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

January 1, 1966 — September 30, 1966

Contract No. NAS 5 — 10105

Prepared by

W. H. WEBSTER and R. T. FOLEY

For

National Aeronautics and Space Administration

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Greenbelt, Maryland

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Research into Fundamental Phenomena Associated
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Calorimetry of Nickel-Cadmium Cells

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ABSTRACT

This report summarizes the work accomplished during the first nine months of the project. The program has been directed toward the design and development of an isothermal continuous flow calorimeter capable of measuring the thermal characteristics of batteries undergoing typical orbital cycling.

An isothermal continuous flow calorimeter was developed and calibrated over the range of 0.10 to 1.00 watt which range is characteristic of the thermal output of a six ampere-hour nickel-cadmium cell. The thermal response was found to be linear in this range and the instrument was sensitive to 0.01 watt.

A Gulton six ampere-hour prismatic nickel-cadmium battery complete with an Adhydrode electrode was subjected to the following:

a) 79 cycles undergoing 25% depth of discharge and a 110% recharge

b) 74 cycles undergoing 15% depth of discharge and a 114% recharge

c) 93 cycles undergoing 25% depth of discharge and a 114% recharge

During the above testing the oxygen pressure in the cell and the rate of heat generation by the cell was recorded. The enthalpy changes (ΔH) corresponding to the reactions occurring during the charge and discharge processes were calculated from the thermal data. These values were in excellent agreement with the literature values for these reactions.

In view of the successful operation of the instrument and the findings to date, additional testing will be performed at various percentages of recharge and depths of discharge.

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I. INTRODUCTION

The major purpose of this program is to train electrochemists to perform research and solve problems in the space battery field. The problems are those specifically encountered by NASA's Goddard Space Flight Center.

During the first nine months of the project, work was performed as follows:

1) A literature survey into subjects of calorimetry and thermodynamics of electrochemical systems, specifically nickel-cadmium batteries, was conducted.
2) An isothermal continuous flow calorimeter was designed and constructed.
3) This calorimeter was calibrated.
4) A six ampere-hour Gulton prismatic nickel-cadmium battery was tested under the following orbital conditions:
    a) 79 cycles undergoing 25% depth of discharge and a 110% recharge
    b) 74 cycles undergoing 15% depth of discharge and a 114% recharge
    c) 93 cycles undergoing 25% depth of discharge and a 114% recharge

5) Cell data such as oxygen pressure and the rate of heat generation were collected and the changes in enthalpy (ΔH) for the system undergoing the various processes were calculated.

II. BACKGROUND AND LITERATURE REVIEW

1. Calorimeters (In General)

The design and construction of a suitable calorimeter is one of the first problems encountered in measuring the thermal characteristics of any system. During the past thirty years, descriptions of over two hundred calorimeters have appeared in the literature. In his text Experimental Thermochemistry, Skinner[1] points out the principle factors which influence the choice of calorimeter design:

(a) the rate of the reaction under investigation;

(b) the magnitude of the heat effect to be measured;

(c) the temperature of the experiment;

(d) the level of accuracy it is desired to achieve;

(e) the nature and number of phases (gas, liquid, solid) taking part in the reaction;

(f) the corrosive nature of the reactants;

(g) the pressure to be applied to the reactants during the experiment.

The first factor is the most critical for it determines the duration of the experiment. Fast ($\lesssim$ 15 - 20 min.) and moderate speed experiments are best studied in non-isothermal type calorimeters. In these calorimeters the heat liberated (or absorbed) by the reaction causes a proportional change in the temperature of the calorimeter. Non-isothermal calorimeters are operated either under adiabatic conditions, or with constant temperature environment. The adiabatic calorimeters are used to investigate reactions of only moderate speed while constant-temperature-environment calorimeters are used to investigate fast reactions.

2. Constant-temperature-environment calorimeters

A constant-temperature-environment calorimeter is completely encased in a jacket of constant and uniform temperature for the purpose of defining the thermal head betweem the calorimeter and its surroundings. Skinner[2] states that, "in a well-designed calorimeter and jacket system, the leakage modulus (degree/sec.) should be constant within limits of about 2 percent, and as small as is practicable. The following points of design should invariably be met:

(a) The jacket walls must be of uniform temperature throughout the experiment.

(b) The outside surface of the calorimeter and the inner surface of the jacket should be highly polished in order to minimize heat transfer by radiation between them.

(c) The air-gap between calorimeter and jacket should be evacuated, if possible, to reduce transfer by conduction.

(d) If it is impracticable to evacuate the air-gap, this should not at any point exceed about 12 mm in thickness, in order to minimize transfer by convection.

(e) If the calorimeter contains a liquid, the stirring must be good enough to insure uniformity of the calorimeter temperature, and the stirring rate must be kept constant to insure constant heat of stirring throughout the experiment.

(f) If the calorimeter contains a liquid, it should preferably be completely sealed, to prevent evaporation loss during the experiments."[2]

3. Adiabatic Calorimeters

An adiabatic calorimeter operates by maintaining zero thermal head between the calorimeter and its jacket. Because the task of matching jacket and calorimeter temperatures is difficult, this type of calorimeter is not used for fast reactions.

4. Isothermal Phase-change Calorimeters

The only true isothermal calorimeters are those which use a phase change as a measure of the amount of heat produced by a reaction. The most classical example of this type of calorimeter is the Bunsen ice calorimeter. In this type one has ice and water in equilibrium in a closed system and the heat liberated by the reaction produces a decrease in the volume which is measurable. Another example of this type of phase calorimeter is the liquid-vapor calorimeter which was developed by Kraus et al.[3] for the measurement of the heats of solution of alkali metals and various metallic salts in boiling ammonia.

