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# Lightweight Nickel Electrode for Nickel Hydrogen Cells and Batteries

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# LIGHTWEIGHT NICKEL ELECTRODE FOR NICKEL HYDROGEN CELLS AND BATTERIES

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## SUMMARY

The nickel electrode has been identified as the heaviest component of the nickel hydrogen ($Ni-H_2$) battery. The NASA Lewis Research Center is developing nickel electrodes for $Ni-H_2$ battery devices which will be lighter in weight and have higher energy densities when cycled under a low earth orbit (LEO) regime at deep depths of discharge.

The lightweight plaques are first exposed to 31 percent potassium hydroxide for 3 months to determine their suitability for use as electrode substrates from a chemical corrosion standpoint. The pore size distribution and porosity of the plaques are then measured. The lightweight plaques examined in this study are nickel foam, nickel felt, nickel plastic and nickel plated graphite.

The plaques are then electrochemically impregnated in an aqueous solution. Initial characterization tests of the impregnated plaques are performed at five discharge levels, C/2, 1.0C, 1.37C, 2.0C, and 2.74C rates. Electrodes that passed the initial characterization screening test will be life cycle tested.

The lightweight electrodes are approximately 30 to 50 percent lighter in weight than the sintered nickel electrode.

In a bipolar battery design, the current flow is perpendicular to the electrode surface thereby eliminating the need for a current collector making the lightweight substrates applicable for this design.

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## INTRODUCTION

The NASA Lewis Research Center is currently involved in the development and design of nickel hydrogen ($Ni-H_2$) cells and batteries primarily for low earth orbit (LEO) applications. These designs have been incorporated into both the individual pressure vessel (IPV) cells as well as bipolar batteries using active cooling. The objective of this program is to improve the components, design and performance of $Ni-H_2$ devices. This can be achieved by improving the energy density and cycle life when cycled under a LEO regime at deep depths of discharge.

The nickel electrode has been identified as the most critical and heaviest component of the $Ni-H_2$ battery system. The state-of-the-art nickel electrode has been made conventionally by sintering fine nickel powder onto a wire screen at elevated temperature (1000 °C) in a reducing atmosphere. This material has the advantage of providing a highly conductive and porous substrate for the active material but has the disadvantage of being heavy in weight. The nickel hydroxide active material is deposited into the pores of the plaque either by chemical or electrochemical methods.

The most recent advances in the nickel electrode that is expected to have a positive effect in life, weight, cost and performance is the use of a lightweight nickel plaque in place of the heavy sintered nickel plaque. The weight of the components in a typical 125 AH $Ni-H_2$ bipolar battery is shown in figure 1. A major weight reduction of as much as 14 percent can be accomplished by the use of lightweight electrodes.

Several commercially available materials have potential as a plaque for the active material. These plaques are lightweight and some of them have pore sizes comparable to a typical commercial nickel plaque. These lightweight plaques are less conductive than commercial nickel plaques but in a bipolar design the current flow is perpendicular to the electrode surface; hence the need for high lateral conductivity is eliminated (ref. 1).

## LIGHTWEIGHT PLAQUES

Plaques other than sintered nickel plaques that may be used to support the active material are the nickel plated plastic plaque developed at NASA Lewis earlier (refs. 2 and 3), commercially available Feltmetal (TM) and a needle-punched Ni-Cr webbing (80 percent Ni, 20 percent Cr) from Brunswick Technetics, nickel plated graphite mat from American Cyanamid and Fibrex (TM), a fiberous mat from National Standard Co. The nickel plated plastic plaque consists of a porous polyvinyl chloride (PVC). Nickel metal is plated by an electroless plating process. The Feltmetal (TM) fiber metal is an interlocked structure of metal fibers sintered to produce metallic bonds at points where the fibers touch each other. The nickel plated graphite is coated with nickel metal using an electroplating process producing a strong bond between metal and graphite. The Fibrex is made from fine nickel fibers by a direct chemical and metallurgical process. The lightweight plaques except for the Feltmetal are about 50 to 90 percent lighter than the standard sintered nickel plaque. The Feltmetal is about 5 percent lighter than the sintered nickel plaque.

## EXPERIMENTAL

### Initial Screening Test

The lightweight materials to be used for plaques are first exposed to 31 percent potassium hydroxide (KOH) at 80 °C for 3 months to determine their suitability for use as electrode substrates. The plaques are weighed before and after exposure to KOH. The loss in weight determines if there has been any chemical corrosion of the plaques.

