N88-11023

250AH/90A ACTIVE LITHIUM-THIONYL CHLORIDE CELL FOR CENTAUR-G APPLICATION

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ABSTRACT

A high rate active Li/$SOCl_2$ cell has been designed for use in a 28 volt, 250 amp-hour space battery system. The lithium battery is being considered as a replacement of its heavier silver- zinc counterpart on board the "Centaur-G" booster rocket which is used to launch payloads from the un-manned space vehicles.

Basically a feasibility study, this development effort is demonstrating the ability of the lithium cell to deliver up to 90 amps safely at power densities of approximately 25 watts per pound. Test data on 4 prototype units is showing an energy density of 85 watt-hours per pound and 9.0 watt-hr/in^3. The cells tested demonstrated 280 to 300 amp-hours under ambient temperature test conditions using alternating continuous loads of 90, 55 and 20 amperes throughout life.

The cell is hermetically sealed in a welded stainless steel envelope of 103 in^3 volume and weighs 10.9 lbs. The cell's internal impedance is a low 3.5 milliohms achieved by means of close electrode spacing, a low resistance internal bussing structure and large 3/8 inch diameter nickel pin terminals.

Data from four cells tested are presented to demonstrate the capability of Li/$SOCl_2$ technology for a C/3 discharge rate in active and hermetic cell units.

A simple thermal model was developed, which predicts the heat transfer characteristics and cell temperatures as a function of time and current.

DESIGN

Four cells were constructed and tested individually during this development effort. They were designed to provide slightly over 250 ampere-hours to achieve the capacity required and to have reserve capacity to guard against possible over-discharge (reverse voltage) of a cell in a multiple series circuit.

A cylindrical case configuration was chosen due to its inherent strength and ease of manufacture. The case is 4.50" O.D. and 5.06" tall. Internal to this stainless steel case, a pile construction of multiple anodes and cathodes with non-conductive but porous separator material was selected. The current collectors within these electrodes have tabs which protrude from the pile with a 120° dispersion angle between anode and cathode tabs. These anode and cathode tabs are separately brought together and welded for the electrical parallel connection to the respective electrode terminals.

The anode disc is 4.0 inches in diameter and 0.007 inches thick. Two such discs of lithium sandwich the nickel current collector plate. Each bi-anode assembly has correspondingly 162 cm^2 of active surface area and a theoretical capacity of 5.94 AH.

The cathode is of similar diameter to the anode and contains 1.24 g of carbon in each disc. Two such cathodes, separated by a nickel current collector plate, form the bi-cathode assembly. Each cathode assembly supports 5.2 AH of cell reaction and therefore limits the cell's capacity delivery.

The overall cell contains a substantial excess of electrolyte which is accessible to the cathode and separators by capillary attraction.

Two minor variations of the basic design were built and tested. The first two cells (S/N 001 and 002) consisted of 57 bi-electrode pairs. The second two cells (S/N 003 and 004) were constructed with 54 bi-electrode pairs within the same cell envelope. At the 90A peak current the two designs operated at 9.7 and 10.3 mA/cm^2 respectively.

The latter cell design variation is preferred from the standpoint of ease of manufacture and the resultant capacity and performance still meet technical objectives.

Special emphasis was placed on the internal bussing design of the cell. It was recognized that at the intended high rates, the internal resistance must be minimal to avoid excessive internal heating, loss of voltage and internal pressure build-up. The cell was therefore designed with the largest nickel conductor cross-sectional area possible within the constraints of space available and manufacturability.

The measured voltage drop at 90 amperes across this internal bussing system is 58 millivolts, indicating 0.64 milli-ohms resistance per terminal. The sum of the two terminal assemblies is therefore 1.3 milliohms for the nickel conductors. Resistance contributions from electrochemical components raise the cell's total internal impedance to about 3.5 milliohms; an acceptable level for 90A delivery.

The bulkiness of the bussing system necessitated large terminal boxes to be located around the bussing terminations (at 120° locations around the cell). The large size allowed easier and more expedient manufacturing and assembly of the cells. These terminal housings are completely filled with electrolyte and are reservoirs for the substantial excess over the capacity requirement.

