

NICKEL HYDROGEN BIPOLAR BATTERY

ELECTRODE DESIGN

V. J. Puglisi, P. Russell, D. Verrier and A. Hall

Yardney Battery Division

ABSTRACT

Nickel Hydrogen technology is broadening to meet the expanding power requirements of the aerospace industry. This is occurring not only with the individual pressure vessel (IPV), as exemplified by the MILSTAR 70AH cell development and the Air Force Advance Development 4.5 inch diameter cell initiative, but also with multi-cell common pressure vessel development sponsored by NASA (Lewis Research Center). This latter effort is being performed by Ford Aerospace with Yardney Battery Division supporting (1).

The preferred approach of the NASA development effort utilizes a bipolar plate stacking arrangement to obtain the required voltage-capacity configuration. In a bipolar stack, component designs must take into account not only the typical design considerations such as voltage, capacity and gas management, but also conductivity to the bipolar (i.e., intercell) plate. The nickel and hydrogen electrode development specifically addressing bipolar cell operation is the subject of this paper.

Nickel oxide electrodes, having variable type grids and in thicknesses up to .085 inch are being fabricated and characterized to provide a data base. A selection will be made based upon a system level trade-off. Negative (hydrogen) electrodes are being screened to select a high performance electrode which can function as a bipolar electrode. Present nickel hydrogen negative electrodes are not capable of conducting current through their cross-section. An electrode has been tested which exhibits low charge and discharge polarization voltages and at the same time is conductive. Test data is presented.

INTRODUCTION

Nickel hydrogen cell technology is currently being utilized as the basis upon which many of the new satellite power systems are predicated. Current IPV cells have plates connected in parallel to provide an ampere

hour (AH) capacity which is the sum of the plate capacities, and exhibit the characteristic couple voltage (about 1.2V). Cells are grouped in a series string to yield a higher voltage battery. The total available power is typically under 2KW. The MILSTAR satellite program is requiring the development of a 70AH cell capability with a growth potential to 100AH, thereby advancing the state-of-the-art from the current 50AH plateau. In addition, the USAF has initiated an advanced development effort which seeks to obtain a higher capacity cell by increasing the cell's diameter from 3.5 inches to 4.5 inches. This should allow higher capacities, possibly up to 200AH, to be attainable within a passively cooled individual pressure vessel.

NASA (Lewis Research Center) has identified nickel hydrogen technology as a potential candidate to meet the multi-kilowatt power requirements of planned future missions (2). To meet these higher power demands in an efficient manner, NASA is not relying on the existing individual pressure vessel approach, but has embarked on exploration of large common pressure vessel designs (3). These design approaches have been the subject of several publications to date (4-7). Because of the size of the eventual battery (150V, 75AH) and derivatives thereof, the design will require active cooling to maintain the stack components within a 5°C range during the course of the low earth orbit duty cycle. This is a marked departure from passive cooling utilized in the present nickel hydrogen cell technology.

The preferred stack approach, based on projected superior voltage, capacity and relative simplistic design, is the bipolar arrangement shown in Figure 1. This has however necessitated a tailoring of the component design and in many instances, new developments.

This paper reports the status of nickel oxide and hydrogen electrode development being performed under the first task, entitled Initial Design, of the NASA funded effort.

NICKEL OXIDE ELECTRODE INVESTIGATION

The key desirable attributes of the nickel oxide electrode are as follows:

- high energy density and specific power
- cycle life to achieve mission goals
- thick electrodes exhibiting high performance
- conductivity with the bipolar plate

The first two attributes are required in all aerospace designs. The third, a high performance thick electrode, is particularly important with