The pore size distribution and porosity measurements are made by the mercury intrusion porosimeter method.

### Impregnation of Active Material

The plaques are pretreated prior to impregnation in order to eliminate any surface contaminants that were obtained during handling and storage and also to improve the wettability of the plaques. The two pretreatment cleaning procedures used in this study are the wet oxidation cleaning treatment (ref. 4) which consists of heating the wet plaque at 350 °C in air for 20 min and the anodic treatment (ref. 5) at low current density (1.78 $mA/cm^2$) in 1 M $Ni(NO_3)$ solution for 20 min at room temperature. Both pretreatment procedures can be used for all the lightweight plaques except for the Ni plated plastic which cannot withstand the high temperature; hence an anodic treatment is preferred. The cleaned plaques are then measured, weighed and impregnated in a saturated solution of nickel nitrate by the passage of a cathodic current through the plaque using the Bell Telephone Laboratory method (ref. 6). The bath solution contained 2.0 M nickel nitrate, 0.075 M cobalt nitrate and 0.075 M sodium nitrite, made acidic by the addition of 50 percent nitric acid. Optimum impregnation conditions vary for each kind of lightweight material. The plaques are impregnated for various periods of time (90 to 300 min) and current densities (50 to 80 $mA/cm^2$) to determine the conditions needed to obtain 1.6 $g/cm^3$ void loading of active material. The 1.6 $g/cm^3$ void was selected as the optimum loading because the cycle life has been found to maximize at this value when standard sintered plaques are used (ref. 7).

The plaques are impregnated in a reaction vessel which consists of a 600 ml beaker containing 300 ml of the nickel nitrate impregnation solution, a Teflon screen holder and two standard nickel counter electrodes. The impregnations are carried out at a temperature of 95 to 100 °C.

After washing the impregnated plaques, the electrodes are formed using the Eagle-Picher procedure (ref. 8) which consists of eight cycles of 20 min charge and 20 min discharge at approximately 3C rate. After formation, the electrodes are thoroughly rinsed in deionized water, dried at a temperature of 60 °C for 4 hr and weighed. The theoretical capacity rate is determined from the weight of the active material in the electrode using the electrochemical equivalent of 0.289 Ah/g of nickel.

## Characterization Test

The initial characterization tests of the electrodes are performed at five discharge levels, C/2, 1.0C, 1.37C, 2.0C and 2.74C rates. The voltage as a function of time and the capacities at each rate are recorded and compared with the sintered nickel electrode.

After the initial characterization tests, the electrodes are life cycle tested at a LEO regime. The constant current cycling consists of 110 percent charge at 0.96C rate for 55 min and discharge at 1.37C rate for 35 min to 80 percent depth of discharge. The voltage as a function of time is plotted continuously and capacities are measured every 50 cycles during the test for the first 1000 cycles and every 500 cycles thereafter. Failure of the cell is defined as the point where the discharge voltage degrades to -0.2 V versus a mercury/mercuric oxide reference electrode during the 35 min discharge. (This is equivalent to 0.8 V versus the $H_2$ electrode).

## RESULTS AND DISCUSSION

The lightweight plaques exposed to 31 percent potassium hydroxide solution for three months exhibited no weight loss indicating no major corrosive attack.

Figure 2 shows the pore size distribution of the lightweight plaques compared to the standard sintered plaque. Most of these plaques have larger pore radii than the Eagle-Picher sintered plaque. The nichrome punched web and the Fibrex materials have about the same broad distribution at about 20 to 40 μm. The Ni plated plastic, Ni plated graphite and Feltmetal show peaks in the pore size distribution at 10 to 18 μm. The standard sintered plaque has the smallest pore size distribution peak at 7 μm.

The initial impregnation study on the lightweight plaques was done with the Feltmetal plaque. Table I shows the impregnation parameters and the electrode characteristics of the Feltmetal electrode. It can be seen that a loading level of 1.6 g/cm$^3$ void of $Ni(OH)_2$ was attained. The loading level showed a dependence on current density and impregnation time. The initial utilization of these lightweight plaques is low and increases very gradually with time.

In this study, it was determined that the impregnation conditions which appeared to be most promising for obtaining a good Feltmetal nickel electrode are a current density of 54 mA/cm$^2$ for 150 min.