The 3/8" diameter nickel - teflon feed-thru terminals were designed specially for this cell. These were thoroughly tested for hermeticity and reproducibility in manufacture. Special care was taken in the design of welding joints in the cell case to locate the welding zones away from internal lithium. This was accomplished by "dishing" the lids on the case so that the welds are low heat butt-welds located more than 1/4" away from the internal stack. Similarly, the terminal boxes are welded to interface plates which extend from the main cell 1/2" away from lithium. In addition, a full set of heat sinks were developed to maintain the cell at low temperature during welding operations.

TESTING

The cells were equipped with pressure transducers and were further prepared for testing by attaching 7 thermocouples, and lead wires. The power leads were attached to the 3/8" nickel terminals using a clamp-connector attached to welding cable. The transducer, thermocouples, electrode potential leads and power leads were remotely connected to test instrumentation. The instrumentation sampled data every minute and a strip chart recorder continuously tracked data throughout the test. A computer was used to compile the data into tabular and graphical formats. Figure numbers 1,2, 3 and 4 present the data graphically for serial numbers 001, 002, 003 and 004, respectively.

A summary of the test conditions for the 4 cells follows:

S/N 001 - This cell was tested on a 4.0" diameter copper block which was located on a large slab of steel. The copper block was interfaced to the cell with a layer of thermal grease. The cell was discharged 4 times with a 60 minute 90-55-20 amp constant current discharge profile (20 minutes at each level). The cell was then discharged to 2 volts at 20 amps. After a weekend at open circuit, the cell was depleted of energy on a 0.1 ohm resistor.

S/N 002 - This cell was tested on a piece of wood to create a less thermally advantageous situation than in the previous test. Also loaded 4 times with a 90-55-20 amp discharge profile, this cell was then discharged to 2 volts at 20 amps. Subsequently the cell was depleted of its energy on a 1 ohm resistor.

S/N 003 - Since this cell contains 5% less anodes and cathodes than the previous 2 cells, it operates at a slightly higher current density. This cell was, therefore, tested at conditions identical to those for S/N 002 in order to assess the differences in operation due to this current density change. The cell was tested on a wooden block with the same current profile to 2 volts as in S/N 002. On this cell, however, the 20 amp constant current discharge was continued past the 2 volt cutoff, through 0 volts into reverse voltage (about -0.1 volts) for a further 330 AH.

S/N 004 - Since the ultimate application for the cell is in space (vacuum environment), it was decided to test this cell in a near adiabatic condition to determine its behavior under this extreme situation. Both conduction and convection were precluded as far as possible with the exception of negligible conduction down the power leads. The cell was tightly wrapped in foam and placed in a covered styrofoam box tightly packed with styrofoam packing material to minimize heat loss. The cell was discharged at the same 90-55-20 amp constant current profile as its predecessors. After the third profile, however, it was determined that the cell temperature and pressure were high enough, (as expected) to abandon the fourth profile and the remainder of the test was conducted at 20 amps constant current. The cell was finally depleted of its energy on a 1 ohm resistor.

DATA SUMMARY

Table 1 includes the major data points necessary to summarize the performance of the cells. Table 2 contains detailed data on average voltages of the cells.

CELLS S/N 001 AND S/N 002 - Delivered 301 and 294 amp-hours (to 2.5 volts), respectively; well above the 250 AH goal. The energy of both cells, 973 and 956 WH were also very close. Both cells remained at very moderate temperatures and pressures throughout their respective test cycles. S/N 001 rose to a maximum case temperature of 48.9°C and a maximum pressure of 27 psig. S/N 002 achieved 58.1°C and a maximum pressure of 37 psig. The lower values for S/N 001 are clearly due to the fact that heat was conducted from the base of the cell whereas for S/N 002 it was precluded. These cells operated at 9.7 mA/cm^2 on the 90 amp current discharges and they both delivered high energy densities (to 2.5 volts) of about 90 watt-hours per pound.

CELLS S/N 003 AND 004 - Delivered predictably lower capacities than their predecessors due to the 5.3% reduction in carbon cathode weight. A capacity of 281.8 AH is mathematically projected and S/N 003 delivered this capacity.

