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SPACE TECHNOLOGY APPLICABLE TO HYBRID VEHICLE BATTERIES

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ABSTRACT

At present, no battery exists which has the characteristics required for a full performance battery-powered passenger car. Hybrid heat engine/electric systems are one of several classes of hybrid systems being considered as a near term power train for a low-pollutant vehicle. While the lead acid battery can be improved, the resulting vehicle would still have a performance below the target level. Successful development of a nickel-zinc battery could produce a full performance hybrid car for the post-1975 time period. This paper presents examples of aerospace battery technology which could increase the life of nickel-zinc batteries to a point where they become attractive candidates for hybrid vehicle use.

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TO PEOPLE ENGAGED IN battery research and development, few if any problems are more enticing than the development of an electric vehicle to replace the present family car. The technical man sees the challenge of providing high energy density (watt-hours/kg) and high specific power (watts/kg) at a cost competitive with a well developed, highly refined internal combustion engine production capability which is already in existence. Since the technology does not exist to build an all-battery car with performance comparable to the present internal combustion (I.C.) engine powered passenger car, attention has turned to various types of hybrid vehicles using a constant-output heat engine coupled to an energy storage system for acceleration. A recent study (1)* of hybrid heat engine/electric systems shows that the nickel-zinc battery looks promising for the post-1975 time period, provided that life problems which currently exist can be overcome. The purpose of this paper is to identify several specific examples of aerospace battery technology which can be applied to the problem of extending the life of nickel-zinc batteries.

BATTERY REQUIREMENTS FOR HYBRID/ELECTRIC SYSTEMS

The hybrid/electric study prepared for the Air Pollution Control Office (APCO) by Aerospace Corporation (1) is based on the premise that the battery will be discharged only during acceleration, and recharged from the heat engine when the car is cruising so that the battery is fully charged at the end of each driving cycle. The DHEW Urban Driving Cycle chosen for the systems analysis is shown on Figure 1. This cycle demands 73 battery charge/discharge cycles over 1370 seconds operating time, equivalent to 7.5 vehicle miles. Trade off studies involving battery current-voltage characteristics, and vehicle emission characteristics as functions of installed capacity lead to selection of 38 ampere-hour lead-acid and 30 ampere-hour nickel-zinc battery capacities. Based on the driving cycle, these batteries will be required to undergo 975,000 charge/discharge cycles spread over 5,000 operating hours or 100,000 vehicle miles. While they are re-

*Numbers in parentheses designate References at end of paper.

quired to deliver current pulses of almost 500 amperes, the depth of discharge in both cases is less than 5 percent due to the almost continual recharge. It is expected that limiting the depth of discharge in this way will extend the operating life.

LIFE CHARACTERISTICS OF NICKEL-ZINC CELLS

Although the nickel-zinc cell is more than 70 years old, there is a notable paucity of cycle life and failure mode data in the literature.

No testing is reported under conditions of rapid, shallow cycling. Instead, one finds data on nickel-zinc cells discharged to substantial (25-60 percent) depths-of-discharge, generally with recharge over several hours, and information on silver-zinc cells cycled to simulate aerospace use. The latter usually consist of 90-minute or 24-hour charge/discharge cycles with the discharge time being 30 minutes in the short cycle and 72 minutes in the long one. Again, depth of discharge tends to range from 25-60 percent. Data on both systems is relevant, since the major problem areas in each reside with the zinc electrode and the separator. Dirkse (2) in his discussion of the zinc electrode in secondary batteries concludes that redistribution of zinc is the greatest unsolved problem to date. Redistribution, more commonly called "shape change," is the phenomenon whereby the zinc metal tends to shrink from the edges of a battery electrode and consolidate in a dense mass at the center, thereby decreasing the amount of zinc available for use. Examples are shown on Figure 2. Other problems which shorten life are the deterioration of the cellophane or fibrous sausage casing normally used as the separator due to the combined action of electrolyte and the oxygen formed on charging nickel-zinc cells, and the tendency of zinc to plate out in dendritic crystals which grow through the separator and short circuit the cell. While this latter problem can be controlled, as will be discussed later, a combination of the first two limits the reported nickel-zinc cell life as shown in Table I.

