

## NICKEL HYDROGEN CELL CHARACTERIZATION TEST RESULTS

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I am going to present some of the nickel-hydrogen cell characterization test data that we collected during this last year. Our particular work this year was pretty much limited to charge control studies, or the kind of work that would be related to charge control.

The three areas that were covered were capacity versus temperature, our characterization; ampere-hour cycling efficiency; and charge method with respect to particular method. And the method was a voltage level with current limiting.

(Figure 6-44)

This first vugraph shows the characterization curves that we came up with for capacity versus temperature. The ordinate is capacity in ampere-hours, and we show the temperature degrees Centigrade on the abscissa. We have three curves shown here: One a typical nickel-cadmium curve; secondly, a Hughes cell, 50-ampere-hour cell from AF APL; and Eagle Picher nickel-hydrogen cell. That's a 35-ampere hour unit. It is the pineapple slice; it is an Air Force derived cell configuration.

We show the nickel cadmium here as a reference. All these three curves have all been normalized. That is, the data isn't necessarily 50 ampere-hours. It has all been normalized to 50 ampere-hours for comparison purposes.

Some points of interest. This is a different type of a characterization than you normally have; that you see people doing. That is characterizing a cell and/or an energy system where you are looking at capacity versus temperature. But it is one that shows a difference in character between nickel hydrogen and nickel cadmium which is kind of interesting.

We had heard from or we knew of the work at Hughes Aircraft, and they had indicated that capacity was improving with a reduction in temperature. This is one of the reasons we got into this investigation to begin with.

As we went lower with temperature, the capacity kept going up. So we went as far as we could go within the limits of our equipment. We couldn't get below 20 degrees. As a matter of fact, we didn't quite reach 20. I think we got to 18, and because of the means of mounting and cooling the Hughes cell, we couldn't get to minus 10. Unfortunately, with Eagle Picher's cell, we weren't able to increase the temperature because we had thermoelectric units cooling and there wasn't any way that we could maintain temperature control beyond 20°C.

A couple of things that come out as issues or have some interest or conclusions that you might reach.

One is the Hughes cell that is a 50-ampere-hour cell as far as nominal rating. But as you can see, we and most people that have been testing cells have been obtaining more like 40 ampere hours at 20°C. Don Warnock of APL got out a letter saying there was a deficiency in his line that they were correcting.

What is kind of interesting here is whatever the mechanism is that is causing this loss of capacity, it apparently is very temperature dependent, and as we go down in temperature, it approaches the Eagle Picher performance.

One of the issues that comes up is that nickel hydrogen, in general, falls off on capacity output as temperature increases. I think we have seen that on all the different designs.

The issue is, if you wanted to improve higher temperature performance, you might well be able to do it at the cost of your low-temperature performance, since it is performing so well at a temperature below what you would ever intend to operate at. There are things that could be done like the addition of cobalt hydroxide, maybe skewing the electrolyte concentration. There are numerous things that could be done that might work at a detriment to the low temperature, but may well shift the performance on the high end. And this is something that I know our project officers are upset about, and they would like to see better performances on the top end of nickel hydrogen.

This now indicates that we probably have a way, if we can determine a way of doing it effectively, it looks like there is a chance of working that out.

Another point that comes up is if we can improve the higher temperature, and this curve is so flat, the implication is that we may be able to do away with temperature compensation of the voltage level in the operation of nickel hydrogen, which would again be another improvement over the nickel-cadmium system. One of the chief reasons we do temperature compensation is that the nickel-cadmium system falls off so sharply as temperature goes down.

(Figure 6-45)

Something else that we looked at was the cycling efficiency. What we have here is an ampere-hour output on the ordinate, and ampere-hour input on the abscissa. Of course, you plot one against the other, and you come up with efficiency in terms of – I have it in terms of percent. It shows you range, 100 percent, 90 percent, and 80 percent. And along with that I have it in terms of C/D ratio.

The way we conducted this test is that we put a given amount at a rate – we have the different rates listed here – at the 50-ampere-hour rate, we put in on 45 ampere-hours, and we measured what we got out. We started on the low end and worked up, and likewise we started at the low rates and worked progressively to the greater rates.

One of the interesting things that came out of this, we charged as long as 80 ampere-hours on 50-ampere-hour units. We made sure that the overcharge was of such a nature that we got out all

that you could hope to get out of the cell. So this shows you your ultimate capacity out at given rates. Plus, of course, it shows you what efficiency you can expect at these various rates. As you can see, it is very rate sensitive.

At the 50-ampere-hour rate why we had very good efficiency right on up. At about 90-percent efficiency we got very close to rated.