Cell S/N 003 attained a pressure of only 28 psi during discharge - a very pleasing result. This cell was allowed to enter forced discharge (reverse voltage) at 20 amps, for 16+ hours after discharge was complete, in order to access the safety characteristics in this abusive condition. The cell case maintained its structural integrity and hermeticity throughout the entire reverse voltage period.

Because S/N 004, in its near adiabatic condition, operated at a much higher average temperature than S/N 003, it manifested a significantly higher average voltage.

Cell S/N 004 reached a temperature and pressure maximum of 105.1°C and 172 psig respectively during its last few minutes of constant current discharge, due to its near adiabatic state. Again, the cell maintained its structural integrity and hermeticity through-out the entire test.

The design of cells S/N 003 and 004 was validated by the test results and the resultant 85 watt-hours/ pound after 90A (at 10.3 mA/cm^2) delivery exceeds the technical objectives.

THERMAL MODEL

In order to develop a grasp of the thermal operating characteristics of the cells prior to actual testing, a thermal model was developed. The model is based on a simple energy balance where the cell is assumed to be a homogenous thermal mass. The calculated heat capacity of a typical cell is 0.223 cal/g/°C. The predicted average temperature profile is determined by calculating the accumulated energy in the cell as a function of time and dividing by heat capacity and weight. Three paths for heat transfer were identified for the cells - conduction to the surface on which the cell rested, convection to air, and conduction of heat out of the cell through the nickel terminals. Heat transfer coefficients were determined for these paths, and used to formulate an overall heat transfer coefficient for the planned test conditions. The cell model is represented by Figure 5.

The integral of the three thermal transfer modes were calculated to be 1.19, 0.84, 0.84 and 0.09 watts/°C above ambient for cells tested as S/N 1, S/N 2, S/N 3 and S/N 4 respectively.

The results of solving the heat balance for each cell indicated that we could expect moderate cell temperatures for cell tests 1-3. As seen in Table #1, these predictions were quite accurate. The prediction for test number 4, the near adiabatic test, indicated a high temperature of 93.4°C at the termination of testing. Based on this information, a successful test in the adiabatic environment was predicted. As seen in Table #1, the original model is marginally less accurate at high temperatures. The original thermal model was helpful in planning the testing for this development effort. Recent refinement of the thermal model considered accelerated self discharge at elevated temperatures and this new model is useful in the design of the full 28V battery. The model credibly predicts the battery temperature and operating voltage under the various scenarios for solar and earth flux radiation and operating current.

CONCLUSION

This work has demonstrated a safe and efficient lithium thionyl chloride cell design for high capacity (250 AH) with high rate performance (C/3). The cell can deliver a sustained 1 hour at 90A and full 250 AH capacity delivery within an adiabatic environment.

The demonstrated energy density of 85 WH/LB can readily be raised to 115 WH/LB using a less conservative steel case design which is still competant for predicted internal pressures.

The developed thermal model predicts a full 9-cell battery operating safely in a space environment with the factor of two weight reduction over a silver-zinc system for un-manned space vehicle power.

This work suggests that the present high rate Li-$SOCl_2$ technology is ready for full system hardware development and subsequent analysis through testing.

ACKNOWLEDGEMENT

The authors express their appreciation to Ron Mikkelson of General Dynamics - Convair Space Systems Division whose interest and support has made this work possible.