In general this type of calorimeter limits to a great extent the temperature at which the reactions can be investigated.

5. Continuous-flow Liquid Calorimeters

This type of calorimeter is not exactly isothermal - it might be more accurately described as "very nearly" isothermal. The phase change type of calorimeter is the only pure isothermal calorimeter. In a continuous flow liquid calorimeter the temperature of the liquid is known and monitored as it enters the reaction chamber and passes over the heat generating source. The outstanding advantage of this type of calorimeter is that it isothermally measures the heat generated over long periods of time.

In 1866, Callender[4] used a continuous electrical calorimeter to explore applications of a platinum thermometer. This first rough apparatus consisted of a glass tube approximately 30 cm. long and 3 mm in diameter through which passed a steady stream of water. The water was heated by a platinum resistance heater which nearly fitted the tube. A pair of mercury thermometers were used to measure the steady difference in temperature between the inflowing and the outflowing water. The electrical energy supplied to the heater was measured by potentiometric techniques.

Because of external heat losses, errors in electrical units, etc. the results of these experiments were of little or no value. However the series of preliminary experiments did suggest to Callender a solution to one of the most basic problems confronting the science of calorimetry, i.e. a lack of knowledge of the heat capacity of water over its entire temperature range from 0° to 100° C. The heat capacities could be determined by this new method of calorimetry, i.e. a continuous or steady flow method in which a stream of liquid could be made to continuously carry off a definite and measurable supply of heat.

In 1902, Barnes published a complete set of experimental values for the heat capacity of water from 0° to 100° C determined with a continuous-flow liquid calorimeter. The results were accurate to 1 part in 10,000 of their true values.

The general theory of a continuous-flow liquid calorimeter as stated by Barnes is:

> If we have a flow of liquid, Q per second, continuously heated by an electrical current in a fine tube enclosed in a vacuum-jacket, the walls of which are maintained at the temperature of the liquid flowing into the fine tube, then when equilibrium has been established,
>
> $$Js\,Qt\,(\theta_1 - \theta_0) + (\theta_1 - \theta_0)\,ht = ECt$$
>
> where
>
> J is the mechanical equivalent of heat,
> s the specific heat of the liquid,
> θ_0 the temperature of the inflowing liquid,
> θ_1 the temperature of the outflowing liquid,
> h the heat-loss per degree difference in temperature between the surface of the fine tube and the walls of the vacuum-jacket,
> EC the electrical energy generated per sec., and
> t the time of the flow.[5]

To further appreciate the method, a diagram of the continuous-flow liquid calorimeter in its simplest form is shown in Figure 1.

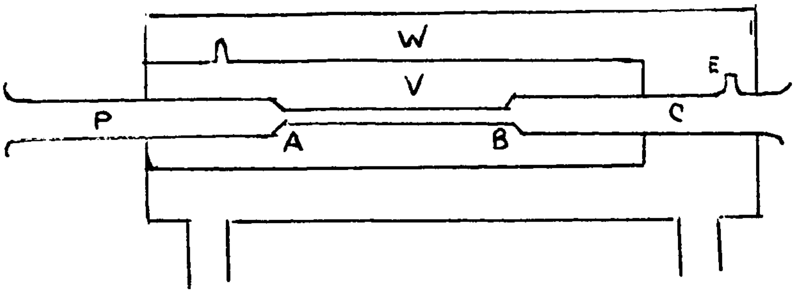

Fig. 1. Diagram of Barnes' Continuous-flow liquid Calorimeter (Ref.5) In this diagram AB represents the fine tube in which the water is heated while flowing through V, the vacuum-jacket, and C & P, the inflow and outflow tubes connected to AB, in which the thermometers are placed. The water-jacket is shown at W, and includes the vacuum-jacket and inflow tube C. The water enters the calorimeter at E from a reservoir separate from that supplying the water for the jacket, but maintained at the same temperature. The electric heating current passes through the fine tube AB through a platinum wire extending the whole length, but is arranged so as not to generate heat in the vicinity of the thermometer bulbs. The thermometer in C measures the temperature θ_0 of the inflowing water, and that in P the temperature θ_1 of the outflowing water, warmed by the passage of the electric current.[6]

In 1922, Keys, Gillespie and Metsukwi[7] successfully applied the principle of continuous flow calorimetry as developed by Callender and Barnes to the determination of the heat of neutralization. The principle of the method and the general apparatus are demonstrated in the following procedure.

Two reservoirs containing the reacting liquids were placed in a constant temperature bath [∓ 0.1°C]. Silver coils deliver the liquids to a mixing calorimeter housed in a precision thermostat which was controlled to ∓ 0.001°C. The difference in temperature between a platinum thermometer in the mixing chamber and one in the precision thermostat was a measure of the heat liberated as the reaction proceeded.

The above investigators, using hydrochloric acid and carbonate free sodium hydroxide, found a heat of neutralization of 13,280 calories per mole which agreed with the literature value for the same reaction. However, this agreement was based on a correction factor being introduced as was pointed out by Roughton in 1930.

> The correction due to exchange of heat with the surroundings was found to vary between 2 percent and 6 percent, according as the velocity of the fluid was varied from 3.6 cc. per second to 1.2 cc per second.[8]

Roughton was able to reduce this correction factor by immersing the entire apparatus in a constant-temperature bath, by increasing the velocity of the reactants to facilitate mixing in 0.01 secs, and by increasing the sensitivity of the thermometers by using a more sensitive galvanometer.

