34 AMPERE-HOUR NICKEL-CADMIUM MINIMUM TRICKLE CHARGE TESTING

Paul J. Timmerman
Martin Marietta Denver Aerospace
Denver, Colorado

ABSTRACT

The current rates used for trickle charging batteries are critical in maintaining a full charge and in preventing an overcharge condition. The importance of the trickle charge rate comes from the design, maintenance and operational requirements of an electrical power system. This paper describes the results of minimum trickle charge testing performed on six, 34 ampere-hour, nickel-cadmium cells manufactured by General Electric. The purpose of the testing was to identify the minimum trickle charge rates at temperatures of 15°C and 30°C.

INTRODUCTION

Five 34 ampere-hour, nickel-cadmium cells were series connected into a cell pack and used as the test article for trickle charge testing. The pack had been used in previous developmental tests, but showed no signs of degradation that might impart a bias into the test results. The pack was instrumented for battery and individual cell voltages, and a single skin temperature measurement. Data leads were soldered to the cell terminals and a copper constantine thermocouple was attached to the top of the center cell. All instrumentation leads were interfaced to the Automatic Control and Data Acquisition System (ACDAS) depicted in Figure 1.

At each of the two test temperatures, a series of four tests were performed. The first test was a baseline capacity check. This test consisted of a 1.70 ampere charge (C/20) for forty hours, followed by a -17.0 ampere (C/2) discharge to a 1.0 volt/cell cutoff. The self-discharge test has a sixteen day (384 hour) open circuit phase between the charge and discharge phases. The results of this test are used to calculate the self-discharge rate. The next test was to do the C/20 charge, a sixteen day low rate trickle charge, using the self-discharge rate as the low rate trickle charge value, and finally the C/2 discharge to the 1.0 volt/cell cutoff. The high rate trickle charge test was similar to the low rate, except the trickle charge rate was twenty-five milliamperes above the self-discharge rate. All tests were completed by shorting the cell with one ohm resistors to below 50 millivolts.

TEST RESULTS

The voltage profiles for all tests are shown in Figures 2 through 7. The capacities of the test are given in Table 1. By comparing the capacities achieved (in the self-discharge, low rate, and high rate tests) to the baseline capacity, values for the capacity losses are calculated, as shown in Table 1. The listed capacity losses are corrected values, using methods described below.

Baseline Capacity - End of 16 Day Capacity = Capacity Loss

The rate of discharge was calculated for the sixteen day open circuit or trickle charge phases. The following method was used.

Capacity Loss/Phase Time = Discharge Rate

The discharge rates at various trickle charge rates are given in Table 2. Figure 10 shows the 15°C and 30°C plots for the trickle charge rate versus the self-discharge rate. Note that the X-intercepts provide the theoretical rates of a zero capacity loss.

The efficiencies for the tests are given in Table 3. They were calculated using the following formula.

$$\text{Efficiency} = \frac{\text{Trickle Charge Rate - Discharge Rate}}{\text{Trickle Charge Rate}} \times 100$$

The Self-Discharge Rate Profile, Figure 12, shows the projected self-discharge for a zero to forty Celsius range.

The test results were calculated in a way which minimizes all possible sources of error. The effects of test anomalies on voltage are seen in Figures 3 and 4. Figures 8 and 9 reveal that temperature is a direct cause of some of these anomalies. The temperature plots reveal a direct correlation between temperature and voltage. The effect of these anomalies upon other calculated parameters is not nearly as apparent. Using the curves for efficiency, self-discharge, trickle-charge effectiveness, and voltage, it is possible to evaluate the effect of, and often compensate for, these variations.

The sixteen day long phases of testing were sometimes punctuated with anomalies. We can talk about two types of these anomalies. The first type is the simple test abort during a self-discharge test. The down time experienced can be compensated for in an easy manner.

Discharge Rate = Capacity Loss/Phase Time + Down Time

The second type of anomaly occurred during a trickle charge phase. A method for compensating for the second anomaly was as follows:

$$\text{Corrected Capacity Loss} = \text{Measured Capacity Loss} - \text{Self-Discharge Rate} \times \text{Down Time}$$

This method yielded accurate corrections if the down time was accurate and the self-discharge rate was truly representative.

One case where the self-discharge rate was not a true representation of the changes occurring was the low rate trickle charge at 15°C (Figure 4). Figure 9 shows a 15°C temperature while the test was running. The peaks represent chamber control failures, which resulted in test aborts. The temperature while in a test abort condition were not represented. Test histories show that 30°C is a more representative temperature during the test's down time. It follows that the 30°C self-discharge rate, and not the 15°C self-discharge rate, was the correct factor to use.

The effect of changing the abort temperature is to raise the used self-discharge rate from 10 mA to 14 mA. The recomputed corrected capacity loss was affected by 4% for the low rate trickle charge test at 15°C. The measured capacity loss was -3.39 AH. With a 10 mA self-discharge rate, the correction factor for the 31.7 hours of down time was +0.32. And with a 14 mA self-discharge rate, the recomputed correction factor for the 31.7 hours of down time was 0.44 AH. Thus, the baseline and recomputed corrected capacity losses were -3.07 AH and -2.95 AH respectively. The discharge rates were 8.0 mA and 7.7 mA respectively, which also reflected a 4% delta.

The high rate trickle charge test at 15°C shows variations in voltage during the sixteen day test phase which appear unnatural (see Figure 3). Figure 8, the low rate trickle charge temperature plot, reveals an inverse relationship between the temperature and voltage which is quite sensitive. The cell characterization plots, Figures 10 through 12, demonstrate the effects of deviations and anomalies. Figure 8 depicts a temperature deviation as great as 1.5°C.

With a slope of +0.32 (mA/°C) for the Self-Discharge Rate Profile, Figure 12, the 1.5°C drop in temperature would result in a smaller self-discharge rate by 0.5 mA. Another significant factor is the efficiency's dependency on temperature. The slope depicted in Figure 11, Trickle Charge Efficiency, is +0.80 (%/°C). This results in a 1.2% decrease in the efficiency of the trickle charge.

The direct effect of the 1.5°C decrease on the 34 mA trickle charge at 15°C was to alter the effective charge rate by 6%, from 7.2 mA to 6.8 mA. This is the result of the efficiency decreasing to 19.8%, which in turn gives us a -3.2 mA discharge rate. The additional 0.5 mA decreases the discharge rate to -2.7 mA. The net change from -2.8 mA is 4%.

The 1.5°C value used was a worst case figure, which is too large for the temperature plot for test 211. A more realistic figure is a 0.5°C drop average over the length of the sixteen day test phase. This would point to an error of slightly over 1% in the calculated results.

CONCLUSION

By using the curves generated from the test results, trickle charge rates can be determined for most circumstances. A rate can be calculated after the temperature and acceptable rate of discharge have been determined. One constraint upon this is that the temperatures considered are not extremes of the range studied. The linearity of the graphs, often dictated by only two points, undoubtedly falters at the extremes. This also applies to the rates, which must also be in the normal range. The normal operating temperature for the 34 ampere-hour battery is represented by the curves in this report. The plot for trickle charge effectiveness, Figure 10, represents the most critical data for design, maintenance, and operation. With the three existing points, the linearity of the plots were supported. A linear interpolation gives us the values for zero loss trickle charge rates at 15°C and 30°C. The respective rates were determined to be 49 milliamperes and 40.5 milliamperes. It is interesting to note the lower rate necessary at the higher temperature. This can be attributed to the greater trickle charge efficiency at the higher temperature.

