FIFTH PROGRESS REPORT

FOR

RESEARCH INTO FUNDAMENTAL PHENOMENA ASSOCIATED WITH SPACECRAFT ELECTROCHEMICAL DEVICES — CALORIMETRY OF NICKEL-CADMIUM CELLS

July 1, 1967 — September 30, 1967

Contract No. NAS 5 — 10105

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ABSTRACT

The objectives of this project are to train electrochemists in the area of battery research and to collect electrochemical and thermodynamic data of value to projects being conducted at the Goddard Space Flight Center.

The work completed during this reporting period involved measuring the thermal characteristics of a 20 ampere-hour nickel-cadmium cell during 90-minute cycles including 30-minute discharge at 25% depth and 60-minute charge at 105% rate. The data tabulated from the experiment were taken from the selected orbits numbers 18, 19, 20, 30, 40, 50, 60, 70, 82, and 90. The parameters measured during the course of the experiment were, the thermal output, the electrical work, the cell potential, the pressure transducer signal, and the Adhydrode signal. The maximum thermal output of 4 watts is tentatively reported, recognizing that its variation from other measurements must be explained by further investigation. The enthalpy (ΔH) of reaction was calculated from this experiment as 31.5 Kcal/equiv.. The relationship between the above cell parameters during the experiment were also observed and discussed.

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Research Into Fundamental Phenomena Associated With Spacecraft Electrochemical Devices - Calorimetry of Nickel - Cadmium Cells

I INTRODUCTION

The objectives of this project are

1) to train electrochemists in the area of battery research and

2) to collect electrochemical and thermodynamic data of value to projects being conducted at the Goddard Space Flight Center.

A review of the accomplishment just prior to July 1, 1967 would show

1) the design and construction of a larger calorimeter to accommodate higher capacity cells;

2) a change in the flow pattern of the oil external to the calorimeter to achieve more uniform thermal response;

3) the construction of an improved heat exchanger for the constant temperature bath and

4) the construction of a new thermopile.

Following the above changes , calibration experiments were performed on the heater and the pressure transducer.

During the present reporting period the first in a series of experiments on a 20 ampere - hour nickel-cadmium cell were performed. This experiment consisted of cycling a 20 ampere-hour cell through 90 orbits at 25% depth of discharge and a 105% rate of recharge.

II. EXPERIMENTAL

Experimental Series F involved cycling a 20 ampere- hour nickel-cadmium cell through 90 orbits. Each orbit was of 90-minute duration -30 minutes in discharge and 60 minutes in charge. The discharge was at 25% depth or actually at 9.90 amperes; the charge rate was 105% or 5.20 amperes. The nickel-cadmium cell was a Gulton Industries type VO-20 HSAD fitted with a pressure transducer. During the test program the current and voltage of the cell were recorded on individual Honeywell Electronik 17 recorders, Model 311. The Adhydrode* signal and the pressure transducer signal were both recorded in millivolts on Moseley Autograf Strip Chart Recorders Model 680. The thermal measuring circuit consisted of an L & N stabilized DC microvolt amplifier #9835-B and the L & N Speedomax Tupe "G" recorder. A complete desciption of the apparatus used is given in the First Progress Report. The parameters measured during a typical orbit are plotted as a function of time in Figure 1. The magnitude of these quantities varies from run to run depending on the capacity of the cell and other factors but this figure illustrates the over-all measurement program and the relationship of the measurements to each other.

