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Short Communication

Effect of charge rate on instantaneous charge efficiency of nickel/hydrogen cells

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Abstract

The charge efficiency of a nickel/hydrogen cell is an important parameter. In this work, the instantaneous charge efficiency has been determined at different charge rates and temperatures. It is found that higher charge rates result in a lower instantaneous charge efficiency over most of the charge regime. This behaviour is probably due to the effect of hydrogen on the nickel oxide electrode.

Introduction

Nickel/hydrogen batteries are widely used in space applications. Thus, studies of the operating characteristics are essential for the proper design and management of such batteries on board spacecraft. Instantaneous charge efficiency is an especially important parameter in this application. The data are required for the calculation of heat dissipated in the battery and for estimation of the battery capacity for a given recharge ratio. Since attempts to measure the instantaneous charge efficiency of nickel/hydrogen cells have been sporadic [1–4], a programme was initiated to examine this feature in a systematic manner.

In the work reported here, the charge efficiencies of a 36 A h (nominal) nickel/hydrogen cell were measured at 0, 15 and 30 °C, respectively. To understand the effect of charge rate on the charge efficiency, tests were conducted at the *C*/15, *C*/10, *C*/5 and *C*/3 rate at each temperature. Thus, the experimental conditions were defined by a matrix of four charge rates and three temperatures. The matrix was selected to encompass the conditions normally encountered in spacecraft and to include one extreme condition, namely, operation at 30 °C.

In most of the earlier studies, discharge was generally taken to only 1 V at the *C*/2 rate. It is well known, however, that considerable capacity can be removed below 1 V, particularly at lower discharge rates. Thus, in this work, cells were discharged to 1 V at the *C*/2 rate, followed by a *C*/5 discharge to 0.5 V.

Experimental

The cell was a 36 A h (nominal) nickel/hydrogen cell, type HRN 36, manufactured by SAFT, France. The design and construction details of this cell are given in

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TABLE 1

Nickel/hydrogen cell

Type	HRN 36
Nominal capacity (A h)	36
Standard capacity (A h)	42
Cell weight (g)	1090
Positive electrode	
Area (cm^2)	45
Thickness (mm)	0.92
Impregnation	electrochemical
No. plates	18
Negative electrode	
Area (cm^2)	45
Thickness (mm)	0.38
Platinum catalyst (mg/plate)	36
No. plates	18
Separator	
Material	non-woven polyamide felt
Thickness (mm)	0.32
Aqueous KOH electrolyte	
Concentration (M)	7.3
Density (g ml^{-1})	1.306
Case	
Inconel of 0.51 mm thickness	

Table 1. Tests were performed in a hot and cold chamber with the temperature controlled within ± 1 °C. The measurements and control was administered through a Solartron data logger.

The cell was discharged completely across a 0.2 Ω resistor to 10 mV and then stabilized at the test temperature for about 4 h. The cell was then charged to the required level, kept at open-circuit for 15 min, and then discharged to 1 V at the *C*/2 rate and to 0.5 V at the *C*/5 rate. The cell was then discharged across a resistor of 0.2 Ω for 16 h before commencing the next test. This procedure was repeated for charge inputs of 20, 40, 60, 80, 100, 120, 140 and 160% of the nominal capacity. At the higher charge rates, the charge input was limited to a cell voltage of 1.6 V. Thus, a charge input versus charge output chart was prepared for different temperatures and charge rates. Before each test, the cell was brought to the same low state-of-charge by discharge across a 0.2 Ω resistor.

Results and discussion

The results were first plotted in the form of charge input versus charge output expressed as a percentage of a 'standard' cell capacity. The latter was defined as the capacity at 15 °C for a charge input of 170% of the nominal capacity (36 A h) after discharge at the *C*/2 rate to 1.0 V. The standard capacity was 42 A h. The instantaneous charge efficiency of the cell was calculated from the local slope of the charge input versus the discharge curve. In the near linear region of this plot a straight line was fitted by linear regression; the regression coefficient was always >0.998.

Figure 1(a), (b) and (c) shows the variation of instantaneous charge efficiency with input at 0, 15 and 30 °C, respectively, for a discharge to 1 V at the *C*/2 rate. Figure 2(a) and (b) gives the corresponding variation for discharge to 0.5 V. It can be concluded from these data that the charge efficiency is relatively high up to an input of about 100 to 115%, and then falls to a low value. This general trend is