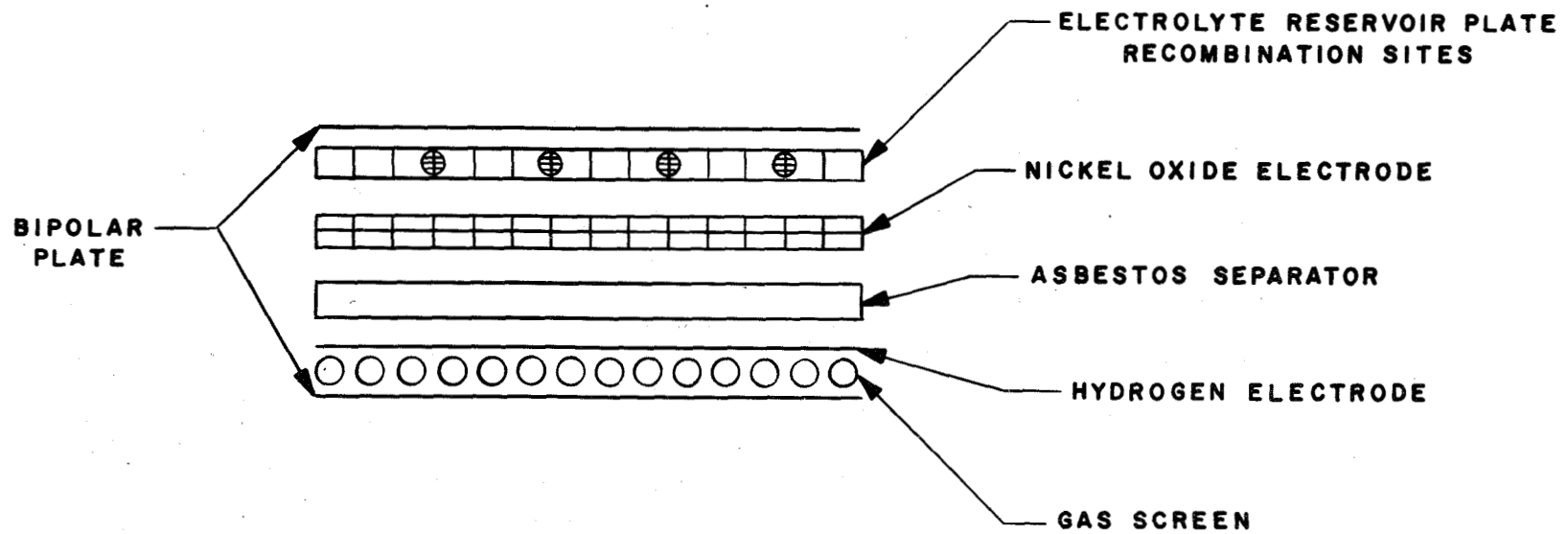


Figure 1. Bipolar Cell Stack Schematic

a bipolar configuration because a reduction in plate area results in a complimentary reduction in ancillary component weight (e.g., cooling system, bipolar plate, electrolyte reservoir plate, etc.) assuming an electrode efficiency independent of thickness. The fourth desirable attribute, conductivity of the nickel electrode with the bipolar plate was, at the program's inception, a key development question. The concern was that oxide formation on the bipolar plate during overcharge would render the interface less conductive and thereby inefficient.

Assessment of the available nickel oxide electrode types relative to a proper selection can only be made with the total system in mind. In particular, the selection must be based on the optimum 75AH battery weight and volume attainable as a function of nickel electrode thickness. For example, a minimal capacity gain, when translated in ancillary component weight savings, may be advantageous in spite of the small corresponding capacity increase with thickness.

To arrive at an electrode data base such that the type of trade-off described above can be made, characterization tests are being performed on a number of electrode types. These types include grid variations (either screen or exmet), variable number of grids per electrode (either 1 or 2), and finally variable electrode thickness (up to .085 inch). All electrodes have been fabricated employing a slurry method to manufacture sintered plaque and an aqueous electrochemical impregnation to deposit the active material within the plaque.

Characterization cycling of these electrodes is being carried out in a nickel hydrogen bipolar test cell. To ensure consistent voltage measurements, a gold-plated, nickel bipolar plate is being utilized and nickel electrode voltages are recorded versus a hydrogen (platinum) reference electrode. Characterization of each electrode type is being performed at two charge rates (15 and 100 mA/cm²) and four discharge rates (15, 50, 100 and 150 mA/cm²). A ten percent overcharge is used in all instances and discharges are terminated at 1.0 volts for purposes of capacity calculation.

Data obtained for screen grid type electrodes is shown in Figures 2 and 3. Figure 2 illustrates the capacity obtained as a function of discharge current density for various electrode thickness. All charges were at 15 mA/cm² and the ambient temperature was maintained at 20 ± 3°C. It is apparent that the dependence of capacity is relatively independent of discharge rate for all thicknesses investigated. It should be noted that the capacities obtained at the lowest discharge rate are virtually identical to the theoretical values calculated from actual active material weight gain.