* Adhydrode, the third control electrode of a Gulton Ni-Cd cell

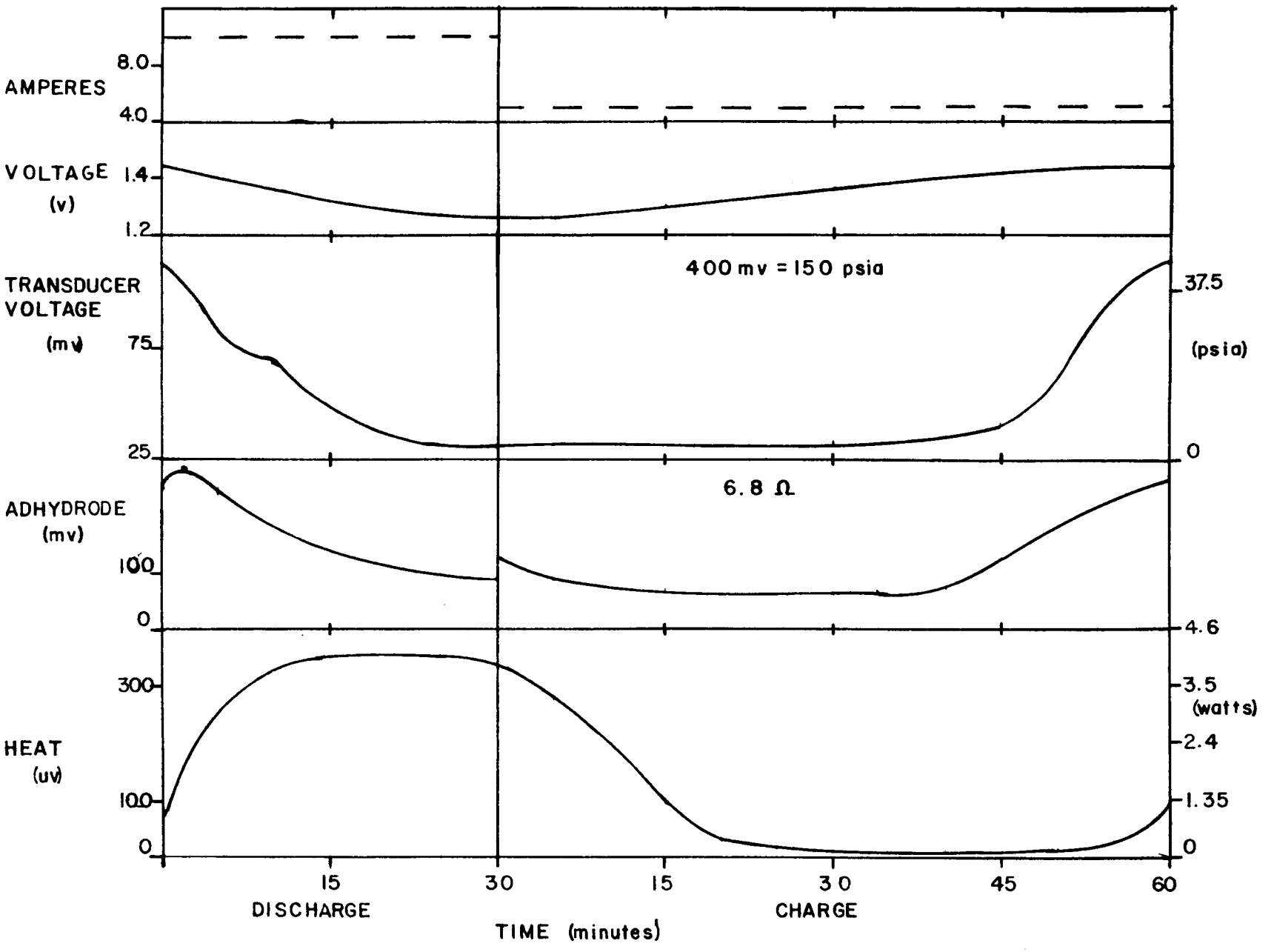

Figure 1. Experimental Parameters measured during a typical orbit

III. RESULTS AND DISCUSSION

After allowing the experiment to run the full 90 orbits the data were tabulated at five minute intervals starting approximately 24 hours after the initial orbit of the experimental series. The data given in Tables 1-10 were taken from orbits numbers 18, 19, 20, 30, 40, 50, 60, 70, 82, and 90 respectively. An examination of Tables 1-10 shows that the cell reached a steady state after about 24 hours. Several points from these data might be discussed.

The first is the heat output during the discharge cycle - which approximates 4 watts after 15 minutes into the cycle. This heat output is high in comparison to some other values. For example, under comparable charge - discharge conditions the 6 ampere-hour cell produced about 0.7 watts (3). On a relative capacity basis a value of about 2.33 watts would be expected. Some recent data collected on another 20 ampere-hour cell of the same type are reported in tables 11-12. The thermal output here approximates 1.2 watts. These different values are reported at this time recognizing that an explanation of the discrepancy requires further work. The best interpretation that can be given at this point is that they represent actual variations in the thermal output of the two cells. This aspect of the problem is under study.

Once the cell reached the steady state condition, achieved in this experiment after 24 hours, there was very little variation in the cell voltage at any specified time during the 90 minute cycle in any of the 90 orbits recorded. The cell voltage was uniform during thelast 10 minutes of the discharge cycle, 1.25-1.26 v.. The cell voltage reached 1.38 v. forty minutes into the charge cycle.

Examination of any one orbit shows that a steady state condition was established about 45 minutes into the charge cycle. Because of the thermodynamic stability of the system at this steady state the data collected at 45 minutes into the charge cycle were used to calculate a ΔH for the change,

$$Ni(OH)_2 + Cd(OH)_2 = Cd + \beta NiOOH$$

The average value for the calculated enthalpy of reaction was 31.5 Kcal / equiv..

Further evaluation of Tables 1-10 shows the relationship between other cell parameters during the 25% depth of discharge experiment. The heat output of the system (q) was greatest during the period of greatest oxygen consumption; as the discharge cycle neared completion the heat output was a maximum and the oxygen pressure was approaching a minimum (Fig. 1). The charging period may be divided into two time segments, the first is characterized by a low rate of oxygen consumption and a sharp decrease in thermal output. The second is characterized by both the oxygen pressure and the heat increasing.

A plot of cell pressure vs. time for an average orbit at 25% depth of discharge and 105% rate of recharge is shown in Fig. 2. It may be noted that a residual pressure of approximately 6.5 psia was observed. This pressure was due to argon, the atmosphere under which the pressure transducer was affixed to the cell. Fig. 2 may be divided into two parts, the charge portion and the discharge portion. The discharge portion shows the usual decrease in pressure with time.