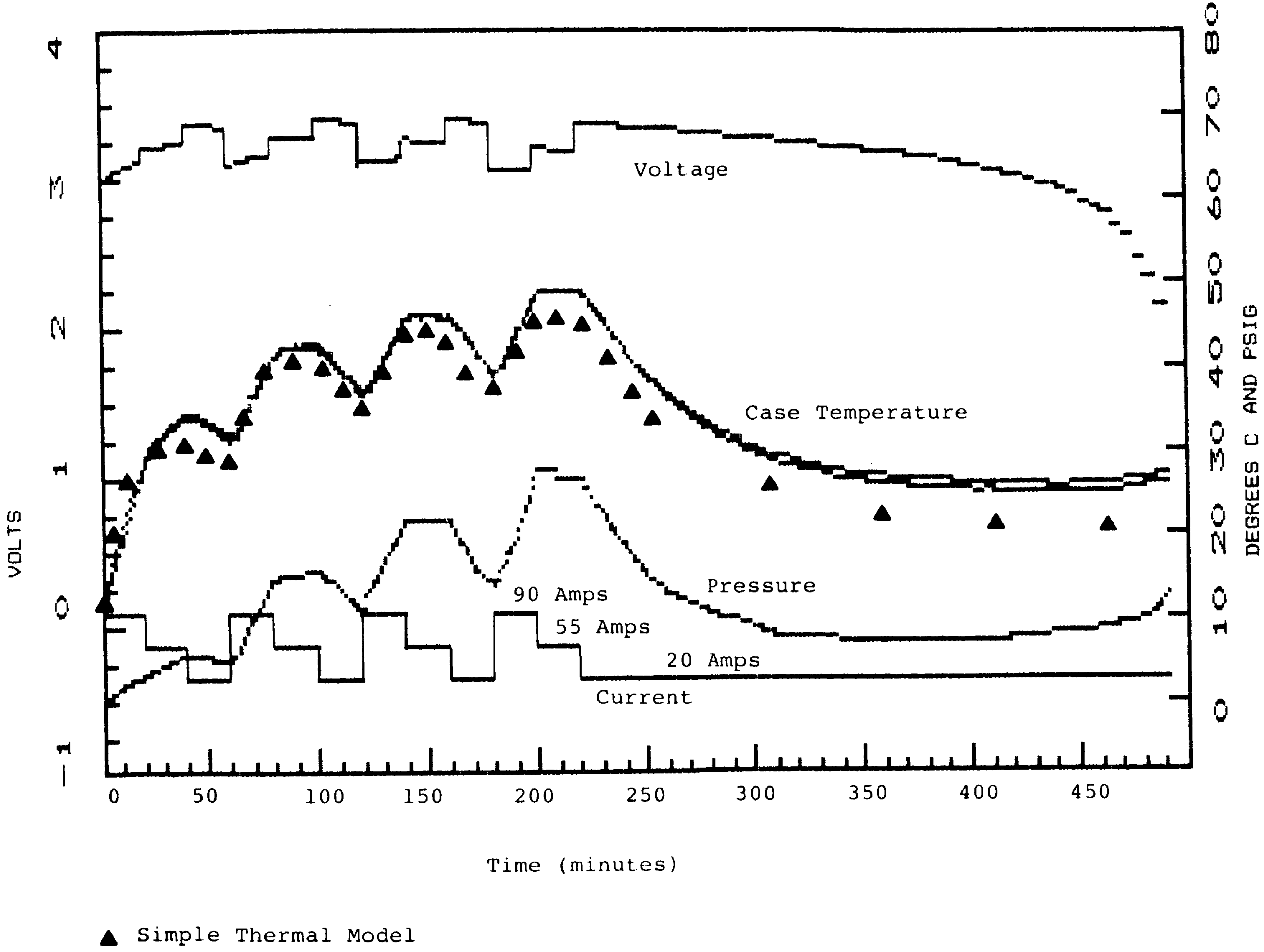

Figure 1. 250 AHr Cell (S/N 001).