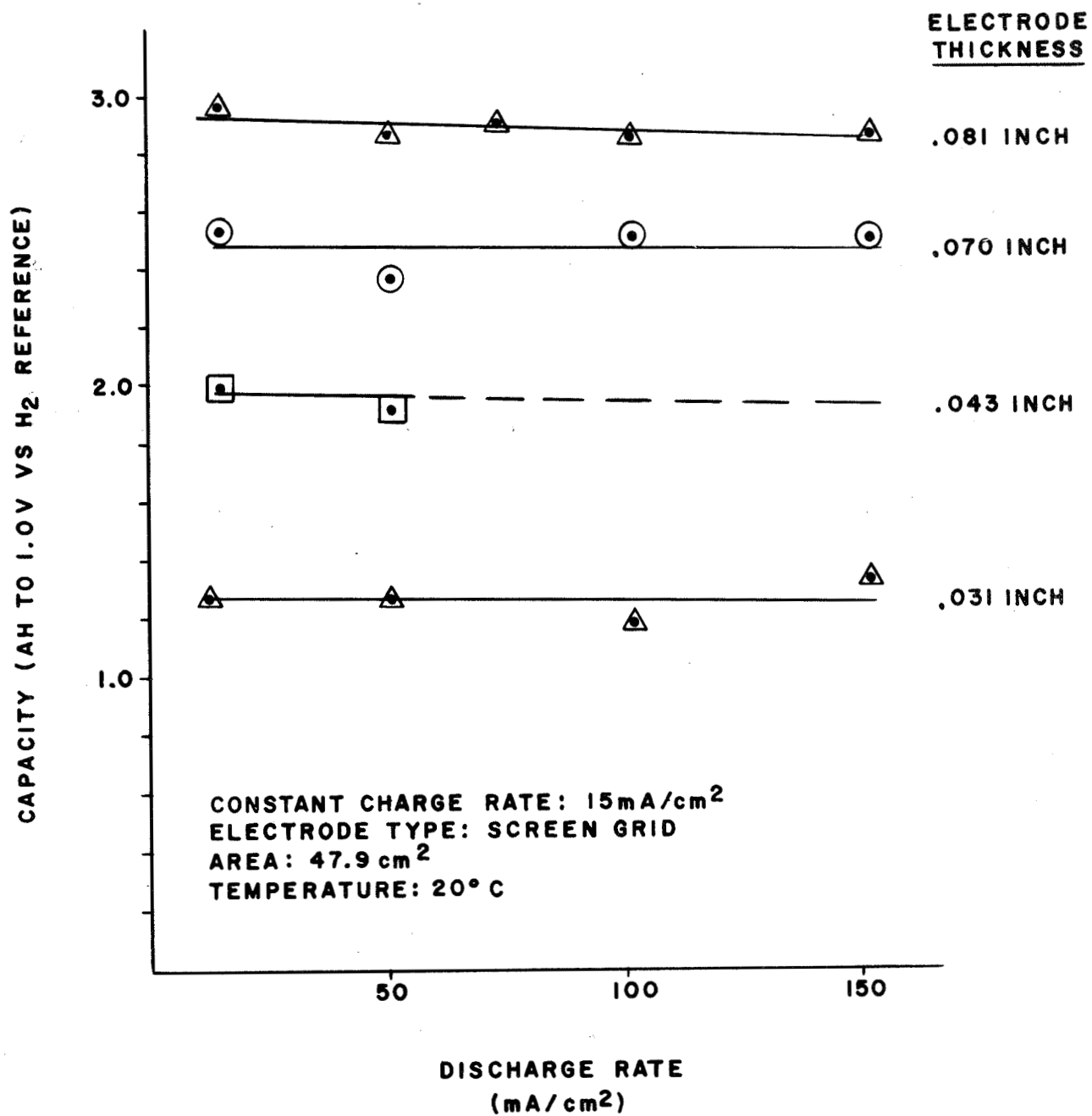


Figure 2. Nickel Electrode Capacity vs Discharge Rate

Figure 3 illustrates the dependence of plate capacity as a function of charge current density for various electrode thicknesses. All discharges were at 50 mA/cm². Although only two charge current densities (i.e., 15 and 100 mA/cm²) were used to generate the curves, the negative influence of higher charge current densities with increasing thickness is apparent.

Table I illustrates the required charge and discharge regime of a 75AH battery operating in a Low Earth Orbit as a function of depth of discharge (DOD). The discharge rate is predicated on having a total plate area of 1238 square centimeters and a discharge time of 35 minutes. The charge rate assumes a 1.10 charge input to discharge output (i.e., C to D) ratio and an allowed charge time of 55 minutes. It can be seen that for operation at 80% DOD, a discharge current density of 83 mA/cm² is required to remove the 60AH in the allowed time. Further, to return that taken out plus 10% (i.e., 66AH) in 55 minutes requires a charge current density of 58.1 mA/cm². By definition, the battery would be rated employing these 80% DOD rates by discharging to 1.0V.