These last two examples illustrate the development of liquid flow calorimeters as well as calorimeters in general, i.e. the basic purpose of all calorimeters is to measure heat and the best container for so doing is dependent upon the nature of the reacting species with the most accurate measurement being determined by the then available instruments such as galvanometers, thermometers, constant-temperature devices, etc.

In 1964, Caulder reported in his thesis the development of a liquid flow calorimeter, "for the specific purpose of measuring the rate of heat evolved during an operational cycle of a Ni-Cd electrochemical cell."[9] The apparatus consisted of a stainless steel chamber large enough to accommodate a nickel-cadmium battery and a calibration heater. This chamber was surrounded by an air jacket which contained entrance and exit tubes to the calorimeter. The calorimeter and air jacket surrounding it were then immersed in a thermal ballast tank for isolating the system from its surroundings. A liquid, either water or a light weight hydrocarbon oil, was circulated through the system continuously passing over the heat generating source. The temperature of the liquid was controlled to 0.001°C via a heat exchanger placed in the thermal ballast tank through which the liquid flowed before entering the top of the calorimeter. At the entrance and exit ports of the calorimeter were placed the hot and cold junctions of a twenty-junction copper-constant thermopile for detecting any changes in the temperature as a result of the reaction taking place.

External of this thermal ballast tank which contained (1) the calorimeter; (2) air jacket; (3) heat exchanger and (4) the stirrer were the devices for controlling the flow rate of the liquid and a constant-temperature bath for regulating the temperature at which the experiment would be performed (0-100°C).

The liquid was circulated throughout the entire system by a constant volume metering pump which would draw the liquid from the base of the thermal ballast tank and deliver it to the external heat exchanger. From the external heat exchanger the liquid then proceeded to a reservoir 8 feet above the instrument and from here via a gravity feed into the internal heat exchanger in the thermal ballast tank, thus completing the cycle.

Caulder calibrated this instrument in the region corresponding to the heat liberated by a Ni-Cd battery, i.e. 0.1-1.0 watt. A typical calibration experiment was performed by passing a known amount of current through a calibration heater (constantan wire) with a known resistance and plotting the watts in against the microvolt signal output from the 20 junction copper constantan thermopile. These experiments were performed at several different temperatures (23°, 26°, 10°C) using either water or oil as the liquid. In Table I appears the maximum signal obtained for each set of conditions.

Another interesting observation from Table I is the comparison of the results obtained by varying the flow rate of the oil. Instead of the signal doubling when the flow rate was decreased by 50%, the signal was cut in half.

Both of these abnormalities can probably be attributed to the direction of the flow through the calorimeter. Also, it should be noted that any trouble would most likely be seen during the oil experiments since the accuracy and precision are much greater because of the low specific heat of the oil.

TABLE I.

Caulder's Calibration Data

Temp.	Media	Flow Rate	Wattage in (cal. heater)	Signal Out
23°C	oil	2000cc/min	0.6	19 µv.
23°C	oil	1000cc/min	1.0*	8 µv.
26°C	water	2200cc/min	14.0	67 µv.
10°C	water	2200cc/min	14.0	67 µv.

* Beyond this point the response was no longer linear. This effect is attributed to the positioning of the cold junction of the thermopile at the top of the calorimeter with the flow of liquid entering from the top, passing across the heater and exiting via the bottom. That is to say, heat has a natural tendency to rise thus affecting the readings obtained at the cold junctions of the thermopile.

After completing the calibration experiments, Caulder reported several heat profile experiments on Ni-Cd cells. At that time no discussion or interpretation of the results appeared.

Summary of Calorimeters

The controlling factors in the type and design of a calorimeter are dictated by the nature of the reaction and the type of information we desire to obtain from said reaction. Since in this report we are concerned with the heats of reaction and the heat profile of nickel-cadmium batteries under operating conditions of continuous charge and discharge, all forms of non-isothermal calorimeters, such as adiabatic calorimeters, are eliminated. In the case of non-isothermal calorimeters any heat liberated by the reaction under study is additive. Over a long term study, such as that equivalent to fifty orbits around the earth, we would no longer be evaluating the reaction at $25^{\circ}C$ but at $25^{\circ}C$ plus the heat liberated during each orbit. However, because of the temperature limiting capabilities of the isothermal phase calorimeter, the choice is limited to the "very nearly isothermal" continuous flow calorimeter. It is for these reasons that the work was initiated by constructing a continuous-flow liquid calorimeter similar to that reported by Caulder with improvements in design in order to obtain greater sensitivity.

Before passing directly into the construction of the calorimeter and the experimental sections, additional background is furnished on the particular type of cell which will be investigated and the significance of the thermal data obtained from these investigations.

6. Nickel-Cadmium Batteries

The typical nickel-cadmium cell used in the space program is a hermetically sealed cell containing alternate positive (nickel) and negative (cadmium) plates separated by a single ply non-woven material. The cell contains only enough electrolyte (potassium hydroxide) to completely saturate the electrode separator pack. The interelectrode distances are minimized to facilitate high rate operation and enhance mass transfer from positive to negative electrodes during overcharge. It is during overcharge that oxygen,generated from the positive plate, migrates toward the negative plate. The oxygen is able to recombine electrochemically with the cadmium electrode at the same rate at which it is generated as long as the overcharge rate doesn't exceed c/10 at 25°C. For most spacecraft applications a recharging rate greater than c/10 is required to maintain a fully charged cell.

Charge control by voltage monitors, temperature sensors, and ampere-hour integrators have been used in the past. These devices are bulky, add extra weight to the spacecraft, and in certain instances have been found to be unreliable.