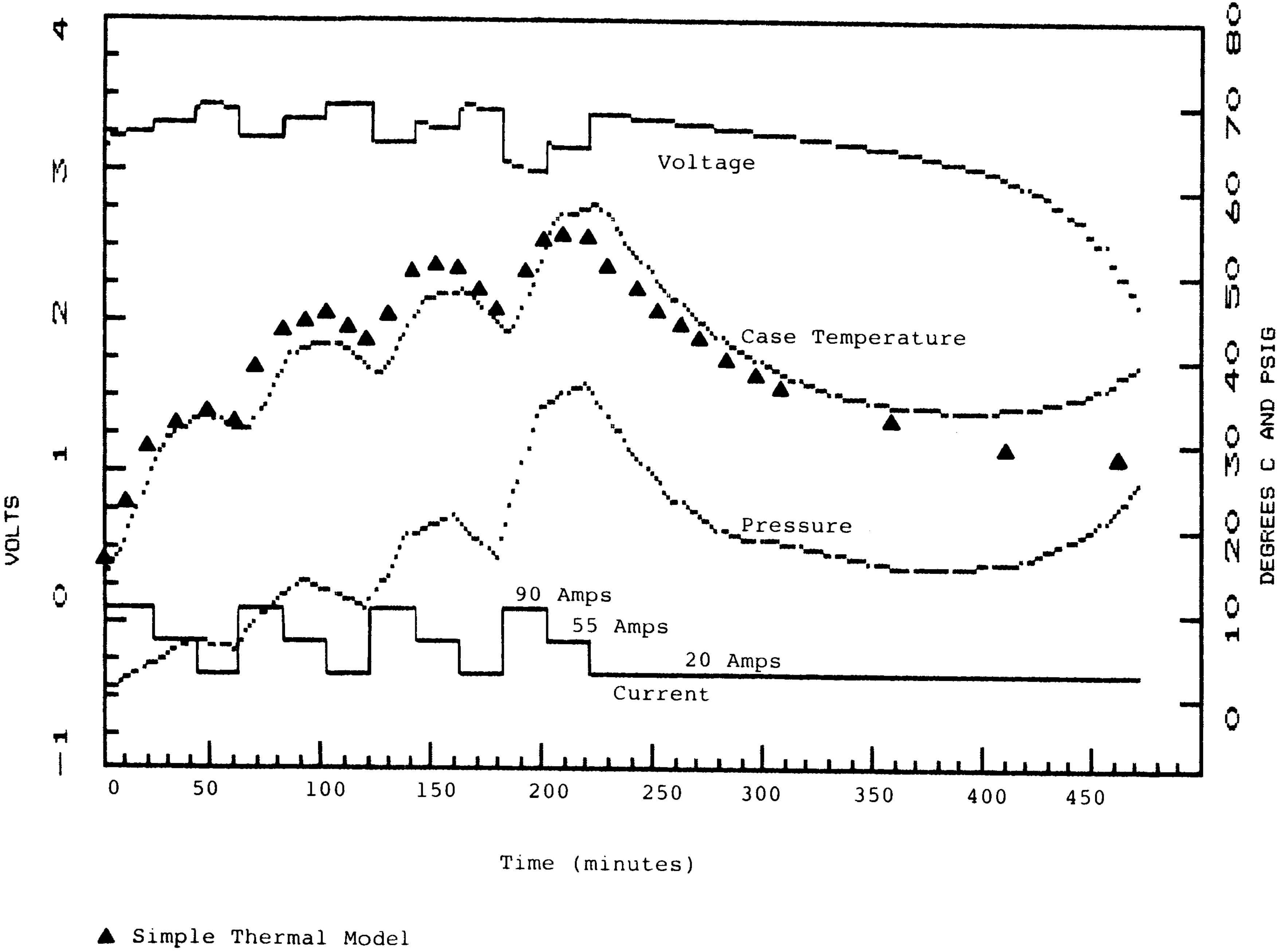

Figure 2. 250 AHr Cell (S/N 002).

