starved condition before being flooded to improve performance.

The other set contained fuel-cell-grade asbestos (impregnated with 2-percent polyphenylene oxide (PPO)) bags on both the positive and negative electrodes. The negative electrode had four wraps of Celgard. The asbestos was used for two reasons: (1) to provide an absorber capable of keeping both the nickel and zinc electrodes wet and (2) because the asbestos appeared to provide a better margin of insulation against the effects of nickel electrode warping. The asbestos bags were closed on the sides and bottom by a polyethylene foam tape containing an acrylic adhesive on both sides. The edges were then heat sealed to ensure zinc oxide (ZnO) containment. These cells contained 35-wt % KOH.

From table I, it can be seen that the set with the PP absorber material began to lose capacity after about 300 cycles. The failure of these cells was due to the warping and blistering of the nickel electrode and the resultant contact with the zinc electrode. No zinc dendrites were found. The zinc electrodes were in surprisingly good condition for 300 cycles of operation; that is, there was no shape change. This would indicate uniform current density.

The other set of cells containing the asbestos absorber had completed 1130 cycles by July 1976, with no failures and no loss of capacity since the start of testing. These cells were reconditioned after 1000 cycles. They still retained 64, 73, and 81 percent, respectively, of their original capacities. The charge currents on these cells were initially set to provide overcharges of 0, 5, and 10 percent, respectively, and have been

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<sup>1</sup>Celgard is a product of Celanese Plastics, Greer, South Carolina.

maintained that way during the course of the test. The range of capacities remaining probably reflects the extent to which the negative reserve has been used up.

### Astropower and Inorganic-Organic Separators in Nickel-Zinc Batteries

Nickel-zinc cells were constructed and cycle tested that contained both the Astropower hand-dipped bags and the I/O separator with the Astropower formula prepared on factory equipment. These cells had a capacity of 5.5 ampere-hours. Details of construction and cell test results appear in table II. Major differences existing in the tests were the following:

(1) The cell designated "Astropower" had a nonwoven, 0.023-centimeter (9-mil) PP bag heat sealed around the positive electrode and an Astropower hand-dipped bag on the negative electrode. The cell contained 35-wt % KOH and was operated in an electrolyte-starved condition.

(2) The cell designated "Astrocontrol" contained Astropower hand-dipped bags on both the negative and positive electrodes and was operated in an electrolyte-flooded condition with 35-wt % KOH.

(3) The cells designated I/O 6D2174-1, 2, 3 had factory-coated separator bags with epoxy edge seals on the negative electrodes and 0.023-centimeter (9-mil) PP, nonwoven, heat-sealed bags on the positive electrodes. They were operated for about 120 cycles in an electrolyte-starved condition before being flooded with 35-wt % KOH to improve performance.

Results in table II indicate several conditions that appear necessary to improve Ni/Zn cycle life. Insufficient electrolyte causes poor performance and premature failure, as is shown by the Astropower cell. No definite conclusions regarding the effect of using nonwetable, nonwoven, polypropylene on the nickel electrode can be made after 120 cycles of operation in an electrolyte-starved condition. The cell designated "Astrocontrol," which was tested after the Astropower cell and which incorporated sufficient electrolyte and Astropower hand-dipped bags on the nickel electrode, had completed 1100 cycles as of July 1976. This cell was reconditioned after 1000 cycles. It still had 65 percent of its capacity remaining. These data regarding the electrolyte and the nickel electrode absorber are consistent with the results of Celgard.

The failure modes of the cells are instructive. The Astropower cell, which was electrolyte starved, failed because of a zinc nodule short. Only the bottom one-third of the zinc and nickel electrodes appeared to have been working because of poor wetting of the PP higher up on the nickel electrodes. The higher current density presumably produced the zinc nodule.

The I/O 6D2174 separator cells apparently failed from several causes, the exact nature of which was not obvious. The cells showed signs of nickel electrode bowing,

zinc electrode slumping, and a mixture of ZnO and zinc metal outside the separator bags in the bottom and along the cell case edges. Upon inspection the separator bags were found to be cracked along the epoxy edge seal; the zinc mixture had been pumped from the interior of the bags into the cell outside the bags. Shorting due to free zinc metal would appear to be the most reasonable cause of cell failure.