A definite sudden shift in the voltage at the end of charging is used to terminate the charging process in silver-cadmium cells. However . . . "for nickel-cadmium cells there is no sharp phase transition at full charge since the nickel oxides are not present as discrete thermodynamic compounds, but rather as solid solutions of nickel oxides varying gradually in average valence, and hence potential, as the electrode changes."[10] In nickel-cadmium batteries the use of an auxiliary electrode for controlling the charge rate has been described by Seiger, Shair, and Ritterman.[11] One electrode of this type is called an Adhydrode. The

Adhydrode reacts with the oxygen liberated at the completion of charging to generate a voltage signal which triggers a control circuit. The manufacturer's description of a nickel-cadmium battery with Adhydrode is given in Table II.

7. Adhydrode

The operation of the Adhydrode is explained by Seiger, Shair, and Ritterman.[11]

> The Adhydrode is an electrode which contains hydrogen atoms, interstitially as well as on its surface. When oxygen reaches the surface of such an electrode, it is reduced by reaction with hydrogen atoms. The Adhydrode mechanism occurs on several catalytic materials at a potential of -0.8 volts (NHE). . . . The electrochemical and chemical reactions which are consistent with the experimental observations at the potential of -0.8 V in a concentrated aqueous KOH colution at room temperature are given by the following equations:
>
> 1.) $4H_2O + 4e^-(M) \xrightarrow{i_a} 4H(M) + 4OH^-$
>
> 2.) $O_2 + 4H(M) \xrightarrow{K} 2H_2O$
>
> 3.) $2H_2O + O_2 + 4e^- \longrightarrow 4OH^-$
>
> A second electrode is required to supply the electrons to eqn. 1, and also to maintain the potential. The appropriate potential is obtained by connecting the auxiliary electrode to the negative (Cd) electrode. . . . The overall process at the auxiliary electrode (eqn. 3) indicates a consumption of water. The electrolyte in the neighborhood of the auxiliary electrode concentrates so that a wick must be supplied to accelerate water transport.

TABLE II

Specifications for Adsorption Hydrogen Electrode(6-Amp-Hr Cells)

AUXILIARY ELECTRODE

Number of auxiliary electrodes used per cell: one

Dimensions:	Length	20.55 cm
	Width	1.79 cm
	Thickness	0.066 cm

Location of auxiliary electrode in the cell: edge of the plate pack on two sides and the bottom.

Internal impedence of auxiliary electrode with respect to cadmium electrode: approximately 7 ohms.

Type of electrolyte wicking used for auxiliary electrode: pellon (2505 Series).

NICKEL-CADMIUM ELECTRODES

Nickel Plate

Number of plates per cell: 9

Dimensions:	Length	5.51 cm
	Width	4.80 cm
	Thickness	.084 cm (per plate)

Weight (dry): 72 gm for 9 plates

Weight of active material: 33.3 gm for 9 plates

Cadmium Plate

Number of Plates per cell: 10

Dimensions:	Length	5.51 cm
	Width	4.80 cm
	Thickness	0.76 cm (per plate)

Weight (dry): 81 gm for 10 plate

Weight of active material: 39.0 gm for 10 plates

According to eqn. 2, assuming this step to be rate determining, the Adhydrode current i_a will be dependent upon the oxygen partial pressure.[11]

Many of the operating parameters of the Adhydrode have been described by Sizemore.[12] In his tests each battery was fitted with piezo-resistive pressure transducer to correlate Adhydrode signal with the oxygen pressure. The procedure for measuring the Adhydrode signal was to place a known resistance externally across the Adhydrode and the negative or cadmium electrode of the battery. The cells in the above test[13] were evaluated using external auxiliary electrode resistances varying from 0.5 ohms to 510 ohms. These tests indicated that the maximum power point for a given pressure occurs when an euxiliary electrode resistance of about 7 ohms was used. For a given pressure (28 psia) and resistance (6.8 ohms) the Adhydrode signal was found to increase with temperature, i.e. 0°C - 150 mv, 25°C - 175 mv, and 40°C - 200 mv.

8. Thermodynamics and Electrochemical Calorimetry

The majority of electrochemical reactions are investigated under equilibrium conditions, i.e. when no pressure-volume work is being performed as the result of gas evolution or when no current is being passed through the cell while e.m.f. data is being accumulated at various temperatures. The enthalpy change (ΔH) for such reactions is then calculated using the Gibbs-Helmholtz equation:

$$\Delta H = nF \left[T \left(\frac{\delta E}{\delta T} \right)_p - E \right]$$

This method unfortunately yields no information about a cell undergoing an irreversible thermodynamic reaction such as the discharge of a nickel-cadmium battery. However, one is able to evaluate such a reaction via the first law of thermodynamics ($\Delta E = q - w$) which is not limited by the reversibility of a process.[14] Also, it is noted that by definition any change in the enthalpy (ΔH) is equal to the change in internal energy (ΔE) plus the pressure-volume work done (PV).

$$\Delta H = \Delta E + PV$$

However, for a hermetically sealed nickel-cadmium battery undergoing a discharge reaction no PV work is performed.

Therefore, for the discharge reaction of the nickel-cadmium battery the enthalpy charge (ΔH) is calculated from

$$\Delta H = q - (\text{electrical work})$$

where $-q$ is the heat liberated by the reaction or system and detected by the calorimeter and the electrical work is equal to the potential (V) drop across the cell terminals while the cell is being discharged at a constant current "I" such that $W_e = (V)(I) = \text{watts}$.