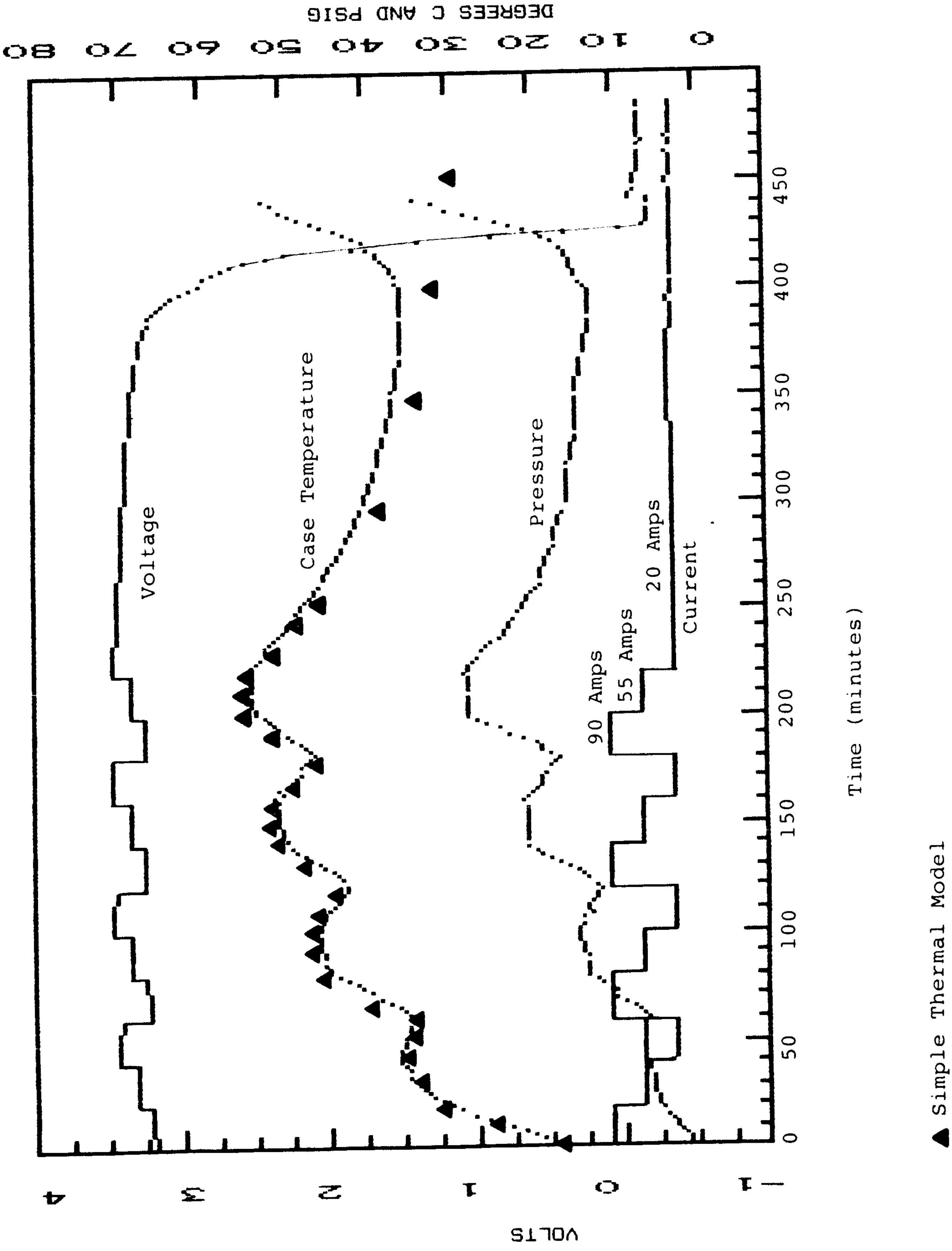

Figure 3. 250 AHr Cell (S/N 003).