To examine the performance of a bipolar cell under various conditions identified in Table I, a .079 inch thick nickel electrode (denoted type A12) was assembled as shown in Figure 1. The bipolar plates were nickel and an 0.04 inch thick electrolyte reservoir plate was interposed between the nickel electrode and the bipolar plate. The actual end-of-charge and end-of-discharge voltages of the nickel electrode versus a hydrogen (platinum) reference electrode are given in Table I. Data obtained at 20°C is presented for 40 and 80% DOD and at 10°C for an 80% DOD. Continued discharge at the 80% DOD rate and 10°C yielded an equivalent battery capacity of 87AH. The voltage data was recorded following 20 such cycles and has shown that the conductivity of the nickel electrode to the bipolar plate is not affected by cycling.

HYDROGEN (PLATINUM) ELECTRODE

The key desirable attributes for a hydrogen electrode operating in a bipolar cell configuration are as follows:

- low polarization on charge and discharge
(<25 mV at 15 mA/cm²)
- cycle life to achieve mission goals
- conductivity through the electrode's cross-section

The first two attributes are common to all aerospace applications. The third is unique to bipolar cell operation.

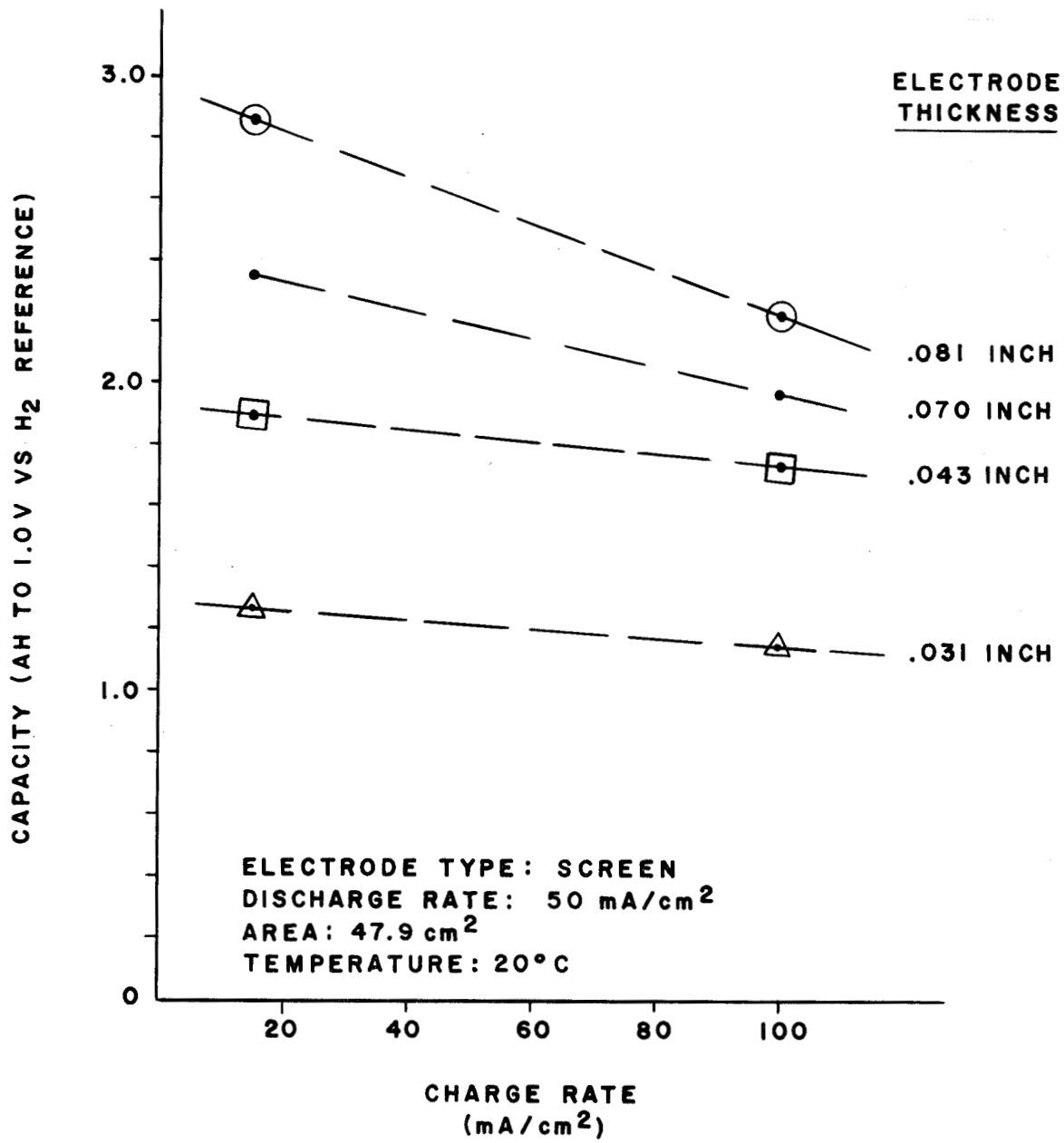


Figure 3. Nickel Electrode Capacity vs Discharge Rate

Table I. LEO¹ CHARGE/DISCHARGE PERFORMANCE VERSUS PERCENT DOD FOR A 75 AHR BATTERY²

% DOD	DISCHARGE		CHARGE		ACTUALS ³	
	AHR DEL'D.	RATE (MA/CM ²)	AHR RET'D.	RATE (MA/CM ²)	EOCV	EODV
10	7.5	10.4	8.25	7.3		
20	15.0	20.8	16.50	14.5		
30	22.5	31.1	24.75	21.8		
40	30.0	41.5	33.0	29.1	1.44	1.28
50	37.5	51.9	41.25	36.3		
60	45.0	62.3	49.50	43.6		
70	52.5	72.7	57.75	50.9		
80	60.0	83.0	66.00	58.1	1.47/1.49 ⁴	1.21/1.20 ⁴

(1) CHARGE TIME OF 55 MINUTES FOLLOWED BY A 35 MINUTE DISCHARGE

(2) POSITIVE PLATE AREA IS 1238 CM²

(3) ELECTRODE A12 IN A BIPOLAR CONFIGURATION @ 20°C, VOLTAGE MEASURED VS H₂ REFERENCE

(4) SAME AS (3) BUT AT 10°C

The commonly employed aerospace hydrogen electrode has demonstrated both low polarization and good cycle life. However, since it has a non-conductive hydrophobic backing, it is not suitable for use in a bipolar configuration. The polarization performance of this type of electrode can serve as a benchmark upon which to grade other electrode types.