(Figure 6-46)

We didn't get as far along with this work as I had hoped we would. But I do have a couple of plots here. What we show on this vugraph is cell-charge voltage versus temperature in degrees Celsius. This is a temperature compensation curve for a constant voltage system with current limit typical of what we are using on many of our spacecraft.

I worked for a current isogram. That is, we set our voltage by trial and error, came up with a constant residual or trickle current and plotted — we did this at various temperatures — and plotted the points and generated this curve. I put in a sample of a nickel cadmium, and you can see, we get very close correspondence. However, the nickel cadmium is generally set up to provide a constant ampere-hour output.

We were concerned about a constant trickle charge. The constant trickle charge is related to capacity and is very close to constant. Almost — it doesn't provide a constant capacity, but it very nearly does.

And at the very low, 0.6-ampere rate for the 50-ampere-hour unit; when we got to this region down here, the voltage for the recharge was so low that we didn't get enough charge return to recharge the battery. So I put an extended dotted line here. But, in fact, the values were so low that they were no longer useful. This is pretty much the minimum that you could work to.

Some of these currents are a little high with regard to what solar arrays normally like to put out. So that, in itself, is of some interest.

## DISCUSSION

LEAR: That first chart you showed where you did the characterization, what was the charge-discharge?

OTZINGER: I didn't mention that. We didn't try to experiment with any. We used what you might call an acceptance cycle. That is, we made certain that we got complete charge return.

(Figure 6-44)

C/10 for 16 hours, and that, by experience, is a value that always got us a full charge. Our discharge was C/2.

As I say, this was a very typical kind of operation. Each point was at least two cycles; in some cases, three and four.

One thing I didn't state that was kind of interesting. This point here, we continued on for about six cycles because we were amazed, the capacitors kept climbing. This is a plot of probably the second or third cycle capacity. But I believe we wound up, with normalization, around 68 ampere-hours. So we were still climbing.

I have asked some electrochemists the question, isn't this a surprise to see the nickel plate becoming more efficient on charge as temperature goes down?

And they said, yes it was. But apparently half-cell tests or that type of test isn't something that anyone has paid any attention to.

SCOTT: Can you say something about the end of charge voltages at these different temperatures?

OTZINGER: As might be expected, they went up. After minus 20 degrees, we were on 1.62. I was watching it carefully. I was getting a little alarmed as it was going up, but at 1.62 at minus 20, it was consistent and we weren't having any problems with it.

The temperature on the end of charge was going up uniformly. We weren't finding any dramatic behavior.

SCOTT: Also, do you know or did you calculate about what utilization of the positive material you were getting at minus 20, minus 10, or minus 20 degrees, and could not that increase in capacity simply be a growth in the actual utilization of the material that wasn't being used early in your cycling?

OTZINGER: That could well be. No, we didn't make that calculation. It is a good point.

MAURER: I want to comment on the capacity increase. That is not the difference between nickel hydrogen and nickel cadmium. It is the presence of the electrochemical positive.

A nickel-cadmium cell will do the same thing if you can make it with electrochemical positives. We used that as a final qualification test on a cell when we were making terrestrial batteries with electrochemical positives. It had to give higher capacity at lower temperatures. Otherwise, it was a reflection of an improperly made nickel electrode, and the lack of capacity increase resulted from corrosion of the sinter during impregnation giving you chemically deposited material in the pores, which massed out this capacity enhancement. If you eliminated corrosion entirely, then you got this big increase.

If you do potentiostatic scanning experiments as a function of temperature, what you find is the temperature decreases. You get the growth of a peak that we just call a gamma peak for lack of any other identification. It is something that comes out of the spectrum because the oxygen

overload goes to higher values enabling you to charge this other species, which probably is related to some nickel-poor compound.

That's what gives rise to the extra capacity. The capacity you get at 20 degrees is approximately equal to theoretical capacity of the electrode, for one electron transducer. And then you get an enhancement at lower temperatures by the introduction of this peak. If you do a potentiostatic stand so that we don't go into this subpeak region, then the capacity remains at the theoretical value.

To get the capacity up at lower temperature, you need to do some of the new things that the commercial industry has done over the years to improve charge efficiencies at the higher temperatures; sodium and various additives that increase the oxygen over potential, to enable you to charge that material. So that having a reasonably steep slope there, perhaps 120-percent utilization of the theoretically active material at roughly zero Centigrade is, I think, a reflection of good and properly prepared nickel electrochemically deposit electrode, we shouldn't try to wash it out.

OTZINGER: One thing we did notice at some higher rate charging that we did at these low temperatures, we did have multiple level voltage indicated. There was a real distortion.

MAURER: That's right. One other thing I didn't mention is at 20 degrees we can get the same effect if we simply charge at a high enough rate. You get enhancement somewhere between  $C/5$  and  $C/2$ . You get theoretical capacity below that; 120 percent above that.