### Improved Flexible Inorganic-Organic Separator in Nickel-Zinc Batteries

Table III contains cycle test results and construction details on 5.5-ampere-hour cells containing improved flexible I/O separators based on the PPO polymer and a rubber-based polymer with the tradename Kraton<sup>2</sup> G. Kraton G is a block copolymer of styrene and ethylene-butylene. Both coating systems contain an organic additive (which is a true plasticizer for Kraton G) and a combination of inorganic fillers. One filler is unreactive with the KOH electrolyte. The other filler reacts with the electrolyte to produce a flocculent precipitate, which presumably fills the void formed by the reaction. Both organic additives hydrolyze in KOH.

The data in table III show the effects of cell construction and separator composition. The scatter in the data is attributed to the laboratory methods of coating application. Some laboratory-coated materials showed surface cracks that were visible under a microscope. These surface cracks were not present in most of the factory-machine-coated materials. These data represent the more successful separator compositions and methods of construction evaluated with laboratory-produced materials.

The X-55-1, -2, -3 cells show rather low cycle lives as compared with other data in the table and with published cycle lives (ref. 5). The separator coating on the asbestos substrate consists of the PPO polymer, an organic additive, and calcium silicate and lead titanate fillers. The second X-55 set of three cells (X-55-4, -5, -6) contained the same coated separator. However, the cells had an extra sheet of asbestos coated on both sides with X-55. This extra separator sheet was placed between the X-55 bag on the zinc electrode and the heat-sealed bag of nonwoven PP on the nickel electrode. Both sets of X-55 cells were cycled approximately 120 times in a starved condition (35 wt % KOH) and were then flooded with electrolyte for the remainder of the test. Based on the data in table III, the extra sheet of separator provided a substantial increase in cycle life, which is probably attributable to the greater electrode separation. The failure mode was basically the same for both sets of cells. The nickel electrode was badly bowed and blistered and appeared to warp into the zinc electrode. A zinc nodule was found in cell X-55-6 and apparently caused the failure. This cell had no free electrolyte, and the zinc electrodes appeared to be dry. Some redistribution of zinc had occurred.

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<sup>2</sup>Kraton is a product of Shell Chemical, Houston, Texas.



The K-19 material was used with the Kraton polymer with a plasticizer and the calcium silicate and lead titanate fillers, but in different proportions than in the X-55 formulation. These cells were also cycled approximately 120 times in an electrolyte-starved condition and then flooded with electrolyte for the remainder of the test. The cycles-to-failure data for K-19 are about the same as for X-55-4, -5, -6. However for K-19, the number of cycles where the cell voltage was less than 1 volt at the end of discharge is substantially greater than for X-55. The failure mode of K-19 was probably due to the combination of bowing of the nickel electrode and thickening of the zinc electrode near the bottom. This thickening was not observed in cells with X-55 coated separators. However, neither zinc dendrites nor nodules were found.

The K-9 cycle data point out one other effect. The cells in both sets were the same except for electrolyte concentration. Fillers used in the coating were magnesium titanate and calcium silicate. The K-9-1, -2, -3 cells contained 35-wt % KOH. The K-9-D, -E, -F cells were filled with 45-wt % KOH. Two of the three cells containing 35-wt % KOH failed during the electrolyte-starved condition of the test, as the data show. The set containing 45-wt % KOH did not. These cells were reconditioned after 1340 cycles and still retained 25, 26, and 45 percent, respectively, of their original capacity. They were not shorted. These cells were reconditioned again at 1800 cycles. Ampere-hour capacities measured as 36, 26, and 44 percent, respectively, of their original capacity. Ampere-hour efficiency (the ratio of A-hr out to A-hr in) improved from the first to the third formation. The cells still were not shorted.

#### Nickel-Zinc Cells with Newsprint Separator

Nickel-zinc cells (5.5 A-hr) were constructed that used 13.5-kilogram (30-lb) basis weight newsprint and coated newsprint as separator materials on both the zinc and nickel electrodes. These cells were used to evaluate the feasibility of newsprint as a low-cost substrate ( $1.1\text{¢}/\text{m}^2$  ( $0.1\text{¢}/\text{ft}^2$ )) replacement for asbestos ( $\$1.60/\text{m}^2$  ( $\sim 15\text{¢}/\text{ft}^2$ )). Newsprint coated on laboratory equipment was used to construct separator bags for these cell tests. The separator bags for the electrodes were sealed by polyethylene foam tape coated on both sides with acrylic adhesive (but they were not heat sealed).