From a thermochemical standpoint, the discharge process can be represented by the following reaction as discussed by Metzger, Weinreb, and Sherfey:[15]

$$2Ni(OH)_3 [s] + Cd [s,\alpha] \rightarrow 2Ni(OH)_2 [s] + Cd(OH)_2 [s]$$

These authors used the literature [16] values for the standard molar heats of formation of the reactants and products which are respectively -162.1, 0.0. -128.6 and -133.3 kcal mole^{-1}. Then, applying Hess' Law, they calculated the ΔH of the reaction as -66.3 kcal mole $^{-1}$ or -33.1 kcal equiv^{-1}.

There is very close agreement between this calculated value for the discharge process and the experimental results obtained by several investigators who applied the above technique to an adiabatic calorimeter. These values are compared in Table III.

The authors, whose work is reported in Table III, chose an adiabatic type of calorimeter because of its ease of construction and the type of information being sought. However, if the task was to obtain heat profile data for cycle after cycle, as well as enthalpy data, their choice would very likely have been a continuous flow calorimeter in which heat is not accumulated from cycle to cycle.

TABLE III.

Comparison of ΔH Values Obtained in Several Adiabatic Calorimeters

Author	Reference	ΔH kcal/equiv
Metzger, Weinreb, Sherfey	#15	33.2,32.8,32.7,32.6,31.8
Metzger, Sherfey	#17	33.0
Bruins, Caulder, Salkind	#18	33.1

III. APPARATUS

1. General Comments

On the basis of what has been reported in the literature it has been concluded that the continuous flow calorimeter was most suited for investigations of the heat effect of batteries which are subjected to continuous orbital conditions. The continuous flow calorimeter was constructed using components available from a previous investigation which was conducted in this Laboratory by S. M. Caulder under the direction of J. M. Sherfey of NASA Space Flight Center, Greenbelt, Maryland. A large number of improvements and alterations were made to the original apparatus design of Sherfey, as described in Caulder's thesis.[9]

2. Improvements and Modifications

a) The direction of liquid flow through the calorimeter was reversed, that is, the oil was introduced at the bottom of the calorimeter at which point it was sensed by the cold junction of the thermopile, next it passed over the heat generating source (cell, heater) and finally exiting at the top of the calorimeter where the hot junction of the thermopile was positioned.

b) The number of copper-constantan couples in the thermopile was increased from 20 to 25, thus increasing the sensitivity of same and enabling one to detect a temperature difference of 0.00096 °C.

c) The junctions of the thermopile were positioned in the center of the flow stream by fixing same with epoxy cement in a 0.75 in. diameter acrylic pipe which is adjusted in and out by means of a stainless steel "Conax" compression fitting which is fastened at the top and bottom of the calorimeter.

d) The internal diameter of the exit pipe on top of the calorimeter was reduced from 2 in. to 1.5 in. so that it was the same size as the entrance pipe at the bottom of the calorimeter.

e) A special fixture was constructed from Lucite for locating the exact position of the battery and calibration heater at all times in the calorimeter. See Fig. 2.

f) The constant level reservoir and 16 feet of pipe used to deliver the liquid to and from the reservoir were eliminated. The device had been used to maintain a constant flow of liquid through the calorimeter which actually is a duplication of the function of the constant volume metering pump.

g) Substitution of polyvinyl chloride pipes for previously used cast iron pipes eliminated any by-products of corrosion from the system.

h) The sensitivity of measurement was increased by using a light weight hydrocarbon oil* with a heat capacity lower than water.

The above engineering changes had the overall effect of increasing the signal by a factor of 28. A signal of 220 microvolts for 1.0 watt at 25°C in oil may be compared to Caulder's signal of 8 microvolts at 1.0 watt in oil at 23°C (see Table I). A more detailed discussion of the results appears in the calibration experimental section. Before proceeding into the experimental section a detailed discussion of the components of the apparatus and their manner of construction are presented. The apparatus consists of two separate systems: (1) the liquid circulating system (Fig. 3) and (2) the electrical system (Fig. 9). The liquid