CHARACTERIZATION CURVES  
CAPACITY VERSUS TEMPERATURE

CAPACITY (AMPERE-HOURS)

80  
70  
60  
50  
40

-20

-10

0

10

20

30

TEMPERATURE (DEGREES CELSIUS)

HUGHES  
NI - H<sub>2</sub>

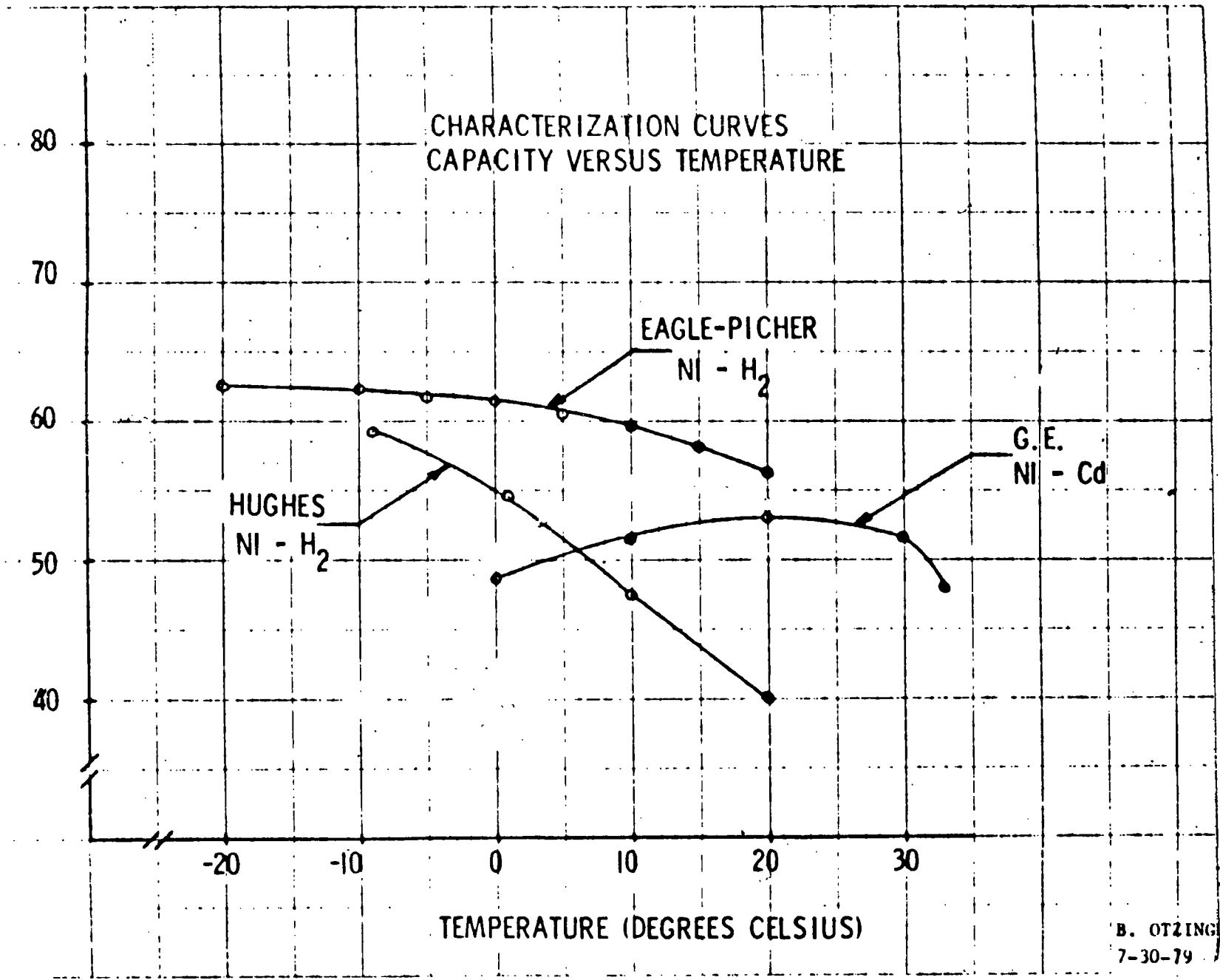