Several types of available Fuel Cell electrodes were tested. These electrodes were attractive since they are conductive through their cross-section and since they have demonstrated long-term operational life. Electrodes ranging in platinum loading from 0.5 to 12 mg/cm² have been tested. It was found that although voltage performance on charge was adequate, voltage performance on discharge was variable at best. This latter behavior appears to result from flooding of these electrodes with the production of H₂O during discharge. This tended to make the voltage unstable, increasing as the discharge proceeded. A third type of electrode, developed at Yardney specifically for bipolar use, was tested. Its charge and discharge voltage performance is shown in Figure 4.

The performance of hydrogen electrodes tested showed a dependence on hydrogen pressure, with improved performance corresponding to higher hydrogen pressures. For that reason, charge and discharge curves are presented at two pressures (i.e., 100 and 600 PSIG). These pressures are projected to be close to the eventual battery end-of-discharge and end-of-charge pressures, respectively. Charge and discharge polarization curves for the standard aerospace electrode are also given as a basis for comparison.

As can be seen from Table I, the full 75AH battery is projected to operate at maximum charge and discharge current densities of 58 and 83 mA/cm², respectively. Anticipated hydrogen electrode polarization at these current densities, taken from Figure 4, are about 35 and 60 mV.

SUMMARY

Nickel electrode characterization is proceeding. Electrodes having thicknesses of up to .085 inch have been fabricated employing slurry plaque and electrochemical impregnation techniques. The dependence of capacity on discharge current density has shown thusfar to be minimal, whereas the dependence on charge current density is significant for the thicker electrodes. Data, typified by that presented above, will be generated for additional electrode types. This data base will be employed in trade-off studies to make an electrode selection yielding the optimum battery.

Candidate hydrogen electrodes have been investigated. Table II summarizes the findings to date. The aerospace type electrode was dismissed for lack of conductivity through its cross-section. The fuel cell type electrodes were found deficient in discharge performance, exhibiting evidence of flooding. A third electrode type, developed by Yardney, appears to be suitable, but must be tested to determine its life cycle capability.