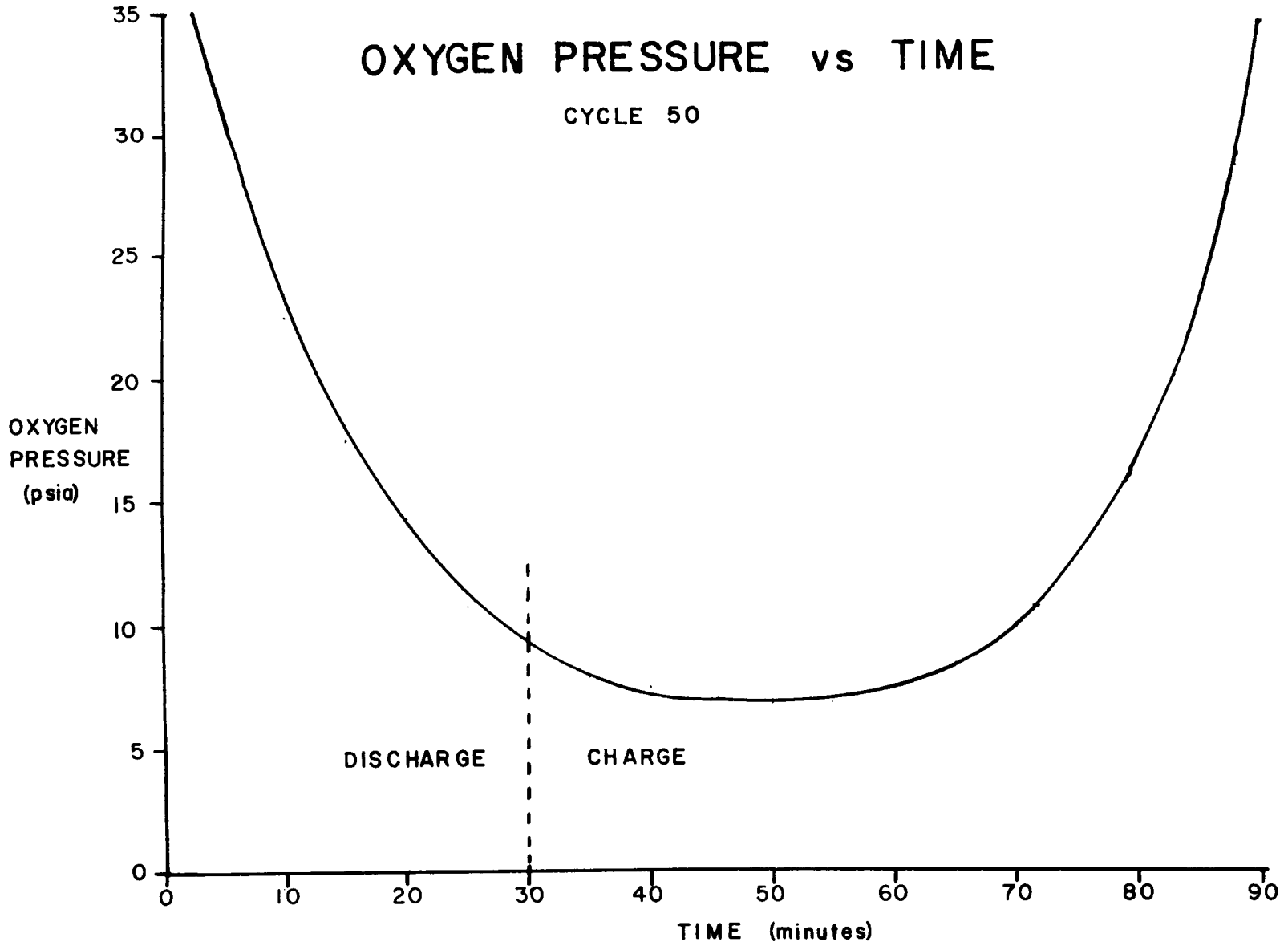

Figure 2. Change of Oxygen Pressure with time during Cycle Number 50

During the charging period the cell pressure decreases to a minimum where it remains relatively constant for a period before it begins to rise. The rate of oxygen production during the charge portion appears to be divided into two periods. The first period includes about 20 to 25 minutes of the charging portion of the cycle. During this period oxygen is produced at a low but continually increasing rate. The second phase starting about 45 minutes into the charging portion of the cycle is characterized by a steep ascent in the oxygen pressure curve.

The relationship between cell potential and cell pressure during the charge and discharge portions of an orbit is shown in Figure 3. At the initiation of the discharge portion of the orbit there is an abrupt drop in potential of approximately 0.1 volt from 1.45 v. to 1.35 v.. This is followed by a gradual decrease until a potential of approximately 1.25 is reached. During the charge portion the changes in cell pressure may also be related to changes in cell potential. The initial step in this portion is a fall in cell pressure to a point where the cell pressure is equal to the residual pressure in the cell. There is a corresponding small increase in the potential of the cell from 1.25 v. to approximately 1.32 v.. When the cell is in the range of 1.32 v. to 1.35 v. the cell pressure remains that of the residual pressure. At a potential of about 1.35 v. the pressure begins to increase. Between 1.35 v. and 1.40 v. the rate of oxygen production is rather rapid. Beyond this point the change in cell pressure with cell potential remains more or less constant for the remainder of the charging period. It would appear that with