Both sets of cells, containing coated and uncoated newsprint, exhibited low capacities during cell formation, approximately 60 and 75 percent, respectively, based on their 5.5-ampere-hour capacity. In spite of their low formation capacities, these cells were cycle tested with charge-discharge currents set for 50-percent depth of discharge based on 5.5-ampere-hour capacities. Cycle test results are shown in table IV. The number of cycles to failure for uncoated newsprint ranged from 93 to 198. Some zinc (metal oxide) escaped from the separator bags, presumably because the edges were not sealed well. Some capacity loss was probably due to this free zinc mixture. Failure

analysis revealed that the free zinc mixture resulted in shorting of the positive and negative electrodes along the edges. The failure analysis also showed that the cellulosic material on the nickel electrode was gone, but the newsprint on the zinc electrode was still intact.

The cells containing the newsprint coated with K-19 were cycle tested in the same manner as the uncoated newsprint. Although ampere-hour efficiency was not good (60 to 70 percent), cycle life to failure for the first cell was 538 cycles. The other two cells as of July 1976 have completed 1030 cycles and are operating at 60 to 70 percent efficiency based on 50-percent depth of discharge for a 5.5-ampere-hour cell. These cells were reconditioned at 1000 cycles. Their capacities were measured as 3.1 and 2.1 ampere-hours, respectively. They were not shorted. Failure analysis of the failed cell showed that the newsprint next to the nickel electrode was gone, leaving only the K-19 film around the electrode. The newsprint on the zinc electrode was not visibly degraded. Failure was again apparently due to shorting by the free zinc mixture.

To determine if the cellulosic material on the nickel electrode was responsible for low formation capacity and ampere-hour efficiency, two more sets of Ni/Zn cells were built and formed. One set contained coated-newsprint separators on both electrodes. The other set had coated-newsprint separators only on the zinc electrodes and asbestos bags on the nickel electrodes. The same formation problems were experienced with newsprint on the nickel electrodes as before. However, the set with the asbestos on the nickel electrodes formed well and have operated at 90- to 95-percent efficiency based on 50-percent depth of discharge during their first 40 cycles.

Several factors considered significant about the use of newsprint as a separator material are

(1) The results of cycle testing are encouraging. Apparently, the newsprint affects the nickel electrode capacity. But the failure analysis observations and continued cycling of the cells suggest that the separator is satisfactory for the zinc electrode when cycled under conditions comparable to other materials tested.

(2) The uncoated newsprint has a lower zinc dendrite penetration rate (ref. 6) ( $7 \times 10^{-4}$  cm/min, two layers, 0.01727 cm (6.8 mils)) than asbestos ( $1.6 \times 10^{-3}$  cm/min, 2-percent PPO impregnation, 0.0254 cm (10 mils) thick). Both exhibit volume resistivities of less than 25 ohm-centimeters.

(3) Using newsprint as the substrate is considerably less expensive than using asbestos.

(4) The feasibility of coating newsprint on factory machinery has been demonstrated. The material produced (only one coat) has not as yet been cycle tested. A further reduction in cost is possible, if single-coated material can be used successfully.

## Separator Costs

A discussion of separator costs is relevant because of the interest in Ni/Zn batteries for electric vehicles and other appliance applications.

The projected costs associated with the various materials reported here are as follows:

(1) A Kraton-polymer-based coating on 13.5-kilogram (30-lb) basis weight newsprint costs \$1.10 to \$1.60 per square meter (10¢ to 15¢ per ft<sup>2</sup>) depending upon final selection of fillers. The present cost of newsprint is about 1.1¢ per square meter (0.1¢/ft<sup>2</sup>).

(2) The Kraton-polymer-based and PPO-polymer-based materials on fuel-cell-grade asbestos impregnated with 2-percent PPO cost \$2.70 to \$3.80 per square meter (25¢ to 35¢ per ft<sup>2</sup>). The PPO material is more expensive because of the higher cost of the polymer.