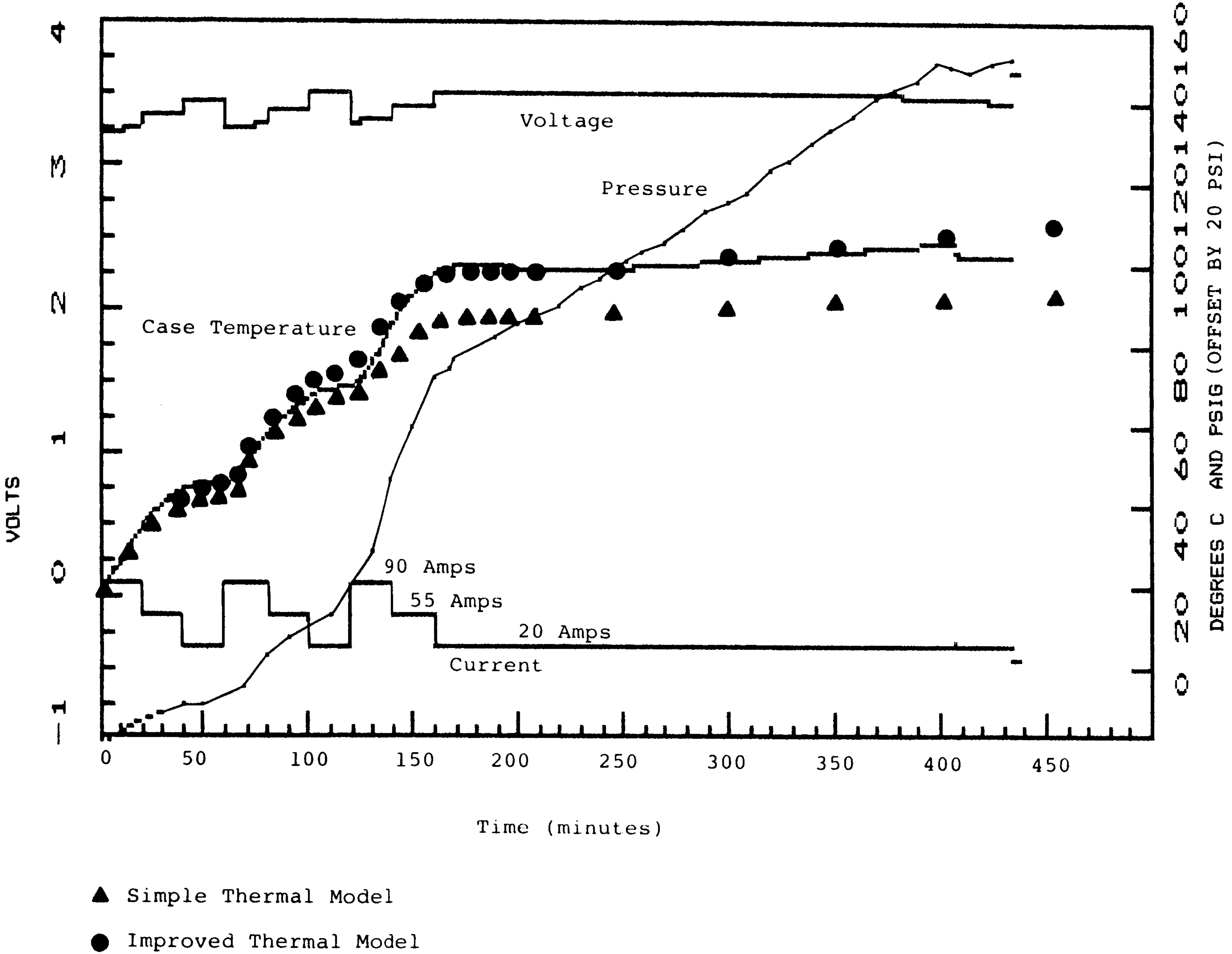

Figure 4. 250 AHr Cell (S/N 004).