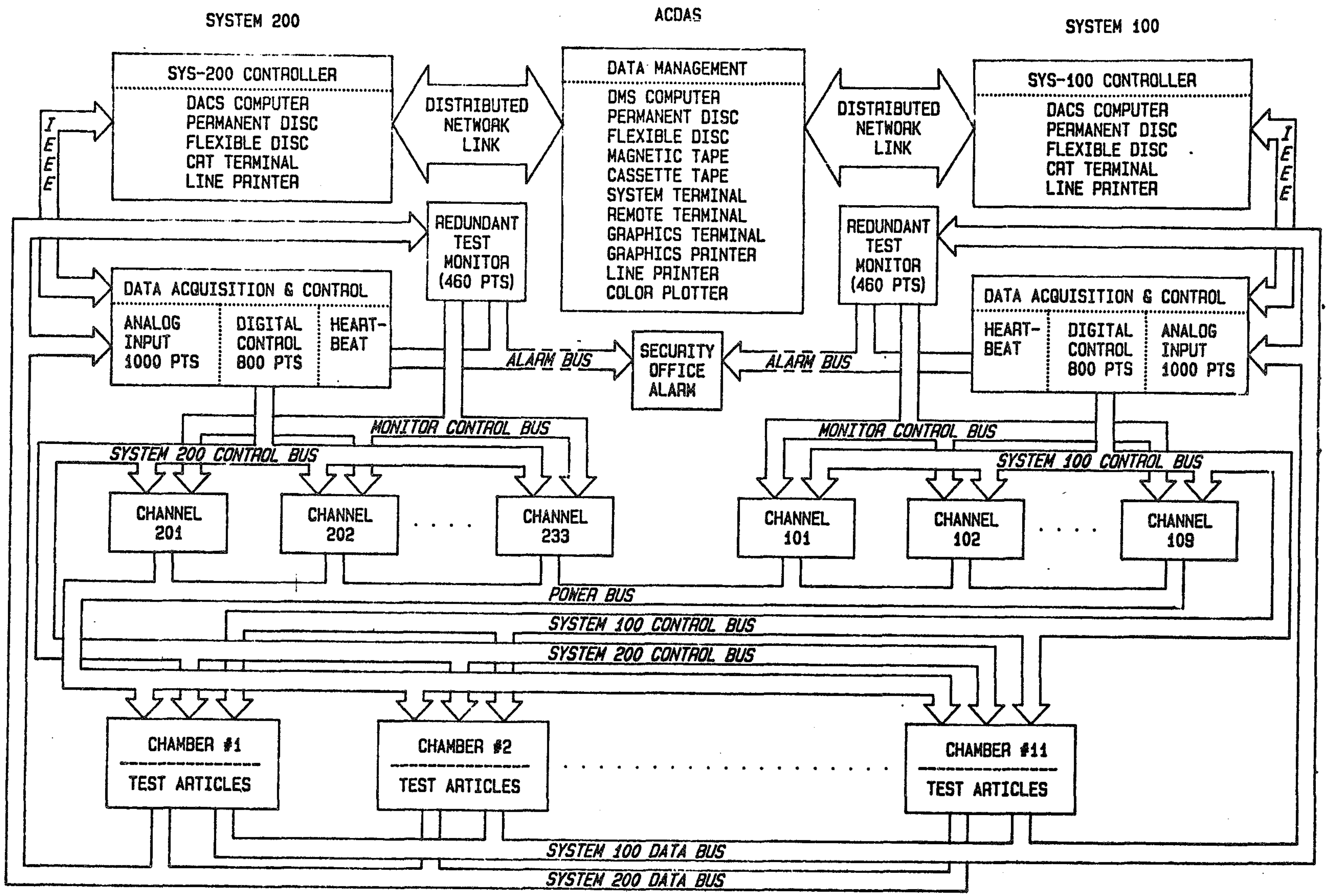

Figure 1. Block Diagram of the Automatic Control and Data Acquisition System

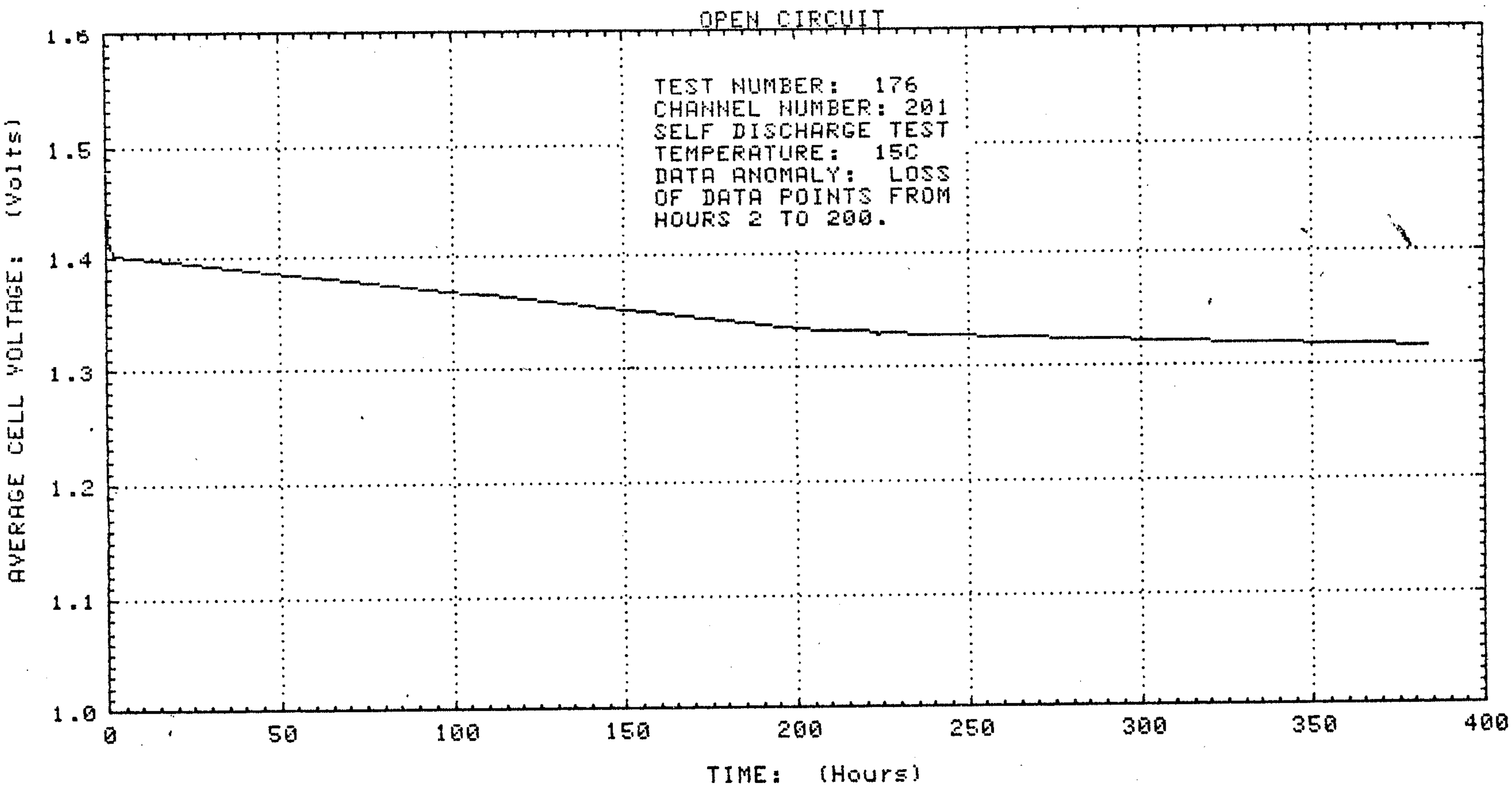
OPEN CIRCUIT
TEST NUMBER: 176
CHANNEL NUMBER: 201
SELF DISCHARGE TEST
TEMPERATURE: 15C
DATA ANOMALY: LOSS
OF DATA POINTS FROM
HOURS 2 TO 200.
AVERAGE CELL VOLTAGE: (Volts)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
50
100
150
200
250
300
350
400
TIME: (Hours)

Figure 2.