EAGLE-PICHER  
NI - H<sub>2</sub>

G.E.  
NI - Cd

530

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Figure 6-44



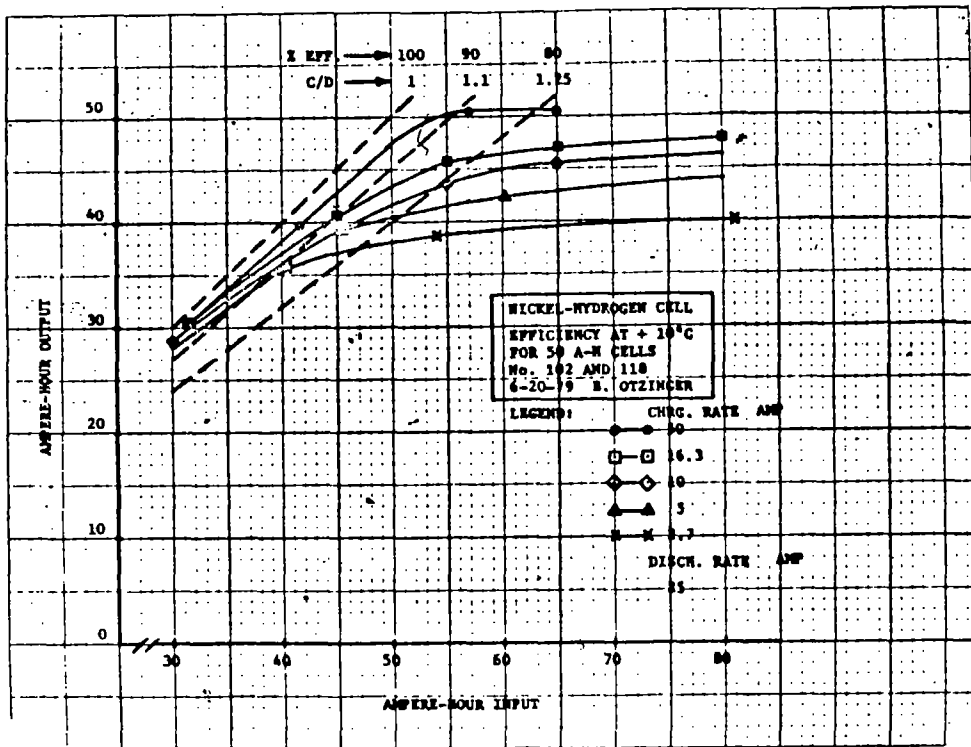


Figure 6-45

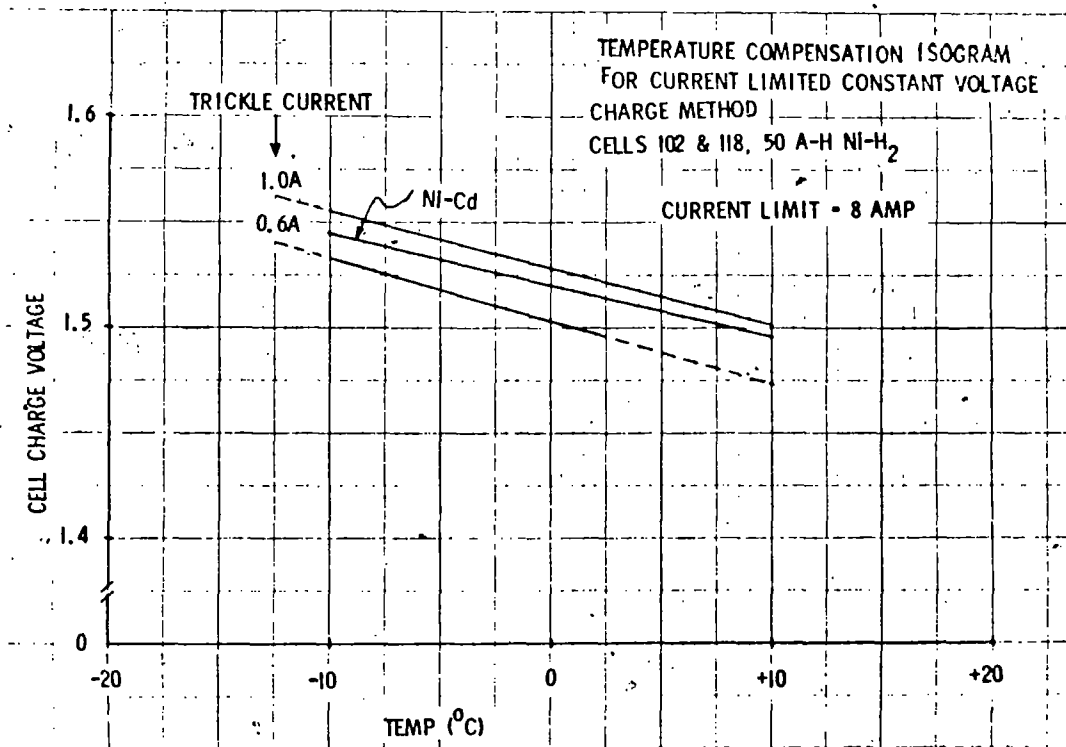


Figure 6-46