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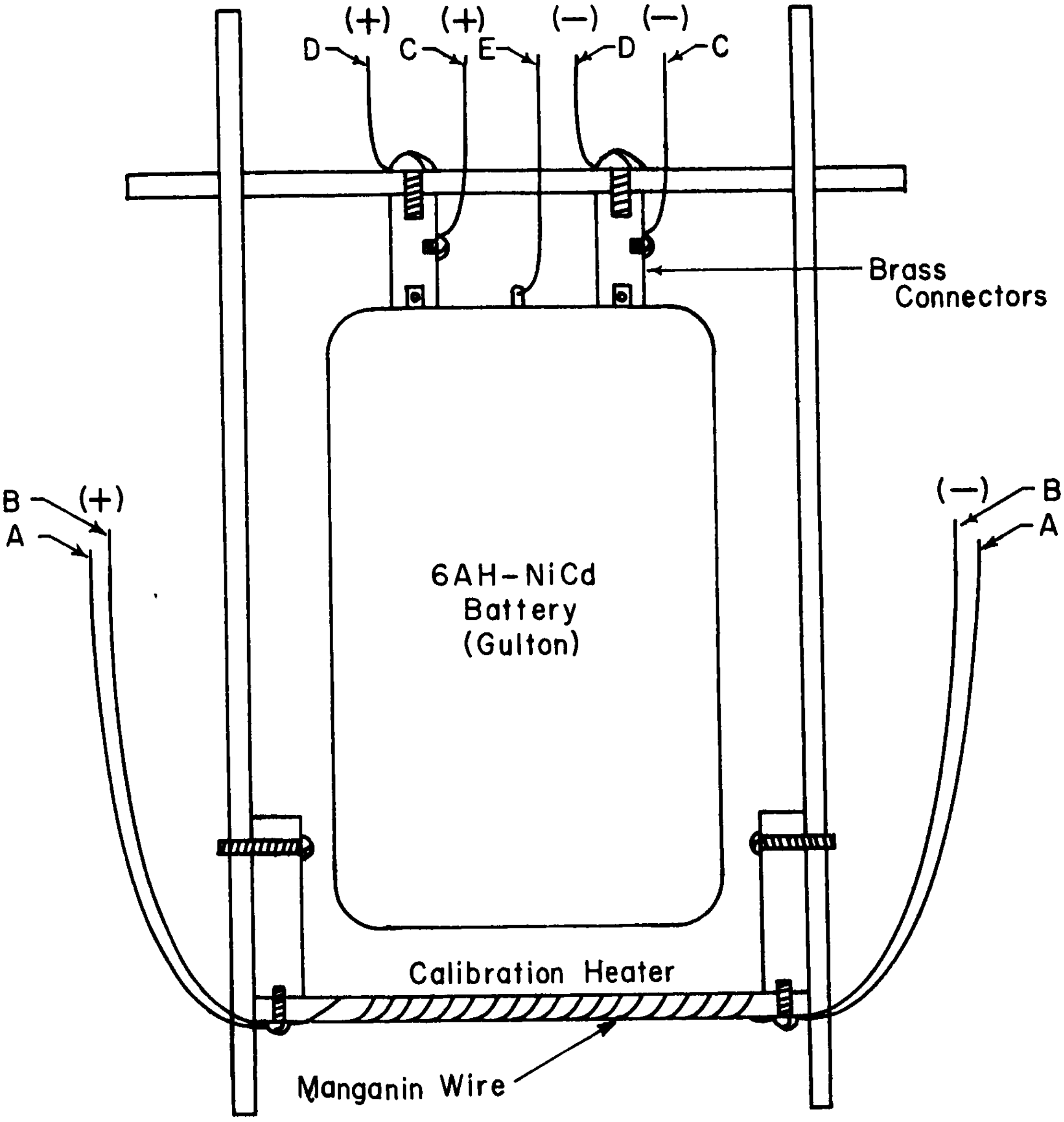
* Marcol 70 obtained from Humble Oil Co.

FIGURE 2. LUCITE FIXTURE SHOWING POSITION

OF Ni-Cd CELL AND HEATER



A. Heater Current Leads
B. Heater Voltage Leads
C. Cell Voltage Leads
D. Cell Current Leads
E. Adhydrode Leads

circulating system then was subdivided into those components contained in the thermal ballast tank and those external of it.

3. Internal Circulating System

a) Console

First, it was necessary to construct a console to house the thermal ballast tank. The frame was fabricated from 1.25 in. "U" shaped channel steel sections to the dimension of 18 in. x 24 in. x 48 in. The floor of the console consisted of two 0.75 in.-thick pieces of plywood separated by 1.25 in. air space which aided in insulating the thermal ballast tank from the surroundings. The console was enclosed on four sides with 0.09 in. aluminum sheet and covered with a 0.25 in.-thick aluminum plate. Rising above the console for another 3.5 feet was steel channeling for use as a supporting structure for mounting various devices such as pulleys, electric motors, etc. The entire structure was then mounted on casters for mobility.

Finally, before placing the thermal ballast tank in the console it was wrapped with 2 in.-thick polyurethane foam. Any remaining air spaces between the thermal ballast tank and the walls of the console are filled with fiberglass insulation.

b) Thermal Ballast Tank (Figs. 4 & 5).

The function of the 40-gallon tank was to maintain the calorimeter environment at the desired operating temperature. The tank was constructed from 0.06 in.-thick type 316 stainless steel. A partial partition (Fig. 4) separates the tank into two compartments. The larger compartment houses the calorimeter and its air jacket while the smaller contains the heat exchanger and stirrer. The function of two compartments is to insure proper mixing similar to the arrangement in a melting point apparatus.