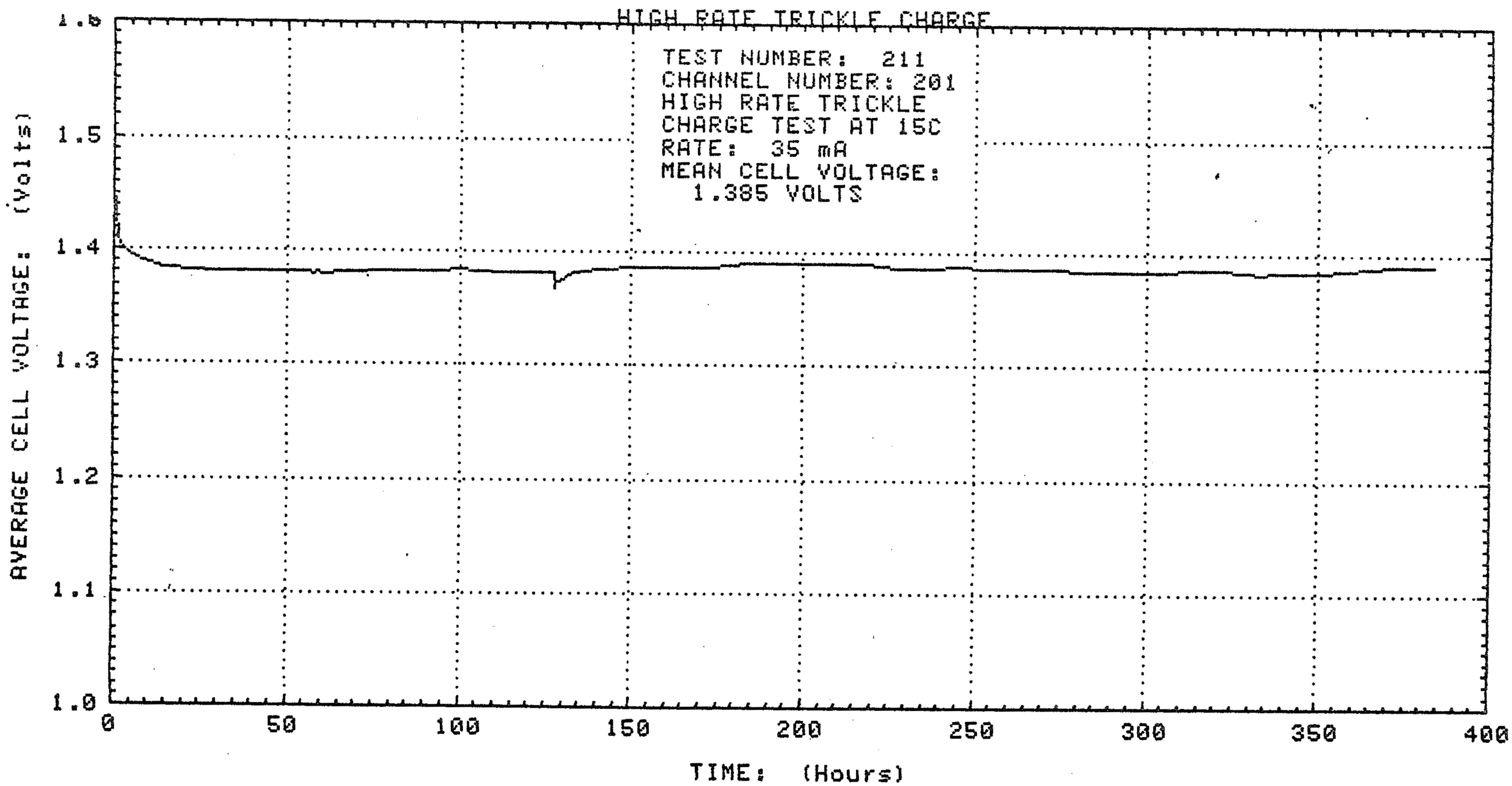
HIGH RATE TRICKLE CHARGE
TEST NUMBER: 211
CHANNEL NUMBER: 201
HIGH RATE TRICKLE
CHARGE TEST AT 15C
RATE: 35 mA
MEAN CELL VOLTAGE:
1.385 VOLTS
AVERAGE CELL VOLTAGE: (Volts)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
50
100
150
200
250
300
350
400
TIME: (Hours)

Figure 3.