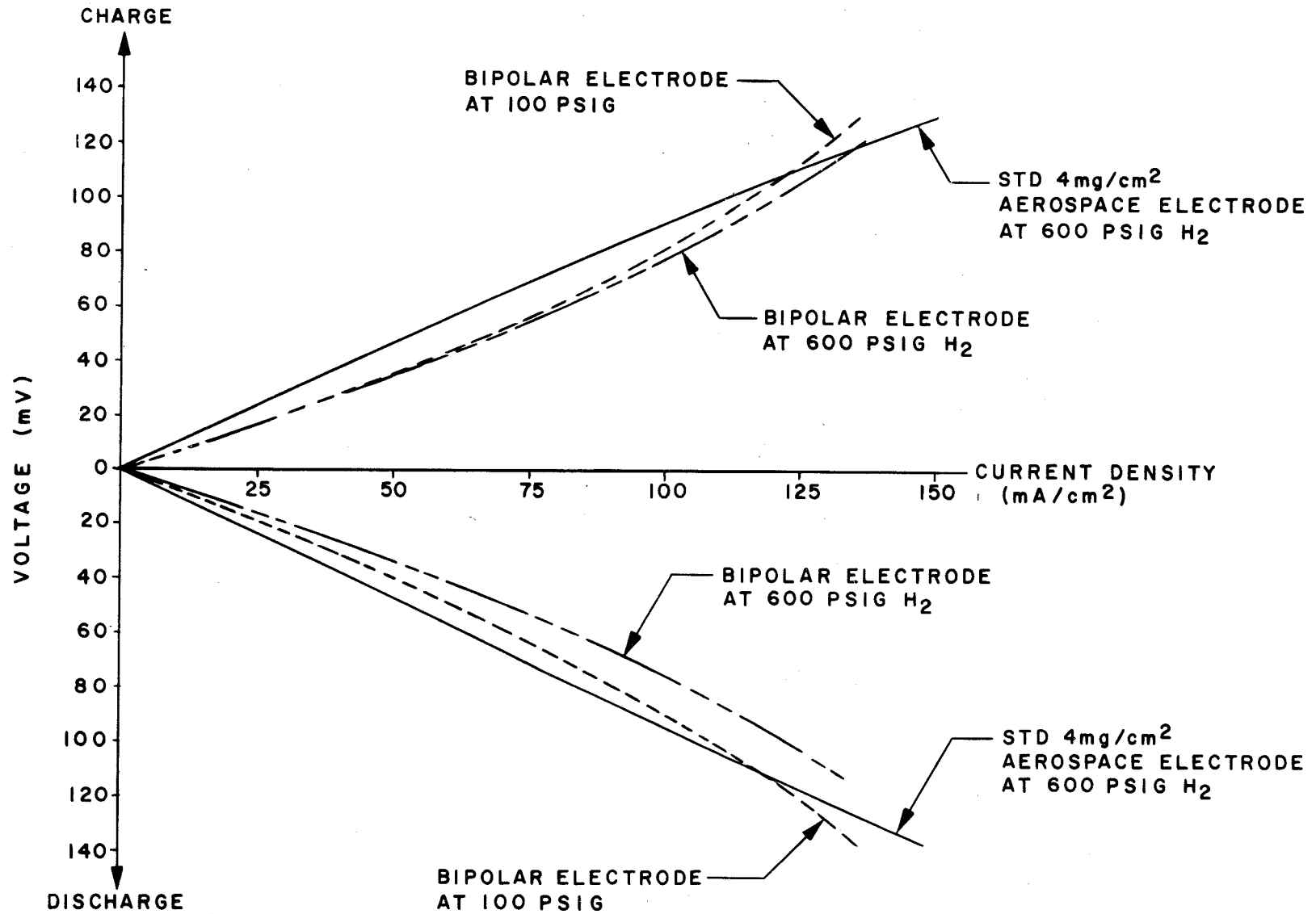


Figure 4. Hydrogen Electrode Polarization

Table II. HYDROGEN ELECTRODE ASSESSMENT

ELECTRODE TYPE	ASSESSMENT OF CHARACTERISTIC			
	CONDUCTIVITY	POLARIZATION		CYCLE LIFE
		CHARGE	DISCHARGE	
1. STATE-OF-ART AEROSPACE (4MG/CM ²)	NO	GOOD	GOOD	GOOD
2. FUEL CELL ELECTRODES	YES	ADEQUATE	POOR	GOOD
3. YARDNEY BIPOLAR ELECTRODE	YES	GOOD	GOOD	TBD

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