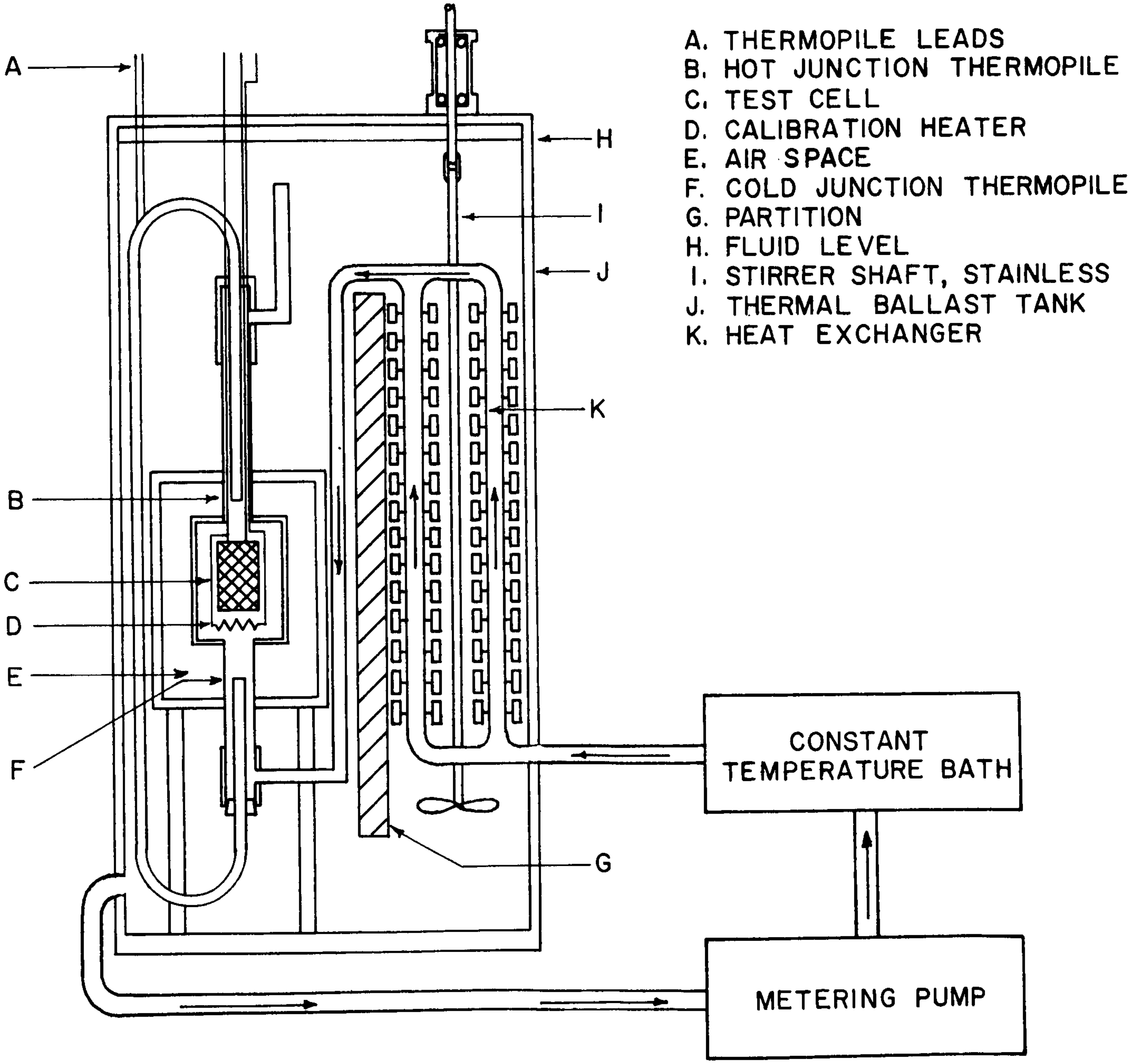


FIGURE 3 LIQUID CIRCULATING SYSTEM

FIGURE 4. THERMAL BALLAST TANK -

TOP VIEW (Ref. 9)

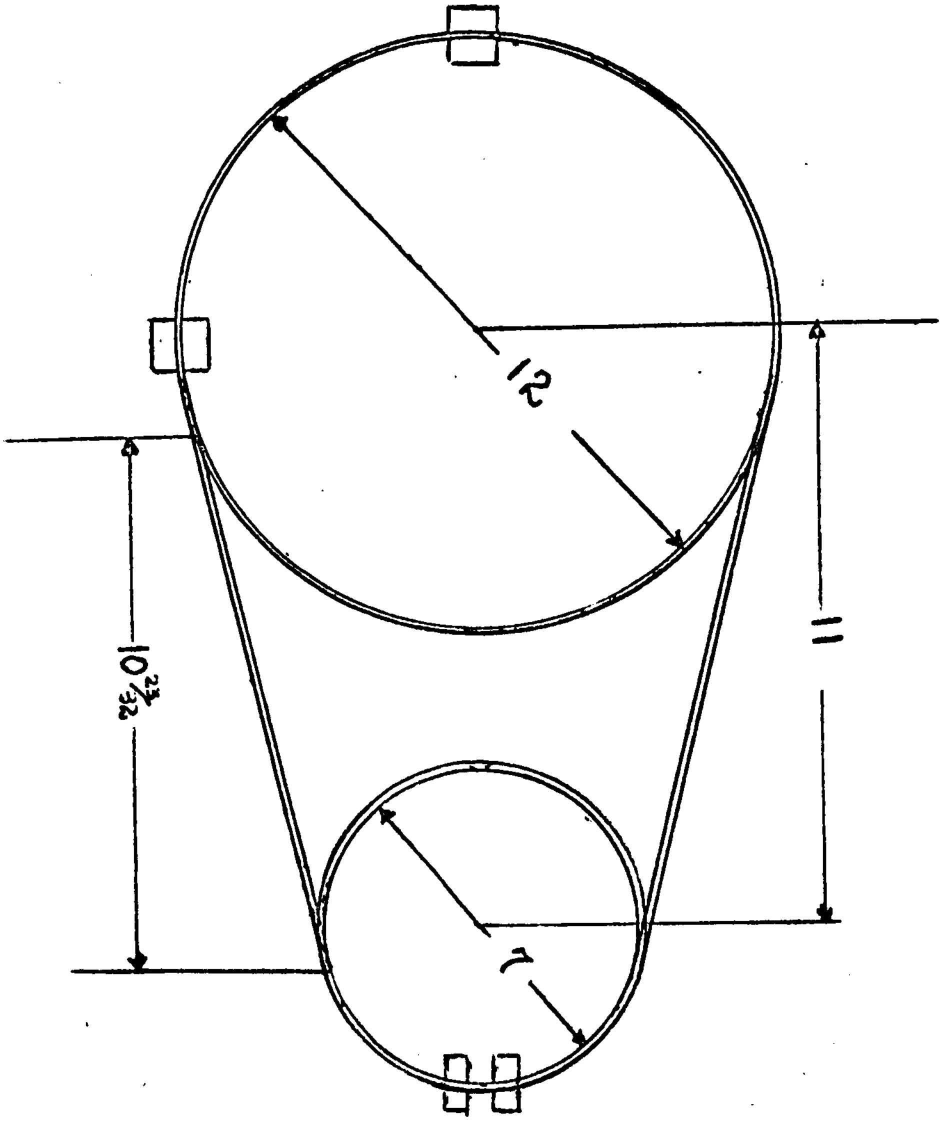
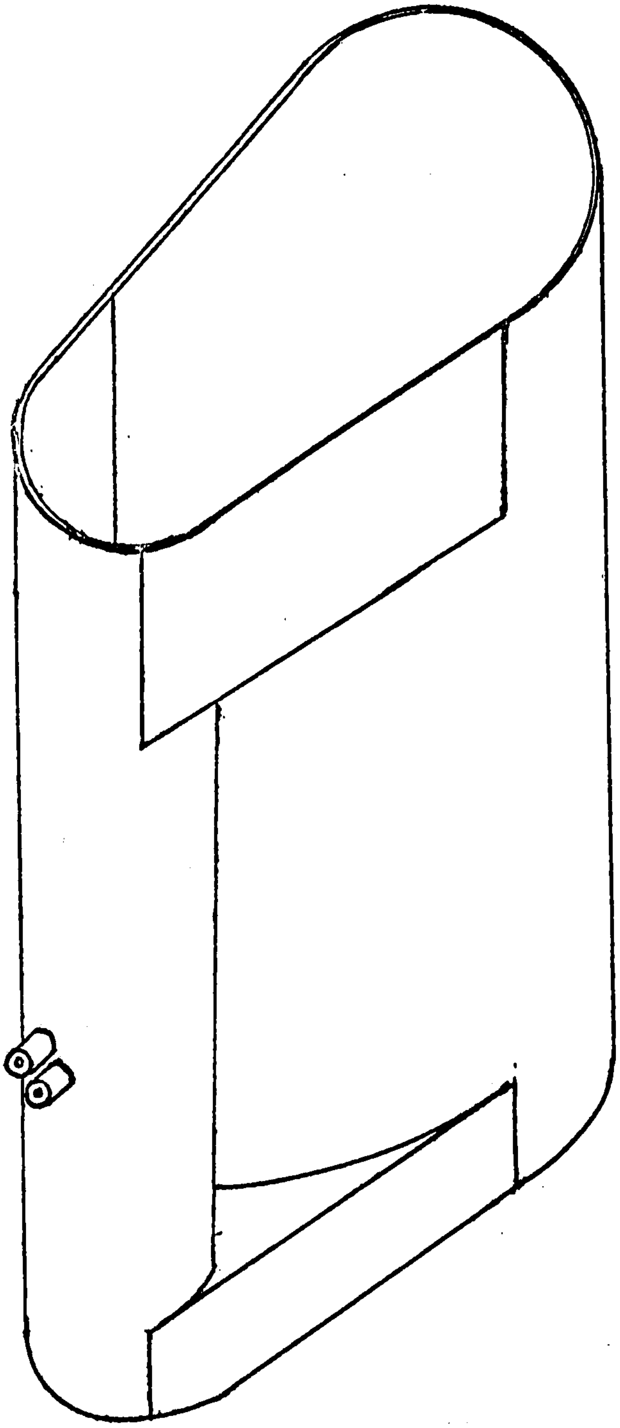