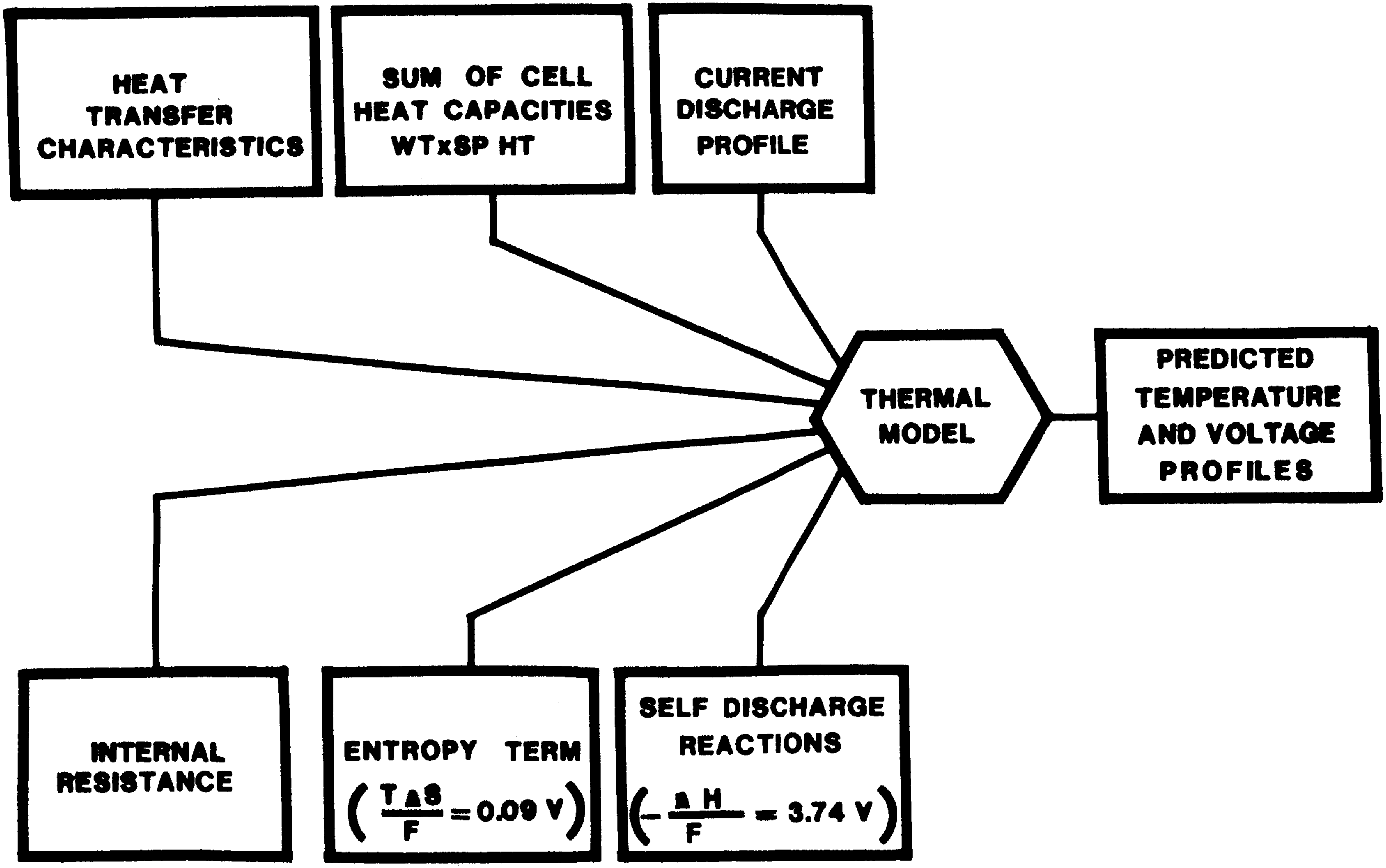

Figure 5. Thermal Model Inputs and Outputs.

Table 1.

DATA SUMMARY

SERIAL NO.	001	002	003	004
CAPACITY TO 2.5 VOLTS (AHRS)	301	294	282	260
ENERGY TO 2.5 V (WHRS)	973	956	950	899
CELL WEIGHT (GRAMS)	4892	4972	4914	4969
ENERGY DENSITY TO 2.5 (WHR/LB)	90	87	88	82
INTERNAL RESIST. (M OHM)	4.6	3.7	3.3	3.2
NO. OF BI-ELECTRODE PAIRS	57	57	54	54
CASE TEMPERATURE (°C)				
LOW	11.6	15.3	16.8	19.0
AVERAGE	33.3	39.5	41.4	83.5
HIGH	48.9	58.1	53.9	105.1
PREDICTED HIGH TEMP.	45.5	54.4	54.5	93.4
PRESSURE DATA (PSIG)				
LOW	0.0	0.0	0.0	0.0
AVERAGE	11.1	17.0	14.9	92.8
HIGH	27.0	37.0	28.0	172.0

Table 2.

VOLTAGE DATA SUMMARY

PULSE #	CURRENT (AMPS)	CELL S/N 1	CELL S/N 2	CELL S/N 3	CELL S/N 4
1	90	3.11	3.28	3.25	3.27
	55	3.28	3.37	3.36	3.37
	20	3.41	3.47	3.47	3.49
2	90	3.19	3.27	3.29	3.32
	55	3.32	3.38	3.40	3.43
	20	3.44	3.49	3.50	3.54
3	90	3.18	3.24	3.30	3.35
	55	3.30	3.33	3.41	3.45
	20	3.44	3.46	3.51	3.55
4	90	3.11	3.06	3.30	-
	55	3.25	3.21	3.40	-
	20	3.42	3.42	3.50	-
AVERAGE VOLTAGES FOR 4 PULSES					
	@ 90A	3.15	3.21	3.28	3.31
	@ 55A	3.29	3.32	3.39	3.42
	@ 20A	3.43	3.46	3.50	3.53