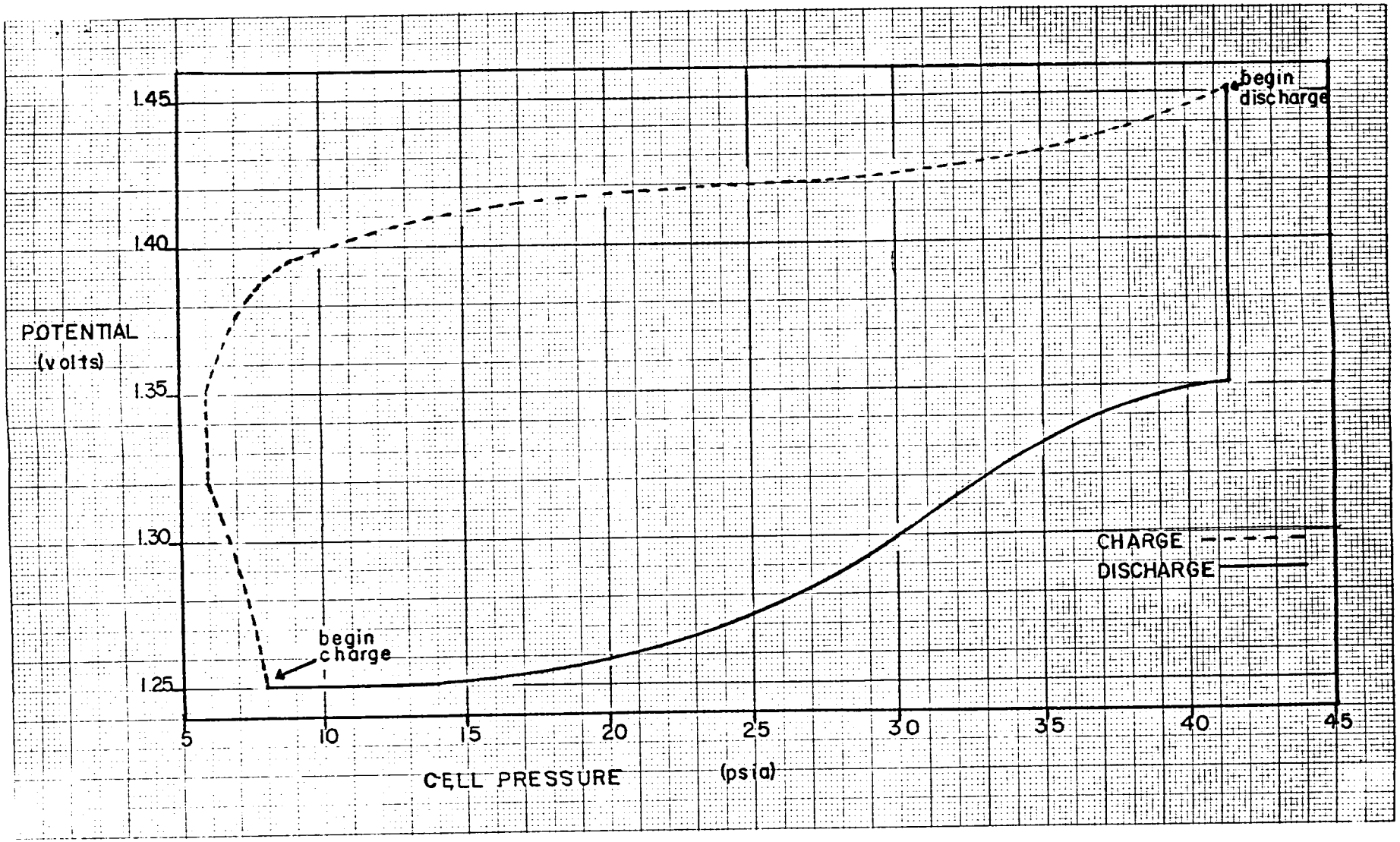

Figure 3. Relationship between cell pressure and cell potential during a typical cycle

further analysis it should be possible to relate the chemical composition of the electrode with potential and oxygen pressure.

IV. CONCLUSIONS

The experimental value of 31.5 Kcal/equiv. for the ΔH of the charging reaction is in reasonable agreement with certain values reported in the literature, e.g. the value of 32 Kcal/equiv. given by Salkind and Bruins (1). Our value of 31.5 Kcal/equiv. is lower than some values given by other investigators, e.g. Othmer and Gilmont (2) and Webster and Foley (3). However, the interpretation of this decrease , or whether it is due to experimental error, must wait for future supporting data.

It is expected that plots relating cell potential and cell pressure such as given in Figure 3 will be useful in interpreting the thermodynamics of the cell reaction during various portions of the charge-discharge cycle.

The large thermal output of 4 watts is difficult to explain in light of other measurements. It appears to be the (abnormal) characteristic of the 20 ampere-hour cell used in the test. This result is being checked.

V. PLANNED FUTURE WORK

It is planned to continue the investigation of the thermal characteristics of the 20 ampere-hour cell utilizing other depths of discharge (15% and 40%).

VI. REFERENCES

1. Salkind, A. J. and Bruins, P.F., J. Electrochem. Soc. 109, 350 (1962).

2. Othmer, D. and Gilmont, R., Ind. Eng. Chem. 36, 858 (1944).

3. Webster, W. H., and Foley, R. T., "First Progress Report for Research into Fundamental Phenomena Associated with Spacecraft Electrochemical Devices - Calorimetry of Nickel-Cadmium cells" Contract No. NAS 5-10105 (1966).