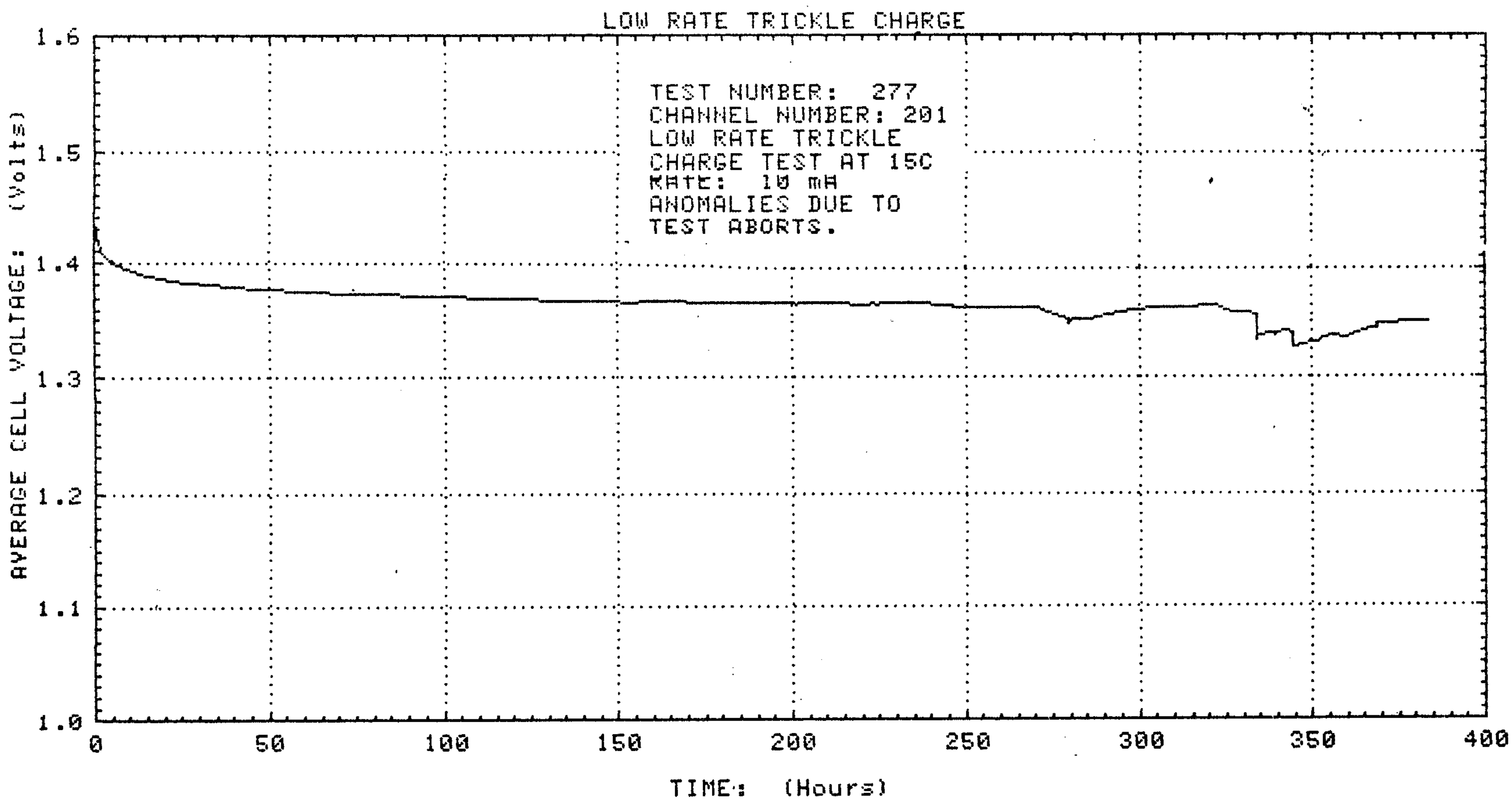
LOW RATE TRICKLE CHARGE
TEST NUMBER: 277
CHANNEL NUMBER: 201
LOW RATE TRICKLE
CHARGE TEST AT 15C
RATE: 10 mA
ANOMALIES DUE TO
TEST ABORTS.
AVERAGE CELL VOLTAGE: (Volts)
1.0
1.1
1.2
1.3
1.4
1.5
1.6
0
50
100
150
200
250
300
350
400
TIME: (Hours)

Figure 4.

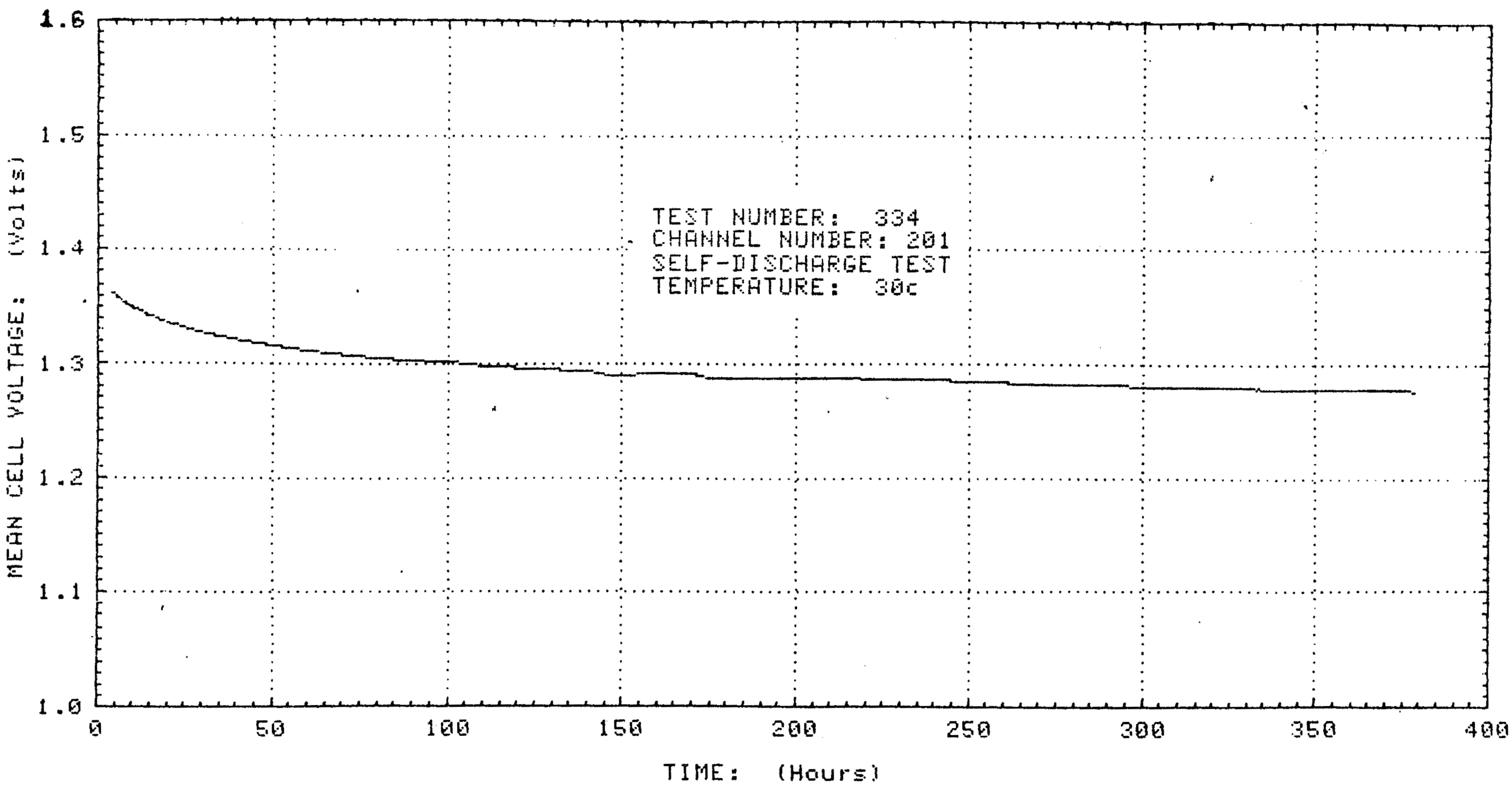
TEST NUMBER: 334
CHANNEL NUMBER: 201
SELF-DISCHARGE TEST
TEMPERATURE: 30c
MEAN CELL VOLTAGE: (Volts)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
50
100
150
200
250
300
350
400
TIME: (Hours)

Figure 5.