The Feltmetal electrode has accumulated over 3000 LEO cycles to 80 percent DOD and is still being cycled. From the life cycle test, the performance of the Feltmetal electrode was evaluated as shown in fig. 3. The figure shows the change in the discharge curve as the electrode is cycled. An increasing utilization was observed as the electrode cycled. A similar increase in utilization was also observed in the earlier work on the nickel plated plastic electrode (ref. 3) and the nickel composite electrode work at Naval Surface Weapons Center (ref. 9).

Figure 4 shows the discharge voltage versus time of the Feltmetal nickel electrode as compared with commercial nickel electrodes at the 1.37C rate of discharge.

Initial impregnation of the Fibrex material has been completed. A longer impregnation time than the Feltmetal (300 min for the Fibrex versus 150 min for the Feltmetal) at the same current density of 54 mA/cm$^2$ was required to get the desired loading level of 1.6 g/cm$^3$ void. Life cycle testing of the Fibrex electrode has been initiated.

## CONCLUSION

A significant reduction in weight resulting in an increase in energy density of the $Ni-H_2$ battery system can be achieved by the use of lightweight nickel electrodes using lightweight plaques.

Increasing the energy density of the $Ni-H_2$ battery system is one of the goals of the technology development program at NASA Lewis. This goal can be achieved by developing lightweight, longer life nickel electrodes.

The electrochemical impregnation of these lightweight plaques using the aqueous bath yields loading levels comparable to commercial nickel electrodes. The lightweight electrodes exhibit a slow increase in utilization in the early cycles followed by a plateau.

Other formation procedures and additives to improve the initial utilization of the electrodes are being investigated.

Impregnation and characterization of the other lightweight plaques will be performed and the electrodes will be cycle tested.

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TABLE I. - ELECTROCHEMICAL IMPREGNATION DATA OF FELTMETAL PLAQUE

| Electrode no. | Electrode thickness,[a] cm | Impregnation condition | | Loading level, $g/cm^3$ void | Active material utilization[b], % |
|---|---|---|---|---|---|
| | | Current density, $mA/cm^2$ | Time, min | | |
| 401 | 0.102 | 59 | 90 | 1.19 | 61 |
| 408 | .102 | 54 | 120 | 1.20 | 81 |
| 407 | .102 | 54 | 135 | 1.31 | 65 |
| 4017 | .108 | 54 | 150 | 1.59 | 51 |
| 4018 | .104 | 54 | 150 | 1.61 | 61 |
| 4013 | .102 | 78 | 60 | 1.07 | 81 |
| 4014 | .101 | 78 | 75 | 1.07 | 77 |

[a]Initial plaque thickness = 0.096 cm.
[b]Measured during the initial characterization screening test at 1.37C rate of discharge.