Experimental Series F

25°C

Table I - Orbit #18

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 105% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Transducer (mv)	Oxygen Pressure (P.S.I.A.)	Adhydrode (mv)
Discharge								
0	-0.95	1.44	-14.3	-15.2	-35.4	115	41	290
5	-2.60	1.30	-12.9	-15.5	-36.0	92	31	265
10	-3.69	1.28	-12.7	-16.4	-38.1	70	23	215
15	-3.97	1.26	-12.5	-16.4	-38.3	55	17	175
20	-4.10	1.25	-12.4	-16.5	-38.4	42	11.5	146
25	-4.09	1.25	-12.4	-16.55	-38.4	38	10	122
30	-3.97	1.25	-12.4	-16.4	-38.1	32	7.5	106
Charge								
5	-3.13	1.29	6.71	3.58	15.9	30	7	102
10	-1.80	1.32	6.86	5.06	22.4	28	6	88
15	-1.00	1.32	6.86	5.86	26.0	28	6	82
20	-0.56	1.34	6.97	6.41	28.4	28	6	80
25	-0.34	1.35	7.02	6.68	29.6	28	6	80
30	-0.20	1.35	7.02	6.82	30.2	28	6	80
35	-0.15	1.37	7.12	6.97	30.9	29	6.5	81
40	-0.08	1.38	7.18	7.10	31.5	31	7	90
45	-0.08	1.38	7.18	7.10	31.5	40	11	112
50	-0.15	1.38	7.18	7.03	31.2	52	20	155
55	-0.28	1.42	7.38	7.10	31.5	75	25	210
60	-0.65	1.44	7.49	6.84	30.3	102	35	305

25°C Table II - Orbit #19

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 105% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Transducer (mv)	Oxygen Pressure (P.S.I.A.)	Adhydrode (mv)
Discharge								
0	-0.95	1.44	-14.3	-15.2	-35.4	115	41	290
5	-2.60	1.30	-12.9	-15.5	-36.0	92	31	267
10	-3.69	1.28	-12.7	-16.4	-38.1	70	23	217
15	-3.97	1.26	-12.5	-16.4	-38.3	55	17	174
20	-4.10	1.25	-12.4	-16.5	-38.4	42	11	145
25	-4.04	1.25	-12.4	-16.4	-38.2	38	10	121
30	-3.97	1.25	-12.4	-16.4	-38.1	32	7.5	105
Charge								
5	-3.13	1.29	6.71	3.58	15.9	30	7	100
10	-1.86	1.32	6.86	5.00	22.2	28	6	88
15	-1.00	1.32	6.86	5.86	26.0	28	6	82
20	-0.60	1.34	6.97	6.37	28.2	28	6	80
25	-0.38	1.35	7.02	6.64	29.4	28	6	80
30	-0.20	1.35	7.02	6.82	30.2	28	6	80
35	-0.15	1.37	7.12	6.97	30.9	29	6.5	81
40	-0.15	1.38	7.18	7.03	31.2	32	7.5	90
45	-0.09	1.38	7.18	7.09	31.4	40	11	110
50	-0.15	1.38	7.18	7.03	31.2	52	20	155
55	-0.30	1.42	7.38	7.08	31.4	75	25	220
60	-0.65	1.44	7.49	6.84	30.3	100	35	300

25°C

Table III - Orbit #20

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 105% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Transducer(mv)	Oxygen Pressure (P.S.I.A.)	Adhydrode (mv)
Discharge								
0	-0.80	1.44	-14.3	-15.1	-35.1	112	39.5	282
5	-2.60	1.30	-12.9	-15.5	-36.0	90	30.5	262
10	-3.63	1.28	-12.7	-16.3	-38.0	70	22.5	210
15	-3.97	1.26	-12.5	-16.4	-38.3	52	15	170
20	-4.09	1.25	-12.4	-16.5	-38.4	42	11.5	141
25	-4.04	1.25	-12.4	-16.4	-38.2	36	9	120
30	-3.97	1.25	-12.4	-16.4	-38.1	32	7.5	103
Charge								
5	-3.06	1.29	6.71	3.65	16.2	30	7	100
10	-1.80	1.32	6.86	5.06	22.4	28	6	87
15	-1.00	1.32	6.86	5.86	26.0	27	5.5	81
20	-0.60	1.34	6.97	6.37	28.2	27	5.5	80
25	-0.34	1.35	7.02	6.68	29.6	27	5.5	79
30	-0.20	1.35	7.02	6.82	30.2	27	5.5	80
35	-0.15	1.37	7.12	6.97	30.9	29	6.5	80
40	-0.11	1.38	7.18	7.07	31.4	32	7.5	88
45	-0.11	1.38	7.18	7.07	31.4	40	11	106
50	-0.11	1.38	7.18	7.07	31.4	52	20	148
55	-0.18	1.42	7.38	7.20	31.9	75	25	212
60	-0.65	1.44	7.49	6.84	30.3	100	35	298