In order to compare these data qualitatively with the hybrid/electric system requirements, the total capacity used in one DHEW driving cycle was calculated to be 4.78 ampere hours. It would be possible to reduce the number of battery charge/discharge cycles by discharging with no recharge for one or more complete cycles, then recharging completely afterward. While this may be an unrealistic way to operate the vehicle, it does allow a rough estimate of the differences between the vehicle battery life requirements and the values in Table I. Based on a 30 ampere-hour nickel-zinc battery, the values in Table II are obtained.

Even though the relationship between life and depth-of-discharge is not a straight line function, it appears that an order of magnitude life improvement will be required for the nickel-zinc cell. Since zinc electrode life is presently far inferior to that of the nickel electrode, effort should be concentrated on it.

AEROSPACE TECHNOLOGY APPLICABLE TO ZINC ELECTRODES

Three problems have been identified which bear on zinc electrode life. These are dendrite growth, shape change, and separator degradation. Work supported by the NASA and reported by Oswin (8) has shown that dendrite growth is related to the overvoltage on the zinc electrode during charge, and that the nature of the deposit can be controlled by regulating the voltage, as shown in Figure 3. The figure shows a strong temperature dependence for the critical current density. Therefore, these data will have to be applied not only in the design of the electrochemical cells, but in the design of the thermal control system of the battery as well.

Since June, 1964, the Lewis Research Center of NASA has been supporting the development of a long-life silver-zinc cell based on use of an inorganic separator. An inorganic separator was selected from the rather obvious viewpoint that the inside of an alkaline electrochemical cell is a strongly oxidizing environment. Organic separators are designed to react with soluble silver ions in these cells, degrading chemically in the process. If enough separator is used, it can outlast the electrodes and the cell fails due to zinc electrode problems. Clearly though, an oxidation resistant separator is a prerequisite for the 2-5 year life-times NASA is seeking. Vented, five ampere-hour cells were built and tested using a lowaltitude orbit cycling regime of 30-minutes discharge followed by 60-minutes of charging. Although it was later found that the separator contained impurities which effected the zinc electrode life, the results shown in Table III were encouraging.

These results are four to ten times better than which would be expected from a conventional silver-zinc cell. The tests at 100° C showed the exceptional chemical stability of the separator and lead to development and testing of a sealed, heat-sterilizable forty ampere-hour silver-zinc cell which could be used for a Mars lander. The cell is shown on Figure 4. The test schedule followed called for heat sterilization for 200 hours at 135° C, followed by wet-stand for either eight or twenty-one months, after which the cells are cycled. Approximately sixty heat-sterilized and forty nonsterilized cells have been on test for periods ranging from 19 to 29 months as of April 1, 1971. Of the three cell failures to date, none was due to zinc electrode problems. Figure 5 shows a zinc-electrode from a cell which failed after 1093 cycles to 40 percent depth of discharge and 17 months total wet-life. No significant amount of shape change is seen.

The lack of shape change with an inorganic separator was also observed by Charkey (4). He compared the results of a cell using four layers of cellophane with ones containing two different proprietary inorganic separators. Under a cycling regime deliberately set to accelerate failure, he obtained 35 cycles with the cell using cellophane and 85 and 108 cycles, respectively, for the inorganic separators. Most significantly, he found severe shape change with the cellophane and none with the inorganic separators. Since the same kind of zinc electrodes yielded 200 cycles in normal cell operation using cellophane, he reported that 500 deep cycles should be possible.

The use of inorganic separators in vented nickel-zinc cells was studied briefly at Lewis Research Center. The results are presented in Table IV.

Cell No. 1 failed due to corrosion of the electrode lead wires. Unfortunately, test Nos. 2-5 had to be stopped before failure.