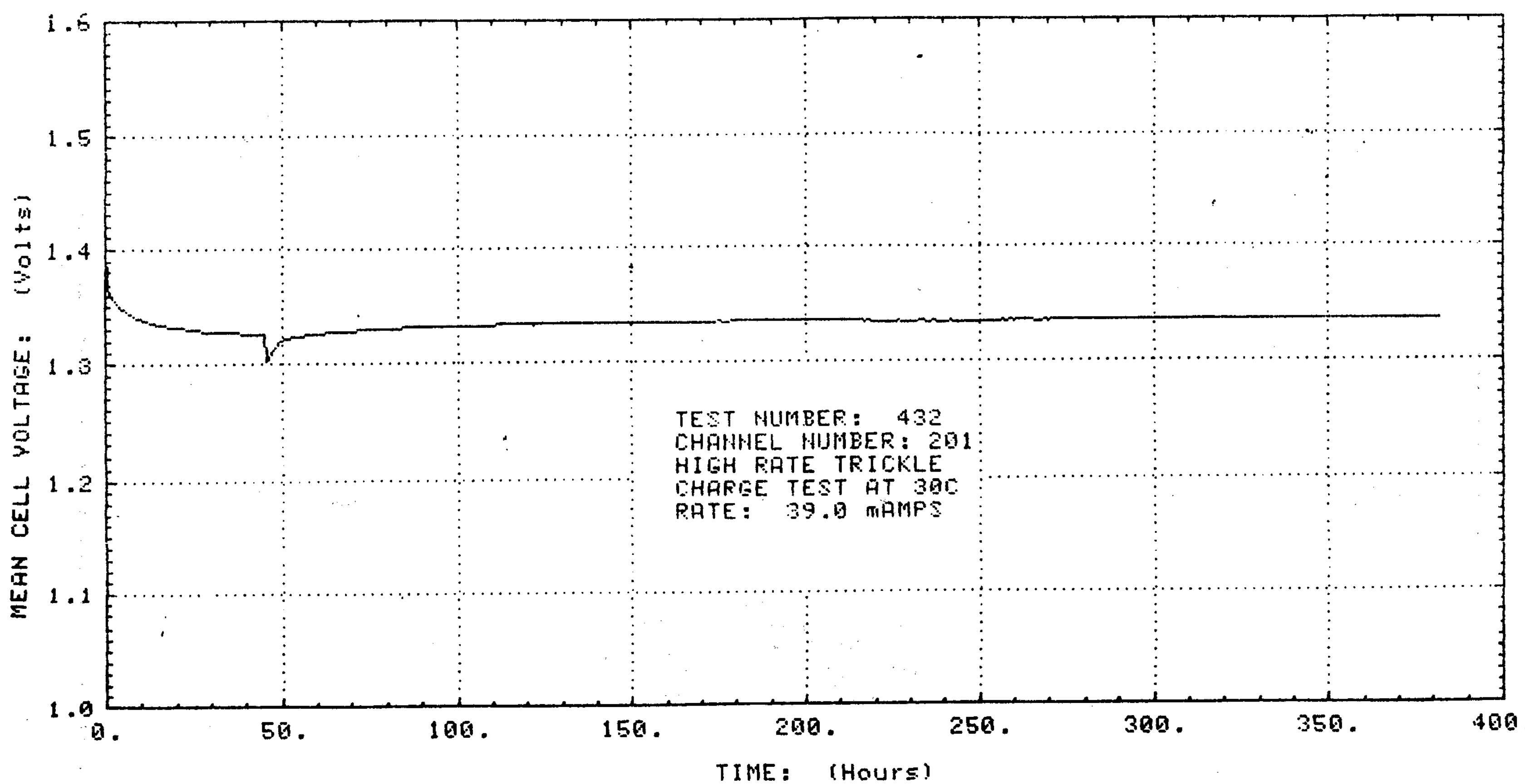
MEAN CELL VOLTAGE: (Volts)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.
50.
100.
150.
200.
250.
300.
350.
400.
TIME: (Hours)
TEST NUMBER: 432
CHANNEL NUMBER: 201
HIGH RATE TRICKLE
CHARGE TEST AT 30C
RATE: 39.0 mAMPS

Figure 6.

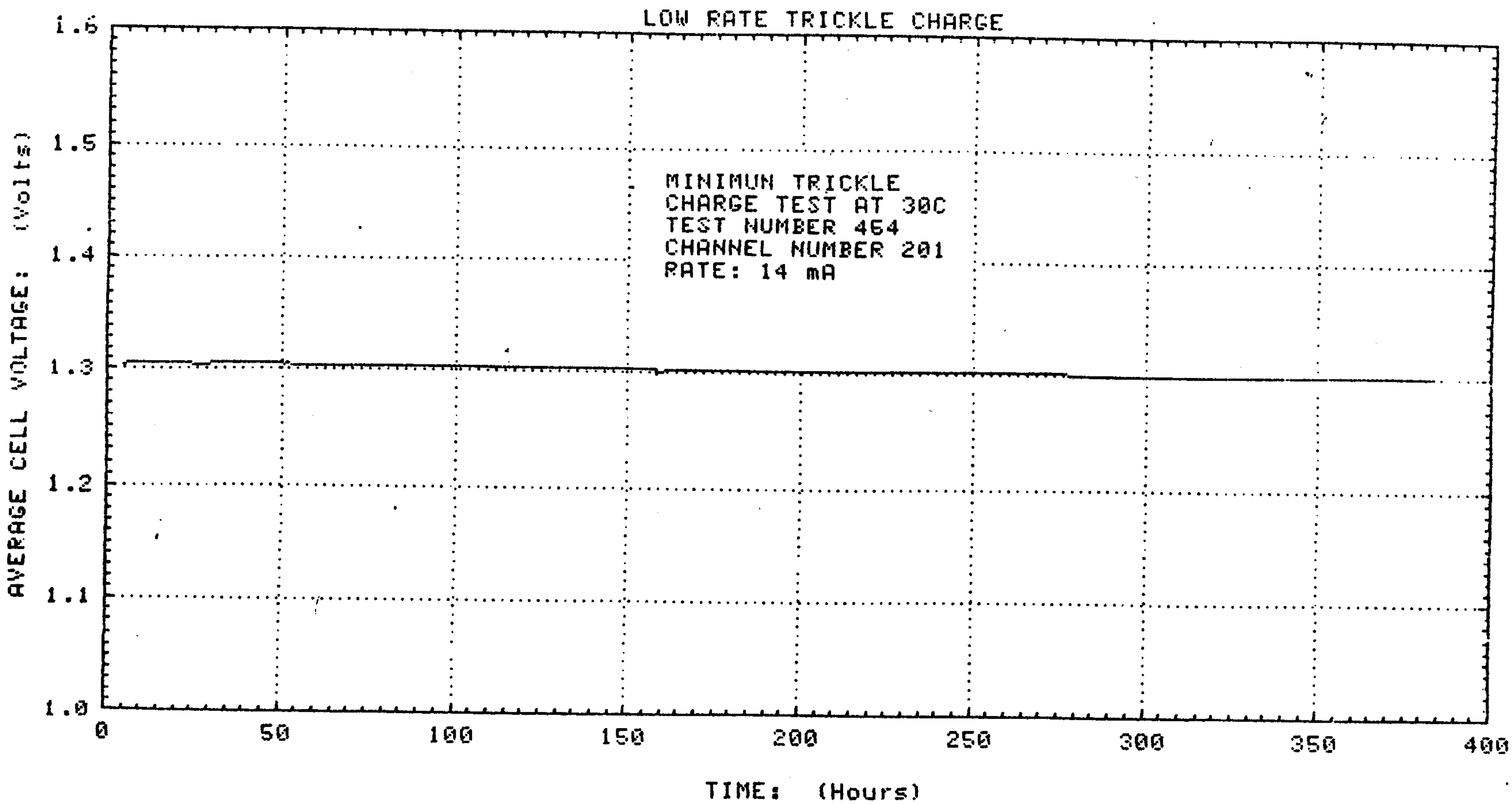
LOW RATE TRICKLE CHARGE
MINIMUN TRICKLE
CHARGE TEST AT 30C
TEST NUMBER 464
CHANNEL NUMBER 201
RATE: 14 mA
AVERAGE CELL VOLTAGE: (Volts)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
50
100
150
200
250
300
350
400
TIME: (Hours)

Figure 7.