Experimental Series F

25°C Table IV - Orbit #30

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 105% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Trans-ducer(mv)	Oxygen Pressure (P.S.I.A.)	Adhy-drode (mv)
Discharge								
0	-0.80	1.44	-14.3	-15.1	-35.1	110	39	250
5	-2.50	1.30	-12.9	-15.4	-35.8	90	30.5	242
10	-3.64	1.28	-12.7	-16.3	-38.0	67	21	194
15	-3.97	1.26	-12.5	-16.4	-38.3	53	16	157
20	-4.04	1.25	-12.4	-16.4	-38.2	44	12	130
25	-3.98	1.25	-12.4	-16.4	-38.1	40	11	110
30	-3.97	1.25	-12.4	-16.4	-38.1	35	8.5	92
Charge								
5	-3.06	1.29	6.71	3.65	16.2	32	7.5	90
10	-1.80	1.32	6.86	5.06	22.4	30	7	81
15	-1.00	1.32	6.86	5.86	26.0	30	7	80
20	-0.55	1.34	6.97	6.42	28.5	30	7	78
25	-0.34	1.35	7.02	6.68	29.6	29	6.5	77
30	-0.20	1.35	7.02	6.82	30.2	29	6.5	76
35	-0.19	1.37	7.12	6.93	30.7	30	7	78
40	-0.08	1.38	7.18	7.10	31.5	33	8	82
45	-0.08	1.38	7.18	7.10	31.5	40	11	94
50	-0.11	1.38	7.18	7.07	31.4	53	16	127
55	-0.19	1.42	7.38	7.19	31.9	72	23.5	180
60	-0.56	1.44	7.49	6.93	30.7	100	35	260

25°C Table V - Orbit #40

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 10% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Trans-ducer(mv)	Oxygen Pressure (P.S.I.A.)	Adhy-drode (mv)
Discharge								
0	-0.80	1.45	-14.4	-15.2	-35.3	110	39	235
5	-2.55	1.35	-13.4	-15.9	-37.1	90	30.5	235
10	-3.64	1.28	-12.7	-16.3	-38.0	70	22.5	186
15	-3.97	1.27	-12.6	-16.5	-38.5	55	17	150
20	-3.98	1.26	-12.5	-16.5	-38.3	46	13	125
25	-3.975	1.26	-12.5	-16.4	-38.3	40	11	102
30	-3.97	1.26	-12.5	-16.4	-38.3	35	8.5	87
Charge								
5	-3.06	1.29	6.71	3.65	16.2	34	8	85
10	-1.80	1.32	6.86	5.06	22.4	30	7	79
15	-1.00	1.32	6.86	5.86	26.0	30	7	78
20	-0.56	1.34	6.97	6.41	28.4	30	7	75
25	-0.34	1.34	6.97	6.63	29.4	30	7	72
30	-0.20	1.35	7.02	6.82	30.2	30	7	72
35	-0.15	1.37	7.12	6.97	30.9	32	7.5	73
40	-0.09	1.38	7.18	7.09	31.4	35	8.5	78
45	-0.08	1.38	7.18	7.10	31.5	42	11.5	90
50	-0.11	1.41	7.33	7.22	32.0	55	16.5	115
55	-0.25	1.42	7.38	7.13	31.6	75	25	168
60	-0.55	1.44	7.49	6.94	30.8	100	35	250

25° C

Table VI - Orbit #50

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 105% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Trans- ducer(mv)	Oxygen Pressure (P.S.I.A.)	Adhy- drode (mv)
Discharge								
0	-0.82	1.45	-14.4	-15.2	-35.4	112	39.5	230
5	-2.60	1.30	-12.9	-15.5	-36.0	90	30.5	242
10	-3.69	1.28	-12.7	-16.4	-38.1	70	22.5	195
15	-3.97	1.26	-12.5	-16.4	-38.3	56	17.5	160
20	-3.97	1.26	-12.5	-16.4	-38.3	48	14	135
25	-4.04	1.26	-12.5	-16.5	-38.5	40	11	115
30	-4.04	1.26	-12.5	-16.5	-38.5	37	9.5	98
Charge								
5	-3.17	1.29	6.71	3.54	15.7	33	8	85
10	-1.80	1.32	6.86	5.06	22.4	32	7.5	83
15	-1.00	1.32	6.86	5.86	26.0	30	7	80
20	-0.55	1.34	6.97	6.42	28.5	30	7	80
25	-0.31	1.34	6.97	6.66	29.5	30	7	80
30	-0.20	1.35	7.02	6.82	30.2	32	7.5	80
35	-0.08	1.35	7.02	6.94	30.8	33	8	80
40	-0.08	1.38	7.18	7.10	31.5	38	10	85
45	-0.08	1.38	7.18	7.10	31.5	42	11.5	99
50	-0.08	1.38	7.18	7.10	31.5	56	17	126
55	-0.20	1.42	7.38	7.18	31.8	80	27	170
60	-0.55	1.44	7.49	6.94	30.8	105	37	283