(3) The Celgard microporous film is presently priced at approximately \$5.40 per square meter (~50¢/ft<sup>2</sup>). A minimum order of approximately 280 000 square meters (~3 million ft<sup>2</sup>) of Celgard is required to bring the price down to the \$2.40 to \$2.70 per square meter (22¢ to 25¢ per ft<sup>2</sup>) range (private communication from M. Slapak of Celanese Plastics, Greer, S. C., March 3, 1976).

(4) The I/O separator based on the Astropower formula produced on factory equipment costs from \$11.80 to \$13.50 per square meter (\$1.10 to \$1.25 per ft<sup>2</sup>) based on the quantity produced.

A 300-ampere-hour cell designed by NASA contains 12 positive and 12 negative electrodes (see appendix). This cell requires a minimum of 2.2 square meters (24 ft<sup>2</sup>) of separator. Projected costs of various materials per cell are as follows:

(1) Based on the Kraton-polymer-coated newsprint with newsprint U-fold inserts, projected separator costs would be \$2.50 per cell.

(2) Based on the Kraton-polymer-coated asbestos, separator costs would range from approximately \$6.00 to \$8.50 per cell.

(3) Based on four wraps of Celgard on the negative electrodes and asbestos bags on both the negative and positive electrodes, the cost would be approximately \$52 per cell at a Celgard cost of \$5.40 per square meter (50¢/ft<sup>2</sup>).

(4) Based on the I/O separator using the Astropower formula at \$11.80 per square meter (\$1.10/ft<sup>2</sup>), the cost would be approximately \$26 per cell.

## CONCLUDING REMARKS

The cycle testing of Ni/Zn cells for evaluating new separator materials has provided insight on other conditions that appear to increase cell life. Some of these conditions are the following:

(1) The cells must operate in an electrolyte-flooded condition. Insufficient electrolyte appears to substantially reduce cell life and performance.

(2) Absorber or interseparator materials used on the nickel electrodes should provide for physical separation between electrodes and be hydrophilic with respect to the electrolyte.

The Ni/Zn battery separator program at Lewis is now directed toward several major goals:

(1) The evaluation of separator materials containing less-expensive fillers and substrates and produced on factory equipment will continue. If this separator technology is to have commercial use (e.g., in electric vehicles and/or small appliances), the primary consideration will be good cycle life at the lowest cost. A reliable separator at \$1.10 per square meter ( $10\text{¢}/\text{ft}^2$ ) is a reasonable goal.

(2) The cycle life of these separators, such as the K-19 coated materials, in 300-ampere-hour cells must be determined. Initial formation capacity and preliminary performance data of K-19 on asbestos in 300-ampere-hour cells are quite encouraging.

(3) These separators will be evaluated in other alkaline battery systems to determine their potential use. The nickel-cadmium system is an example.

#### SUMMARY OF RESULTS

Nickel-zinc cells constructed in the laboratory and containing laboratory-produced separator materials have demonstrated cycle lives in excess of published data on cells that were cycle tested in a similar manner.

The separators in these cells are thought to operate principally as microporous separators. Cell performance and failure modes are very similar to those observed on a commercially available microporous polypropylene film.

Costs of these materials are encouraging for electric vehicle and small appliance applications. Based on the separators tested and reported herein, Lewis-improved separators on newsprint substrate show promise of production at approximately \$1.10 per square meter ( $\sim 10\text{¢}/\text{ft}^2$ ) or less. With the asbestos substrate, the costs appear to be in the range of \$2.70 to \$3.80 per square meter ( $25\text{¢}$  to  $35\text{¢}$  per  $\text{ft}^2$ ).

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National Aeronautics and Space Administration,  
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APPENDIX - 300-AMPERE-HOUR NICKEL-ZINC CELL FOR AN  
EXPERIMENTAL ELECTRIC VEHICLE BATTERY

The electric vehicle is currently being investigated as an alternative method of transportation. Studies show that a practical urban electric car (fig. 1) should have a daily range of approximately 130 kilometers (80 miles). This range cannot be met with the relatively low energy density of present commercially available storage batteries. The search for a practical and economical battery system with higher energy density has stimulated an interest in the nickel-zinc alkaline storage battery. This system can double the vehicle range over that projected for lead-acid batteries and should meet or exceed the 130-kilometer (80-mile) urban vehicle requirement.