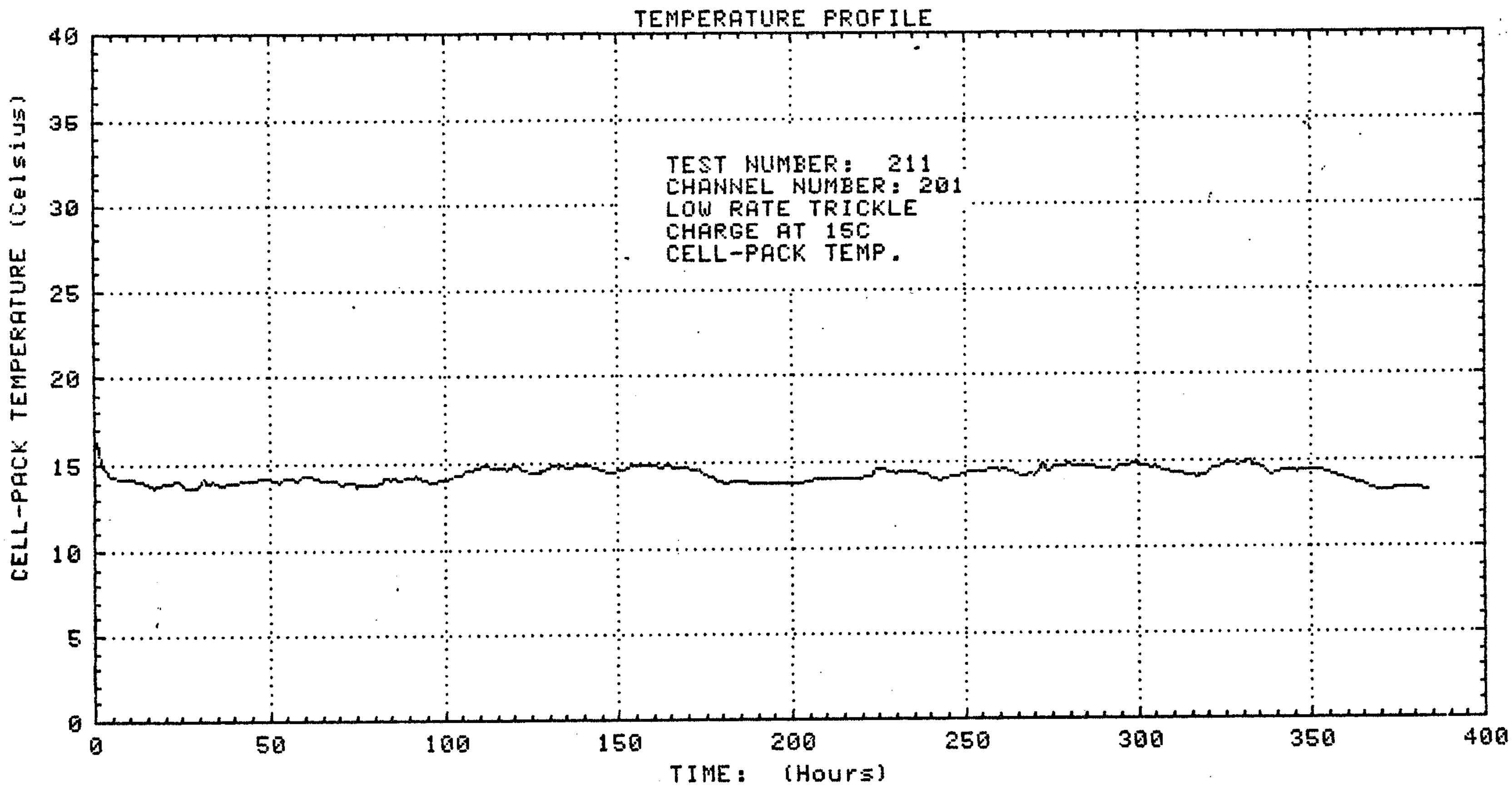
TEMPERATURE PROFILE
CELL-PACK TEMPERATURE (Celsius)
TIME: (Hours)
TEST NUMBER: 211
CHANNEL NUMBER: 201
LOW RATE TRICKLE
CHARGE AT 15C
CELL-PACK TEMP.
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400

Figure 8.

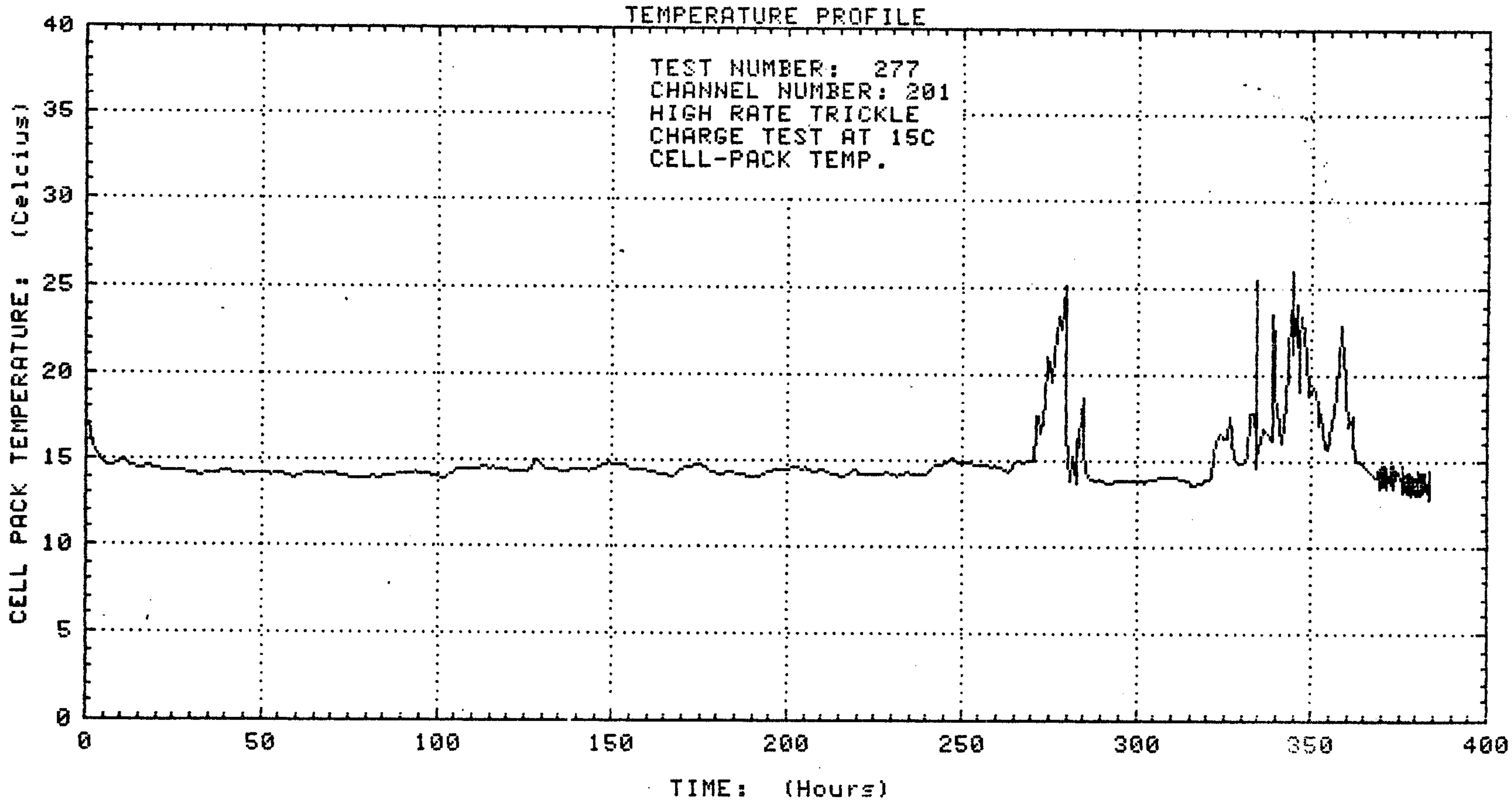
TEMPERATURE PROFILE
TEST NUMBER: 277
CHANNEL NUMBER: 201
HIGH RATE TRICKLE
CHARGE TEST AT 15C
CELL-PACK TEMP.
CELL PACK TEMPERATURE: (Celcius)
TIME: (Hours)
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400