25°C Table VII - Orbit #60

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 105% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Trans- ducer(mv)	Oxygen Pressure (P.S.I.A.)	Adhy- drode (mv)
Discharge								
0	-0.80	1.45	-14.4	-15.2	-35.3	115	41	230
5	-2.60	1.35	-13.4	-16.0	-37.2	92	31	246
10	-3.69	1.35	-13.4	-17.1	-39.7	72	23.5	198
15	-3.97	1.26	-12.5	-16.4	-38.3	58	18	162
20	-4.10	1.26	-12.5	-16.6	-38.6	48	13.5	136
25	-4.09	1.26	-12.5	-16.6	-38.5	40	11	115
30	-3.97	1.26	-12.5	-16.4	-38.3	40	11	98
Charge								
5	-3.06	1.29	6.71	3.65	16.2	35	6.5	86
10	-1.80	1.32	6.86	5.06	22.4	33	8	82
15	-1.00	1.32	6.86	5.86	26.0	32	7.5	80
20	-0.55	1.34	6.97	6.42	28.5	32	7.5	80
25	-0.31	1.34	6.97	6.66	29.5	30	7	80
30	-0.15	1.35	7.02	6.87	30.5	32	7.5	80
35	-0.08	1.38	7.18	7.10	31.5	34	8.5	80
40	-0.08	1.38	7.18	7.10	31.5	37	9.5	86
45	-0.05	1.38	7.18	7.13	31.6	40	11	98
50	-0.08	1.38	7.18	7.10	31.0	54	16	122
55	-0.20	1.38	7.18	6.98	30.8	75	25	169
60	-0.55	1.44	7.49	6.94	30.8	100	35	240

25°C

Table VIII - Orbit #70

Orbital Conditions

1) 30 minutes d.c. at 9.90 amps for 25% depth of d.c.
2) 60 minutes c. at 5.20 amps for 105% recharge rate

Time (mins.)	q (watts)	E (volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Trans- ducer, mv	Oxygen Pressure psia	Adhy- drode mv
Discharge								
0	-0.82	1.44	-14.3	-15.1	-35.1	112	39.5	228
5	-2.60	1.35	-13.4	-16.0	-37.2	92	31	243
10	-3.75	1.29	-12.8	-16.5	-38.5	72	23.5	195
15	-4.09	1.27	-12.6	-16.7	-38.8	60	18.5	160
20	-4.10	1.26	-12.5	-16.6	-38.6	50	14.5	133
25	-4,10	1.26	-12.5	-16.6	-38.6	42	11.5	112
30	-4.04	1.26	-12.5	-16.5	-38.5	40	11	98
Charge								
5	-3.13	1.29	6.71	3.58	15.9	35	9	87
10	-1.82	1.29	6.71	4.89	21.7	32	7.5	82
15	-1.00	1.32	6.86	5.86	26.0	32	7.5	80
20	-0.56	1.34	6.97	6.41	28.4	32	7.5	80
25	-0.31	1.34	6.97	6.66	29.5	32	7.5	80
30	-0.20	1.34	6.97	6.77	30.0	32	7.5	80
35	-0.08	1.35	7.02	6.94	30.8	34	8.5	80
40	-0.06	1.38	7.18	7.12	31.6	40	11	86
45	-0.05	1.38	7.18	7.13	31.6	45	12.5	98
50	-0.08	1.38	7.18	7.10	31.5	58	18	125
55	-0.20	1.42	7.38	7.18	31.8	80	26.4	172
60	-0.55	1.44	7.49	6.94	30.8	112	39.5	242

25°C Table IX - Orbit #82

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 100% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Trans-ducer(mv)	Oxygen Pressure (P.S.I.A.)	Adhy-drade (mv)
Discharge								
0	-0.77	1.45	-14.4	-15.1	-35.3	112	39.5	245
5	-2.69	1.35	-13.4	-16.1	-37.4	100	35	260
10	-3.75	1.29	-12.8	-16.5	-38.5	80	26.5	210
15	-4.04	1.26	-12.5	-16.5	-38.5	65	20.5	175
20	-4.10	1.26	-12.5	-16.6	-38.6	53	16	150
25	-4.10	1.26	-12.5	-16.6	-38.6	47	13	128
30	-3.98	1.26	-12.5	-16.5	-38.3	42	11.5	112
Charge								
5	-3.17	1.29	6.71	3.54	15.7	40	11	100
10	-1.86	1.29	6.71	4.85	21.5	40	11	98
15	-1.00	1.32	6.86	5.86	26.0	38	10	95
20	-0.55	1.34	6.97	6.42	28.5	38	10	93
25	-0.31	1.34	6.97	6.66	29.5	38	10	92
30	-0.15	1.34	6.97	6.82	30.2	38	10	92
35	-0.08	1.35	7.02	6.94	30.8	38	10	95
40	-0.05	1.37	7.12	7.07	31.4	38	10	100
45	-0.02	1.39	7.23	7.21	32.0	39	10.5	112
50	-0.06	1.39	7.23	7.17	31.8	50	11.5	140
55	-0.08	1.42	7.38	7.30	32.4	70	22.5	192
60	-0.55	1.44	7.49	6.94	30.8	100	35	272

Experimental Series F

25°C Table X - Orbit #90

Orbital Conditions:

1) 30 mins. d.c. at 9.90 amps for 25% Depth of d.c.
2) 60 mins. c. at 5.20 amps for 105% Recharge Rate