NASA's Lewis Research Center with the help of two industrial contractors has built an experimental nickel-zinc cell that features an inorganic-organic (I/O) separator adapted from technology for space batteries. The technology used is intended to improve charge-discharge cycle life. Assembled in batteries that are compatible with the battery space available in current electric vehicles (fig. 2), this experimental cell will be evaluated in operating vehicles.

The electrical characteristics of the experimental nickel-zinc battery (fig. 3) are

- (1) Nominal voltage, 1.8 volts
- (2) Capacity (continuous discharge):
  - 250 ampere-hours for 2 hours
  - 350 ampere-hours for 4 hours
- (3) Recommended operating capacity limit, 270 ampere-hours
- (4) Recommended charge-constant current rate, 20 amperes
- (5) Electrolyte, 34-wt % KOH
- (6) Cell case material, 20-percent-glass-filled PPO
- (7) Weight, 8 kilograms (18 lb)
- (8) Vent cap, resealable
- (9) Dimensions, 32.9 cm by 17.8 cm by 7.1 cm (12.95 in. by 7.0 in. by 2.8 in.)

The discharge characteristics of this battery are shown in figure 4. Its performance in a simulated postal vehicle is shown in figure 5. The battery was assumed to discharge at 30 amperes for 1 second and at 200 amperes for 40 seconds and to stand for 7 seconds. The voltage was measured at the end of a 200-ampere pulse. The energy density as a function of current drain is presented in figure 6.

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TABLE I. - CYCLE TEST RESULTS OF CELGARD  
IN NICKEL-ZINC CELLS

Cell <sup>a</sup>	Start date	Number of cycles to failure	Number of cycles to less than 1 volt at end of discharge
CG-1	10/13/74	355	319
CG-2	10/13/74	321	280
CG-3	10/13/74	340	319
CG-AF-1	7/1/74	<sup>b</sup> >1130	<sup>b</sup> >1130
CG-AF-2	7/1/75	>1130	>1130
CG-AF-3	7/1/75	>1130	>1130

<sup>a</sup>Cell construction (5.5-A-hr capacity):

CG-1, 2, 3 - Both electrodes (three Ni(+), two ZnO(-) were bagged with heat-sealed, 0.023-cm (9-mil), nonwoven polypropylene. Zinc oxide electrode also contained three wraps of 0.00254-cm (1-mil) Celgard 2400W with a U-fold on the two electrodes.

CG-AF-1, 2, 3 - Three Ni(+), two ZnO(-); center nickel electrode was a double plate. Zinc oxide electrodes were bagged in a U-fold of asbestos that was heat sealed along edges with polyethylene foam tape. Four layers of 0.00254-centimeter (1-mil) Celgard 2400W were wrapped around electrode. Nickel electrodes were placed in asbestos bags that were heat sealed with polyethylene foam tape.

Electrolyte:

CG-1, 2, 3 - Cells contained 45-wt % KOH in starved condition.

After 120 cycles, enough 45-wt % KOH was added to flood cells.

CG-AF-1, 2, 3 - Cells were flooded with 35-wt % KOH. All cells were heat treated at 100<sup>o</sup> to 105<sup>o</sup> C for 24 hours after electrolyte was added.

<sup>b</sup>Still cycling as of July 1976.

TABLE II. - CYCLE TEST RESULTS OF ASTROPOWER BAGS AND  
INORGANIC-ORGANIC SEPARATOR IN NICKEL-ZINC CELLS

Cell <sup>a</sup>	Start date	Number of cycles to failure	Number of cycles to less than 1 volt at end of discharge
Astropower	10/13/74	66	66
Astrocontrol	7/1/75	<sup>b</sup> >1100	518
Inorganic-organic:			
6D2174-1	10/13/74	292	289
6D2174-2	10/13/74	503	467
6D2174-3	10/13/74	430	430

<sup>a</sup>Cell construction (5.5-A-hr capacity):

Astropower (three Ni(+), two ZnO(-)) - Astropower bags on ZnO electrode, and 0.023-cm (9-mil), nonwoven polypropylene bags heat sealed around nickel electrodes.

Astrocontrol (three Ni(+), two ZnO(-)) - Center nickel electrode was a double plate. Astropower bags on both electrodes.