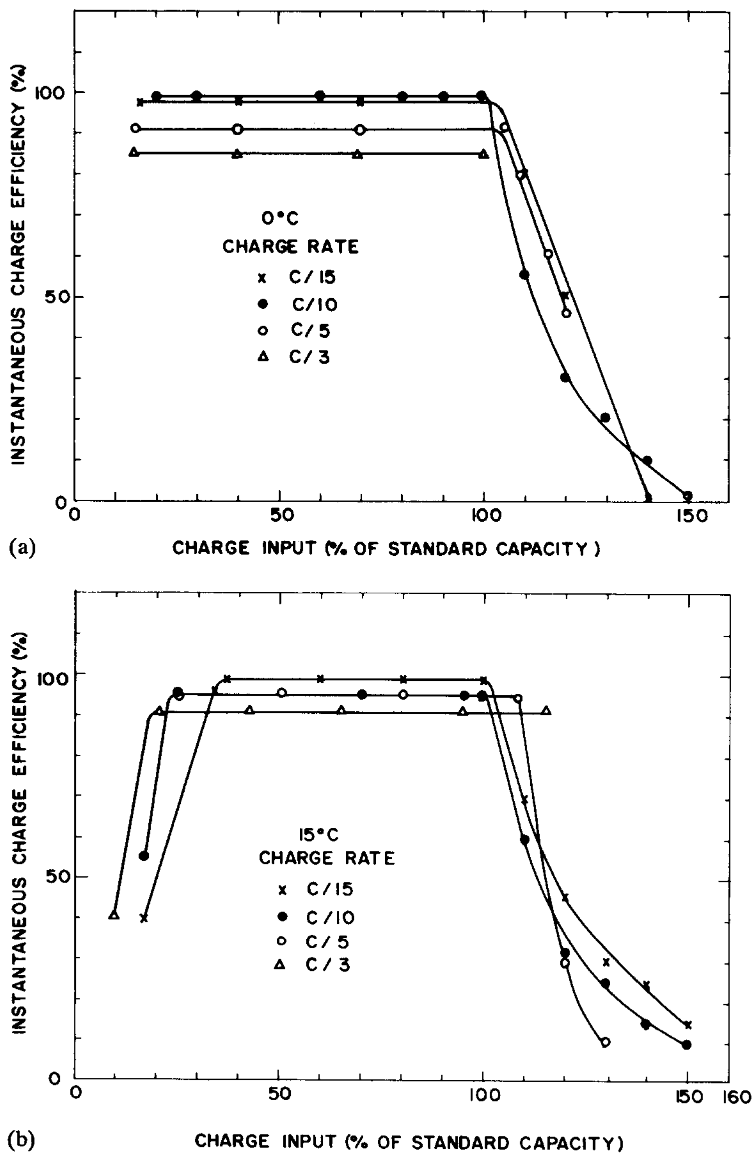
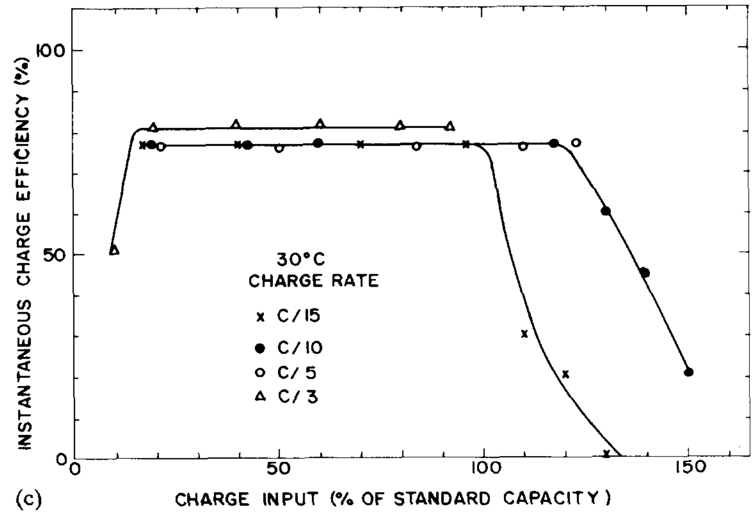


Fig. 1. *(continued)*



(c)

Fig. 1. Variation of instantaneous charge efficiency (%) with charge input for different charge rates. (a) 0 °C; (b) 15 °C; (c) 30 °C. Discharge to 1 V at *C*/2 rate.

expected. The values of instantaneous efficiency in the constant efficiency zone are listed in Table 2.

At 0 °C the charge efficiency in the constant-value zone is ~98% at the *C*/15 and *C*/10 rates, but decreases to 91% and 85% at the *C*/5 and *C*/3 rates, respectively (Fig. 1(a)). This is a surprising result as the charge efficiency is expected to increase with the charge rate. A similar trend is also observed at 15 °C (Fig. 1(b)). At 30 °C, however, the charge efficiency at the *C*/3 rate is higher than at other, lower, rates despite the fact that the absolute values of the efficiencies are lower than the corresponding values at 15 °C (Fig. 1(c)). Similar results are obtained when the discharge is taken to 0.5 V at 0 and 15 °C (Fig. 2(a) and (b)). It appears that the charge efficiency is maximum (in the constant-efficiency zone) around the *C*/10 rate. This is of particular interest in designing nickel/hydrogen batteries for low earth-orbiting satellites where high charge rates are usually employed.

From Table 2, it is found that, at the *C*/15 rate, the charge efficiency is about same at 0 and 15 °C, but decreases at 30 °C. At the *C*/10 charge rate, the charge efficiency decreases as the temperature increases. By contrast, at the *C*/5 and *C*/3 rates, the charge efficiency is highest at 15 °C and decreases at 0 and 30 °C. It appears that the maximum instantaneous charge efficiency is obtained at ~15 °C, although the difference is not pronounced.