Time (mins.)	q (Watts)	E (Volts)	W (Watts)	ΔH (Watt-sec)	ΔH (Kcal/ equiv.)	Pressure Trans- ducer(mv)	Oxygen Pressure (P.S.I.A.)	Adhy- drode (mv)
Discharge								
0	-0.80	1.45	-14.4	-15.2	-35.3	115	41	245
5	-2.72	1.35	-13.4	-16.1	-37.5	105	37	262
10	-3.80	1.29	-12.8	-16.6	-38.6	80	26.5	212
15	-4.10	1.26	-12.5	-16.6	-38.6	75	25	175
20	-4.15	1.26	-12.5	-16.6	-38.7	55	17	150
25	-4.10	1.26	-12.5	-16.6	-38.6	50	14.5	130
30	-4.04	1.26	-12.5	-16.5	-38.5	50	14.5	112
Charge								
5	-3.13	1.29	6.71	3.58	15.9	42	11.5	101
10	-1.92	1.29	6.71	4.79	21.2	38	10	98
15	-1.00	1.29	6.71	5.71	25.3	38	10	95
20	-0.56	1.33	6.92	6.36	28.2	38	10	93
25	-0.31	1.34	6.97	6.66	29.5	37	9.5	92
30	-0.20	1.34	6.97	6.77	30.0	37	9.5	92
35	-0.08	1.35	7.02	6.94	30.8	37	9.5	95
40	-0.05	1.37	7.12	7.07	31.4	37	9.5	100
45	-0.05	1.38	7.18	7.13	31.6	39	10.5	112
50	-0.06	1.38	7.18	7.12	31.6	50	14.5	140
55	-0.15	1.42	7.38	7.23	32.1	70	22.5	190
60	-0.54	1.44	7.49	6.95	30.8	100	35	270

Experimental Series G

25°C

Table XI - Orbit #47

Orbital Conditions:

1) 30 minutes d.c. at 9.95 amps for 25% depth of d.c.
2) 60 minute c. at 5.25 amps for 105% recharge rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (Kcal/equiv)	Pressure Transducer (mv)	Oxygen Pressure (psia)	Adhydrode (mv)
Discharge								
0	0.02	1.323	-13.16	-13.1	-30.4	40	9.9	92
5	-0.37	1.290	-12.83	-13.2	-30.6	40	9.9	110
10	-0.64	1.272	-12.65	-13.3	-30.8	38	9.4	107
15	-0.90	1.256	-12.49	-13.4	-30.0	36	9.0	100
20	-1.04	1.238	-12.31	-13.4	-30.9	34	8.3	91
25	-1.13	1.218	-12.11	-13.2	-30.7	32	7.8	82
30	-1.20	1.205	-11.98	-13.2	-30.5	31	7.5	77
Charge								
0	-1.20	1.273	6.72	5.53	24.2	30	7.4	89
5	-1.02	1.324	6.97	5.95	26.1	30	7.4	78
10	-0.60	1.331	7.01	6.41	28.1	29	7.1	72
15	-0.49	1.344	7.08	6.59	28.9	28	6.8	64
20	-0.21	1.355	7.15	6.94	30.5	27	6.7	56
25	-0.05	1.365	7.19	7.14	31.4	26	6.5	51
30	0.03	1.374	7,24	7.27	31.9	26	6.5	47
35	0.11	1.383	7.28	7.39	32.4	25	6.0	44
40	0.12	1.389	7.32	7.44	32.7	26	6.5	44
45	0.13	1.400	7.37	7.50	32.9	27	6.7	49
50	0.13	1.411	7.43	7.56	33.2	30	7.4	60
55	0.09	1.422	7.49	7.58	33.3	34	8.3	80
60	0.07	1.433	7.55	7.62	33.5	39	9.7	107

Experimental Series G

25°C

Table XII - Orbit #48

Orbital Conditions:

1) 30 minutes d.c. at 9.95 amps for 25% depth of d.c.
2) 60 minutes c. at 5.25 amp. for 105% recharge rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (Kcal/ equiv.)	Pressure Transducer (mv)	Oxygen Pressure (psia)	Adhydrode (mv)
Discharge								
0	0.07	1.313	-13.1	-13.0	-30.1	37	9.2	91
5	-0.26	1.291	-12.9	-13.1	-30.4	37	9.2	99
10	-0.57	1.274	-12.7	-13.2	-30.7	36	9.0	97
15	-0.77	1.255	-12.5	-13.3	-30.7	36	9.0	90
20	-0.98	1.234	-12.3	-13.3	-30.7	32	7.8	82
25	-1.04	1.221	-12.2	-13.2	-30.6	30	7.4	74
30	-1.07	1.201	-12.0	-13.0	-30.2	30	7.4	69
Charge								
0	-1.47	1.277	6.70	5.23	23.0	30	7.4	90
5	-1.02	1.312	6.89	5.87	25.8	30	7.4	83
10	-0.69	1.329	6.97	6.28	27.6	29	7.1	74
15	-0.42	1.343	7.05	6.63	29.1	28	6.8	65
20	-0.23	1.354	7.10	6.87	30.2	27	6.7	58
25	0.00	1.364	7.16	7.16	31.4	26	6.5	52
30	0.01	1.373	7.21	7.22	31.7	25	6.0	47
35	0.08	1.382	7.25	7.33	32.2	25	6.0	44
40	0.12	1.391	7.30	7.42	32.6	26	6.5	44
45	0.13	1.400	7.35	7.48	32.8	27	6.7	49
50	0.11	1.406	7.38	7.49	32.9	29	7.1	56
55	0.09	1.419	7.44	7.53	33.1	32	7.8	74
59	0.07	1.428	7.49	7.56	33.2	36	9.0	94