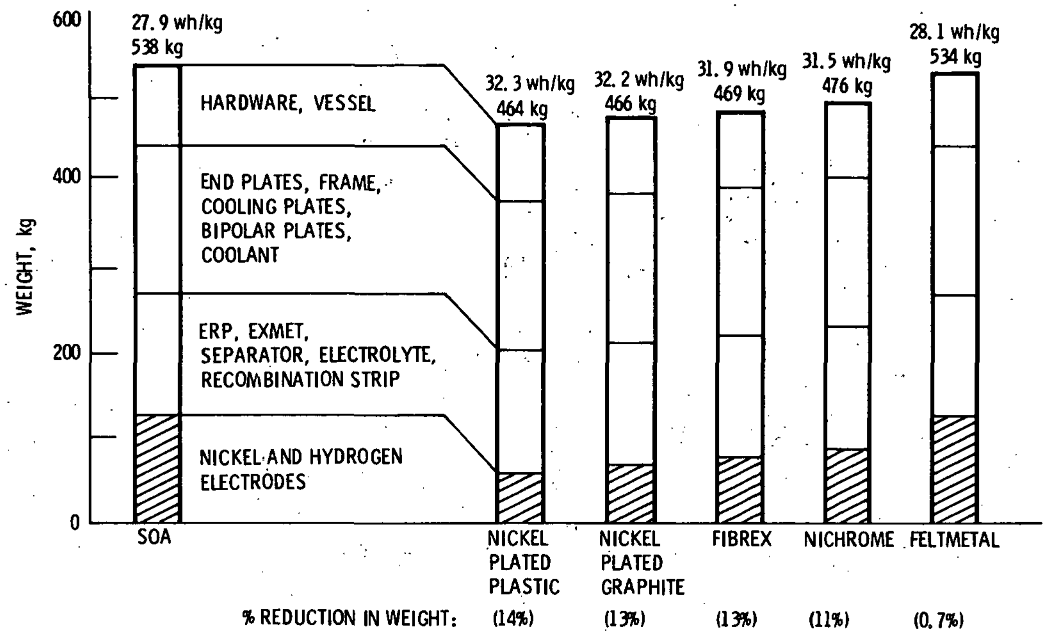


Figure 1. - Weight of components in a 125 AH $Ni/H_2$ bipolar battery and the weight reduction with lightweight nickel electrodes.

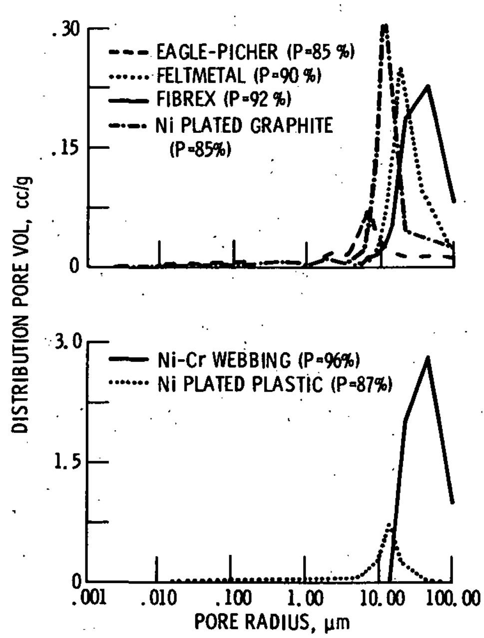


Figure 2. - Pore size distribution curves.

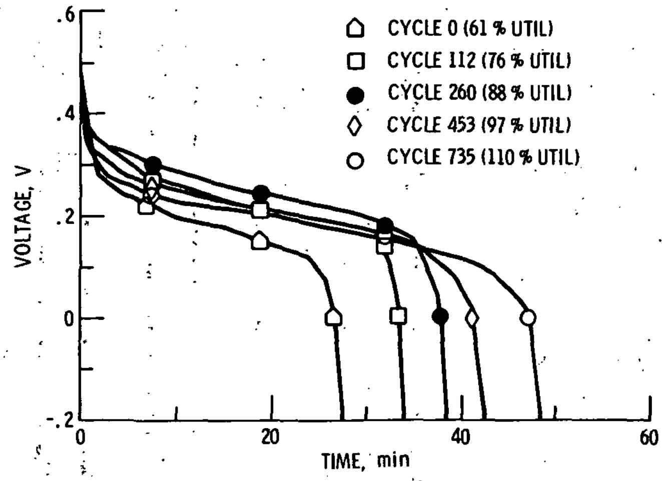


Figure 3. - Cycle life data of Feltmetal nickel electrode. Discharge rate, 1.37 C; 44-minute nominal 100-percent discharge.

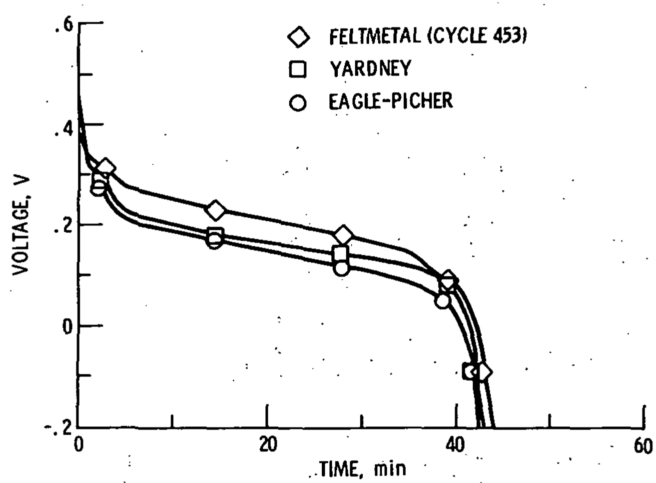


Figure 4. - Discharge curves of Feltmetal and commercial Nickel electrodes at 1.37 C rate.

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16. Abstract

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