6D2174-1, 2, 3 (three Ni(+), two ZnO(-)) - I/O bags on ZnO electrode and 0.023-cm (9-mil), nonwoven polypropylene bags heated sealed around nickel electrodes.

Electrolyte (35-wt % KOH):

Astropower - Cells operated in starved condition.

Astrocontrol - Cells operated in flooded condition.

6D2174-1, 2, 3 - Cells operated for 120 cycles in starved condition then flooded when the polypropylene absorber was found to be hydrophobic.

All cells were heat treated for 24 hr at 100<sup>o</sup> to 105<sup>o</sup> C after electrolyte was added.

<sup>b</sup>Still cycling as of July 1976.



TABLE III. - CYCLE TEST RESULTS OF IMPROVED FLEXIBLE  
INORGANIC-ORGANIC SEPARATORS IN NICKEL-ZINC CELLS

[Start date, 10/13/74.]

Cell <sup>a</sup>	Number of cycles to failure	Number of cycles to less than 1 volt at end of discharge	Cell composition
X-55-1	235	235	PPO, organic additive, CaSiO <sub>3</sub> , PbTiO <sub>3</sub> , asbestos substrate
X-55-2	190	190	
X-55-3	123	120	
X-55-4	841	96	Same composition as X-55-1, -2, -3; extra sheet of separator between bags on positive and negative electrodes
X-55-5	482	467	
X-55-6	985	280	
K-19-1	850	619	Kraton G, plasticizer, CaSiO <sub>3</sub> , PbTiO <sub>3</sub> , asbestos substrate
K-19-2	1012	1012	
K-19-3	333	333	
K-9-1	90	90	Kraton G, plasticizer, CaSiO <sub>3</sub> , Mg <sub>2</sub> TiO <sub>4</sub> , asbestos substrate
K-9-2	87	21	
K-9-3	272	238	
K-9-D	(b)	641	Same as for K-9-1, -2, -3
K-9-E	(b)	641	
K-9-F	(b)	219	

<sup>a</sup>Cell construction (5.5-A-hr capacity): All cells contained three Ni(+), two ZnO(-). The electrodes were bagged with heat-sealed, 0.023-cm (9-mil), nonwoven polypropylene. The ZnO electrodes were contained in separator bags with epoxy seals.

Electrolyte: All cells contained 35-wt % KOH, except K-9-D, -E, -F, which contained 45-wt % KOH. All cells were operated for 120 cycles in the starved condition and then flooded.

<sup>b</sup>Still cycling as of July 1976; ~1800 cycles.

TABLE IV. - CYCLE TEST RESULTS OF  
 COATED AND UNCOATED NEWSPRINT  
 IN NICKEL-ZINC CELLS

[Start date, 7/1/75. ]

Cell <sup>a</sup>	Number of cycles to failure
NP-1	198
NP-2	93
NP-3	132
NPK-19-1	<sup>b</sup> 1030
NPK-19-2	1030
NPK-19-3	538

<sup>a</sup>Cell construction (three Ni(+), two ZnO(-); 5.5-A-hr-capacity):

NP-1, 2, 3 - Two wraps of newsprint on nickel electrodes. Newsprint bags with polyethylene foam tape edge seal on zinc electrodes and two U-folds inside.

NPK-19-1, 2, 3 - Bags of K-19 coated newsprint with two U-folds of newsprint inside each bag were used on both the zinc and nickel electrodes.

<sup>b</sup>Still cycling as of July 1976.



Figure 1. - Typical electric vehicle.