Figure 9.

Table 1.

CAPACITIES

TEST	15c	30c
BASELINE CAPACITY	40.68 AH	39.21 AH
SELF-DISCHARGE	36.99 AH	33.85 AH
HIGH RATE TRICKLE CHARGE	39.65 AH	38.61 AH
LOW RATE TRICKLE CHARGE	37.39 AH	35.48 AH
HIGH RATE CAPACITY LOSS	2.78 AH	0.38 AH
LOW RATE CAPACITY LOSS	3.08 AH	3.73 AH

Table 2.

TEST DESCRIPTION	15 c		30 c	
	TRICKLE RATE	DIS-CHARGE RATE	TRICKLE RATE	DIS-CHARGE RATE
SELF-DISCHARGE	0.0 mA	9.8 mA	0.0 mA	14.0 mA
LOW RATE TRICKLE	10.0 mA	8.0 mA	14.0 mA	9.7 mA
HIGH RATE TRICKLE	35.0 mA	2.8 mA	39.0 mA	0.6 mA

Table 3.

CHARGE EFFICIENCIES

TEST DESCRIPTION	15 c	30 c
LOW RATE TRICKLE CHARGE	20 %	31 %
HIGH RATE TRICKLE CHARGE	21 %	34 %

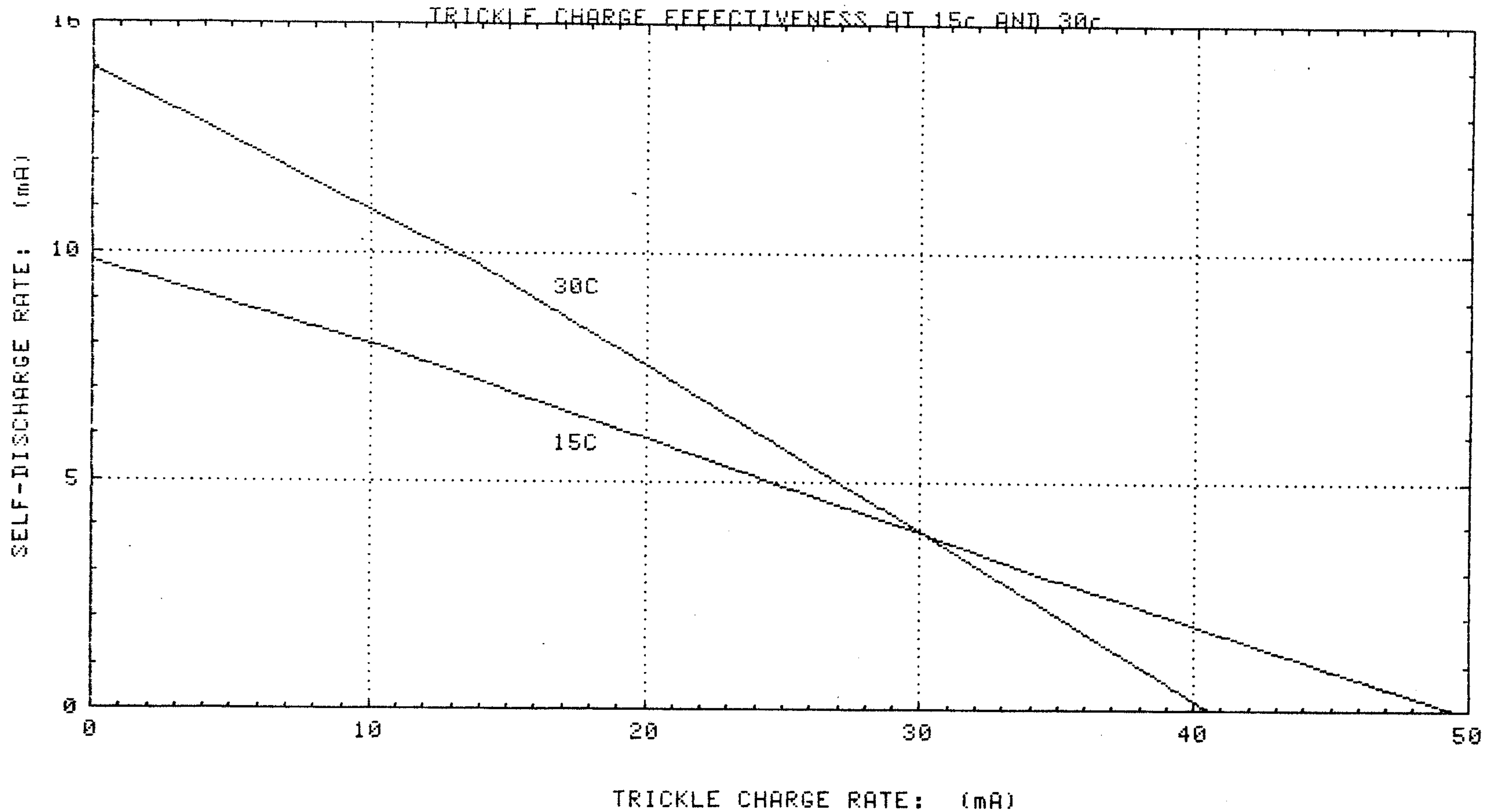
TRICKLE CHARGE EFFECTIVENESS AT 15c AND 30c
SELF-DISCHARGE RATE: (mA)
TRICKLE CHARGE RATE: (mA)
30C
15C
0
5
10
0
10
20
30
40
50

Figure 10.