OTHER TECHNOLOGY OF INTEREST

In addition to the work reported previously on the zinc electrode and separators, other NASA-supported electrochemical projects should be of value in developing a battery for a hybrid vehicle. The work on heat-sterilizable cells (9) produced useful information on plastic cell case design, materials for cell cases, and on terminal seal designs. While the nickel electrode has not been discussed in this paper, its tendency to self-discharge at moderately elevated temperatures (40° C) is well known. The use of cobalt in the nickel electrode to improve charge retention might be considered (10). In addition, the Goddard Space Flight Center is supporting work on developing uniform and predictable materials for preparing nickel battery electrodes.

CONCLUSIONS

There is a strong similarity in the technologies being supported for space purposes, and those required for a nickel-zinc hybrid vehicle battery. Information already in the literature and presently being produced under NASA contracts should be used in developing a nickel-zinc technology program.

Definitive data are lacking on the life of nickel-zinc batteries operating in a hybrid vehicle mode. Testing should be initiated to obtain the information.

Inorganic separators have been shown to substantially increase the life of zinc electrodes and offer a promising route to gaining the life improvements which appear to be needed. A technology program is needed to confirm these preliminary results and develop an optimum separator formulation for nickel-zinc use.

From a systems standpoint, NASA-developed information already in the literature on the influence of operating parameters on zinc electrode morphology must be taken into consideration. This data defines the allowable charge voltage and current density, and therefore fixes the battery size.

By taking into account work already done or underway related to zinc electrode processes and inorganic separators, the development of a nickel-zinc battery for a hybrid/electric vehicle can be undertaken with more confidence and a higher probability of success.

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Table I

Reported Cycle Life of Nickel-Zinc Cells

Cycles	Depth of Discharge	Cell Type	Reference
100-200	50%	Vented	3
50-100	70%	"	4
100	74%	"	5
100-200	70%	Sealed	4
190	100%	Vented	6
200	100%	"	7

Table II

Battery Life Requirements

Number Integrated DHEW Discharge Cycles	Ampere-Hours Discharged	Depth of Discharge	Number of Cycles/ 100,000 Miles
Std. DHEW Cycle	1.34 (Max)	4.5% (Max)	975,000
1	4.78	15.9%	13,600
2	9.56	31.8%	6,800
3	14.34	47.8%	4,534
4	19.12	63.7%	3.400

Table III

5 Ampere-Hour Silver-Zinc Cells

with Inorganic Separators

Test Temperature	Depth of Discharge	Cycle Life
25° C	20%	2500
25° C	30%	2000
100° C	30%	500

Table IV

In-House Nickel-Zinc Cell Tests

Cell No.	Depth of Discharge	Cycles	Status
1	17%	720	Failed
2	17%	835	Terminated
3	34%	429	"
4	34%	429	"
5	50%	266	"

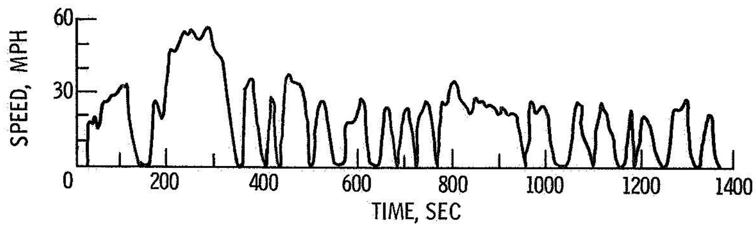

Figure 1. - DHEW urban driving cycle.