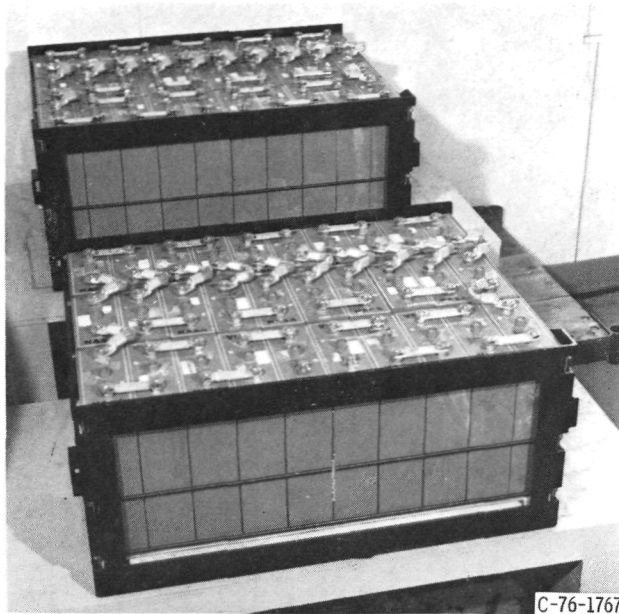


Figure 2. - Batteries assembled for use in electric vehicle.

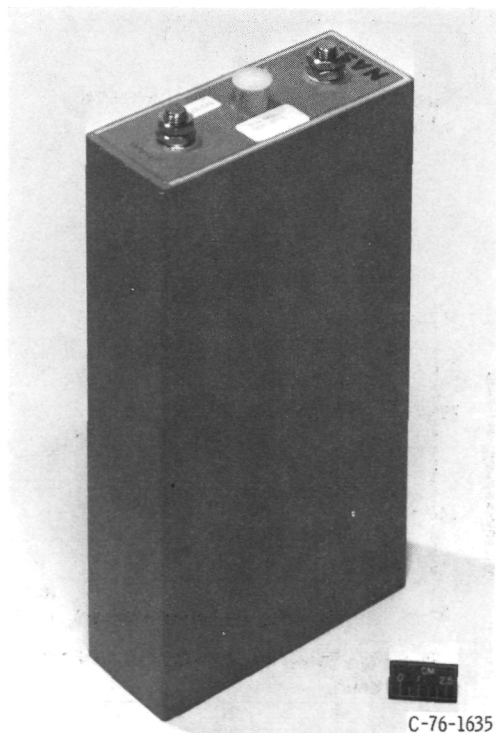


Figure 3. - 300-Ampere-hour nickel-zinc battery.

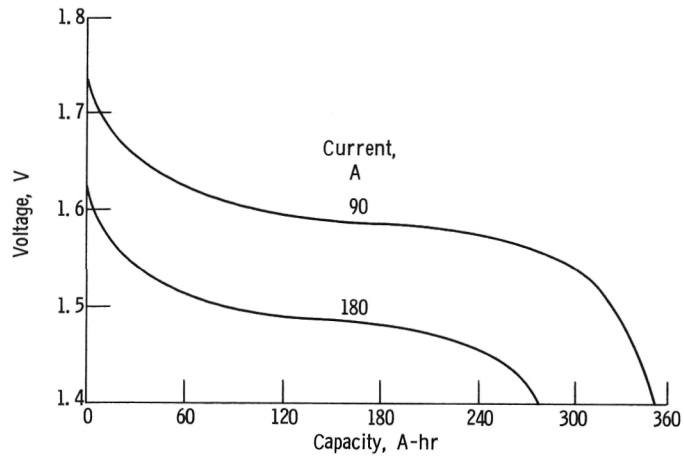


Figure 4. - Discharge characteristics.

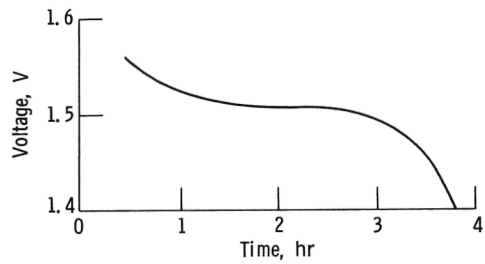


Figure 5. - Performance in a simulated postal vehicle.

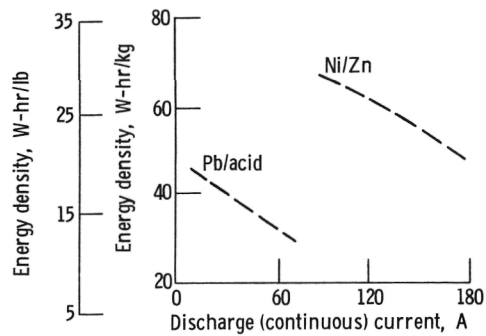


Figure 6. - Energy density as a function of current drain.



POSTMASTER : If Undeliverable (Section 158  
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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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