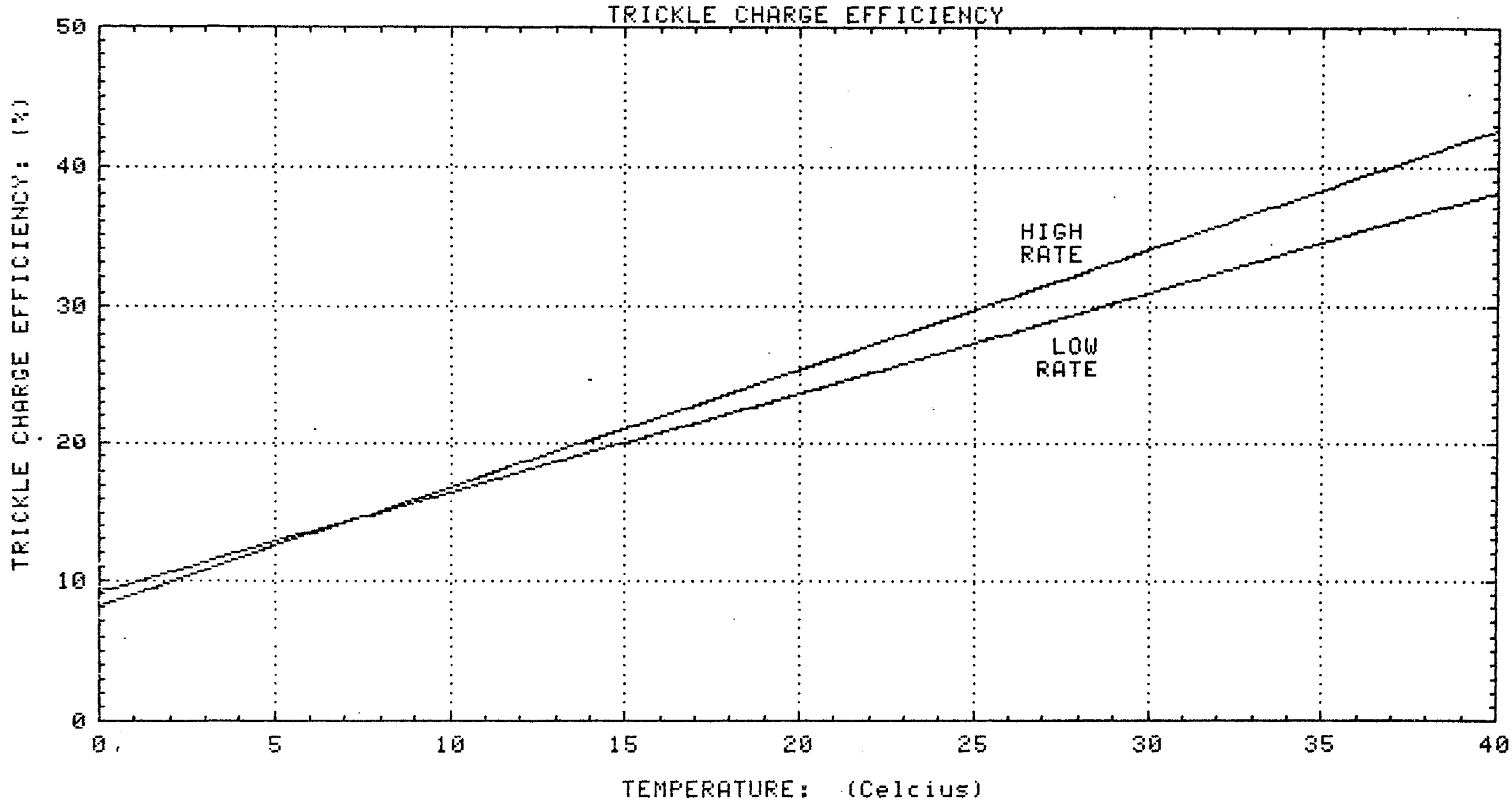
TRICKLE CHARGE EFFICIENCY
TRICKLE CHARGE EFFICIENCY: (%)
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
HIGH RATE
LOW RATE
TEMPERATURE: (Celcius)

Figure 11.

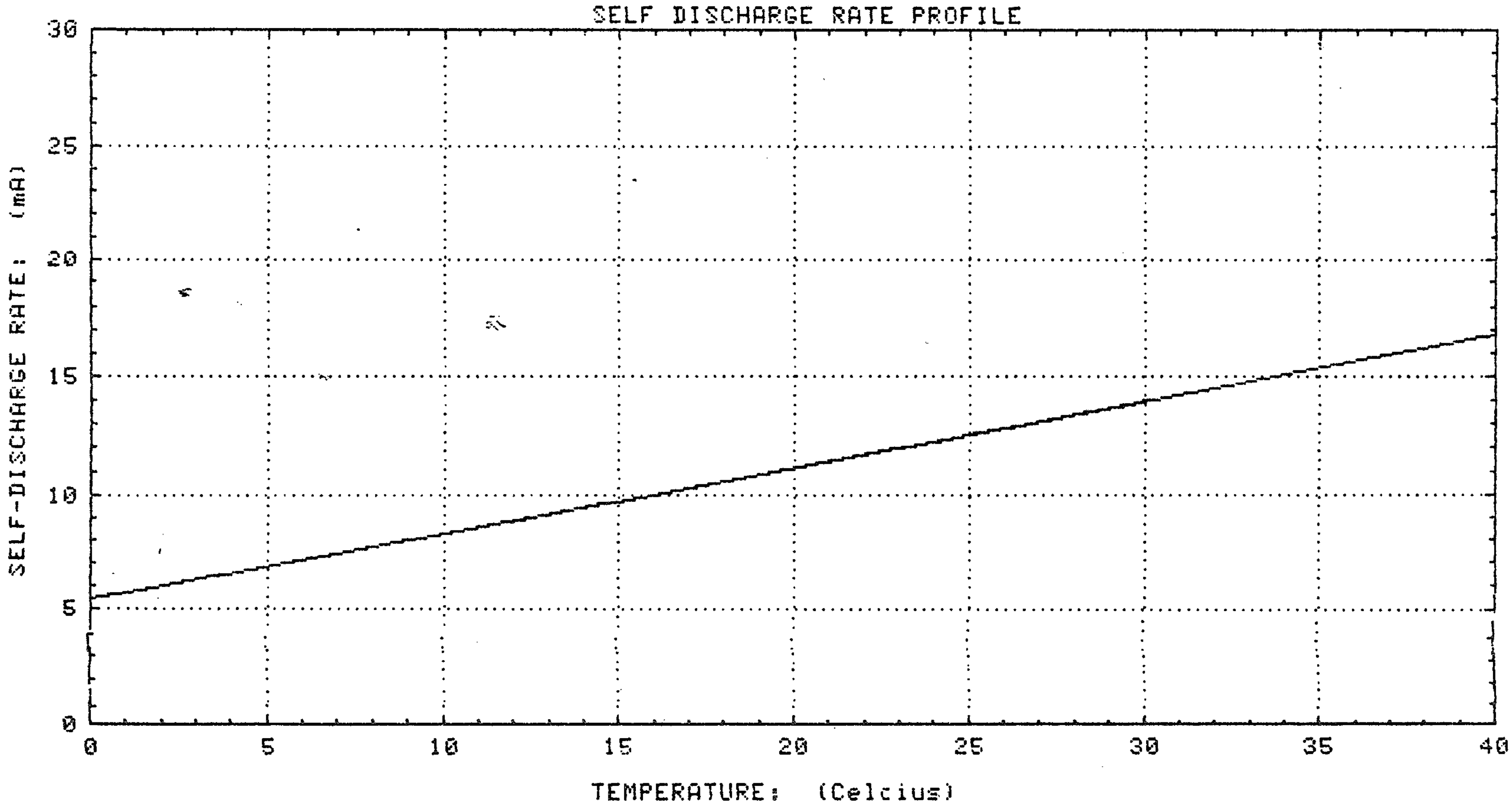
SELF DISCHARGE RATE PROFILE
SELF-DISCHARGE RATE: (mA)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
TEMPERATURE: (Celcius)

Figure 12.