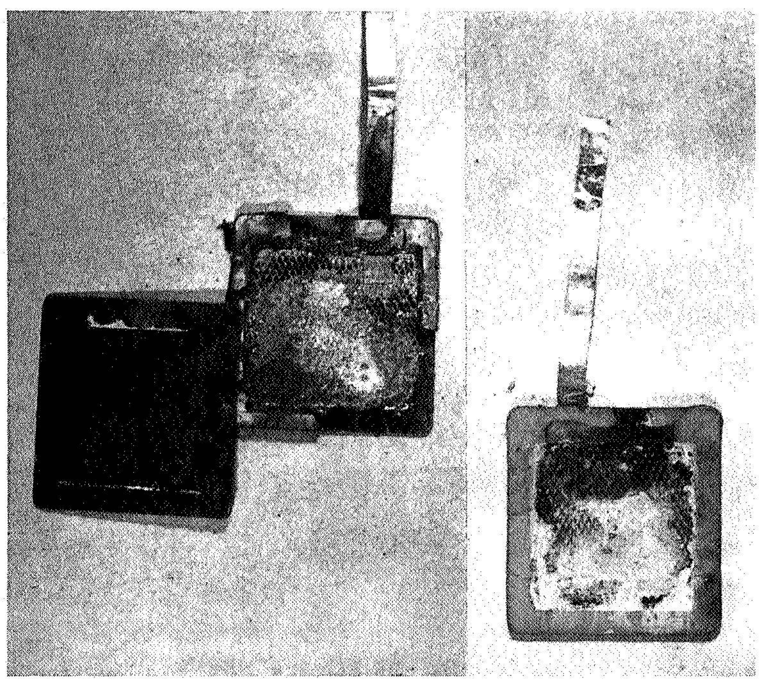

Figure 2. - Zinc electrode shape change.

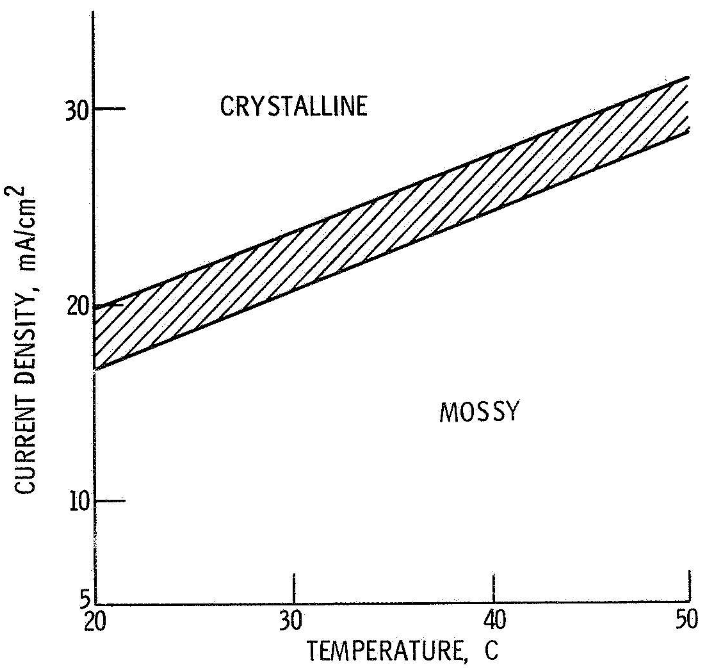

Figure 3. - Variation of critical current density with temperature within experimental limits, 43% KOH, 1.13 m Zn(II); from reference 8.

Figure 4. - Sealed 40 AH silver-zinc cell.

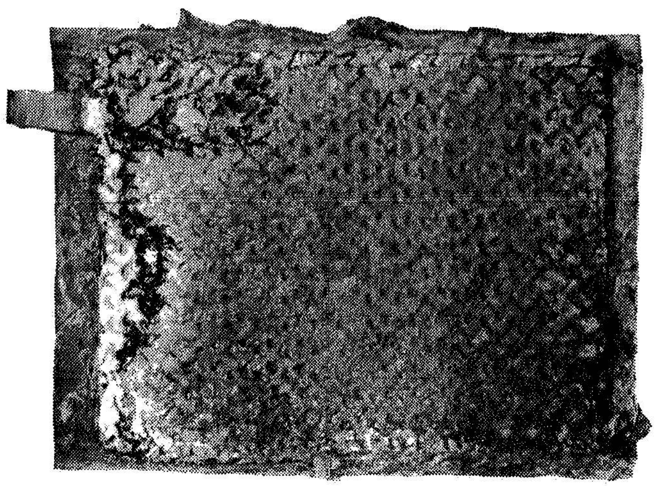

Figure 5. - Typical electrode - 517 days wet life, 1,093 cycles (three cycles per day; 40 percent depth).