The instantaneous charge efficiency for discharge to 0.5 V is about the same, or higher, than corresponding values for discharge to 1.0 V. The constant efficiency extends, however, to about 115% input. Except for these two differences, the general behaviour of the variation of efficiency with charge rate or temperature remains the same as that discussed above for discharge to 1.0 V, though a little less pronounced.

In the region beyond about 100% input, the charge efficiency falls rapidly to low values. No specific effects are discernible. The accuracy of the measurements is likely to be poorer in this region.

It has been suggested by Zimmerman [5] that the behaviour of the nickel oxide electrode in a nickel/hydrogen cell is different from that in a nickel/cadmium cell.

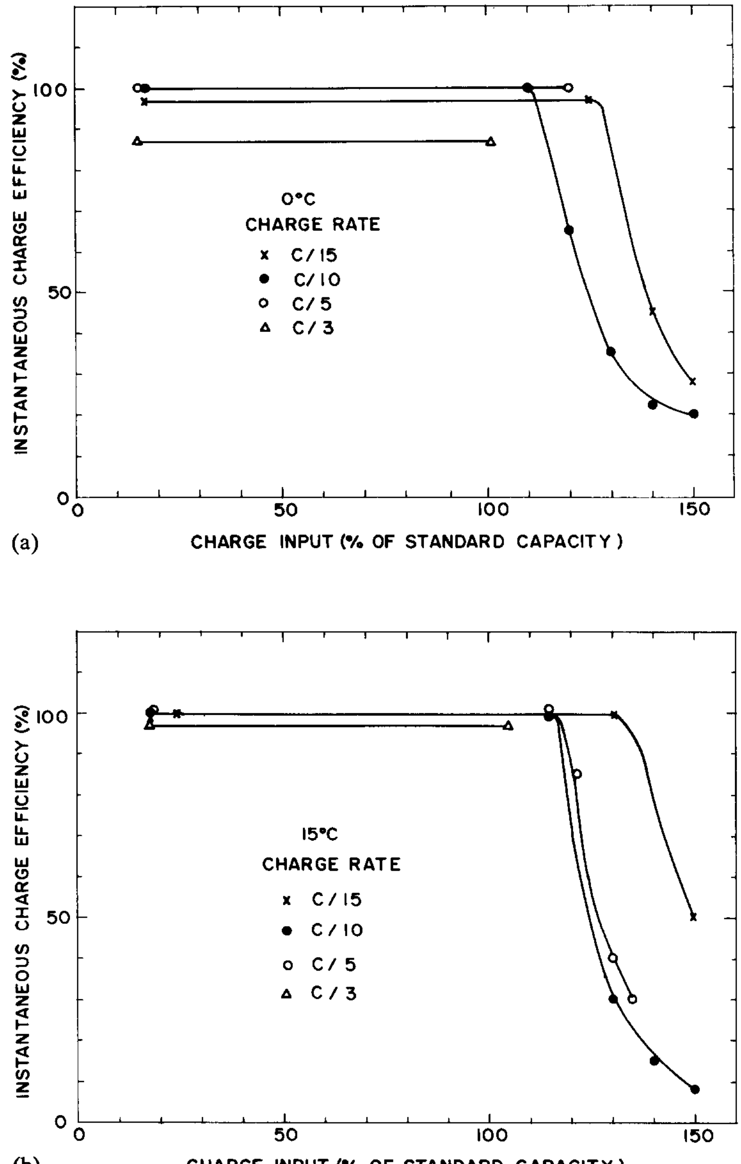


Fig. 2. Variation of instantaneous charge efficiency (%) with charge input for different charge rates. (a) 0 °C; (b) 15 °C. Discharge to 0.5 V.

This is claimed to be due to the interaction with hydrogen. The dischargeability of the nickel oxide electrode is influenced by the composition of the nickel oxides (γNiOOH + βNiOOH) produced during charging. Thus, it can be concluded that the charge rate modifies the composition of nickel oxides and this results in a lowered charge efficiency at high charge rates.

TABLE 2

Instantaneous charge efficiencies (%) of nickel/hydrogen cell

Charge rate	Charge efficiency for <100% input		
	0 °C	15 °C	30 °C
C/15	98 (98)	99 (99)	76
C/10	99 (100)	94 (100)	77
C/5	91 (99)	94 (100)	77
C/3	85 (87)	90 (97)	81

Values in brackets are for discharge to 0.5 V.

Conclusions

Variation of the instantaneous charge efficiency of nickel/hydrogen cells has been measured for different charge rates and different temperatures. It has been found that higher charge rates result in reduced efficiency at 0 and 15 °C.* This anomalous behaviour is probably attributable to the effect of hydrogen. The charge efficiency versus input curves generated in this work are useful for the design of nickel/hydrogen batteries for spacecraft.

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*Note: A variation of $\pm 1\%$ in charge efficiency is most probably due to experimental error. This is not considered significant.