FIGURE 5. THERMAL BALLAST TANK

(Ref. 9)



The tank is insulated as described above and all pipes having contact with or passing through the walls of the tank are made of polyvinyl chloride to minimize heat transfer.

c) Calorimeter (Fig. 6).

The calorimeter was constructed large enough so that the heat generating device and calibration heater would not impede the flow of the liquid nor make contact with the walls. However, at the same time it was constructed as small as possible so that the rate of flow of the oil was sufficiently rapid to maintain essentially isothermal conditions. The calorimeter was fabricated from type 316 stainless steel 0.09 in. thick in the form of a right circular cylinder 4.5 in. diameter and 6 in. high having a volume of 107.3 $in.^3$ Centrally located on the bottom plate was welded 1.5 in. diameter stainless steel tube approximately 5 in. long with an end threaded to which was attached a polyvinyl chloride plumbing tee. The horizontal position on the tee received a 0.75 in. diameter copper tube through which flowed the oil from the internal heat exchanger. The vertical position on the tee received a center drilled rubber stopper for positioning the cold junction of the thermopile which was contained in a 0.75 in. diameter acrylic pipe. The top of the calorimeter was a removable stainless steel lid which was secured by stainless steel screws and an O-ring compression seal. The O-ring seal prevented leakage from the calorimeter into the air jacket chamber. A 2 in. stainless steel pipe 8 ins. in length threaded on one end was welded to the center of the top plate. The internal diameter of this tube was reduced to 1.5 in. to correspond to the bottom tube and to concentrate the heat bearing liquid on the thermopile. Attached to the end of this tube was a polyvinyl chloride plumbing tee. In the vertical opening of the tee was placed a polyvinyl chloride cap for receiving a stainless steel "Conax" compression fitting which was used for positioning the hot junction of the thermopile with reference to the exit of the calorimeter. In the horizontal opening was placed a 0.75 in. diameter polyvinyl chloride pipe for returning the heated liquid back to the thermal ballast tank.

d) Air Jacket (Fig. 6)

The calorimeter is surrounded by an air jacket to minimize heat transfer through the calorimeter wall. The outside surface of the calorimeter and the inner surface of the air jacket are polished in order to minimize heat transfer by radiation. The air jacket was fabricated from type 316 stainless steel 0.12 in. thick in the form of a right circular cylinder 8.0 in. diameter and 11 in. high. The bottom plate of the jacket was welded to the calorimeter entrance tube approximately 3 in. beneath the calorimeter. The lid of the air jacket was designed so that it was removable and could slide up and down the exit tube of the calorimeter. The lid is secured to the top of the air jacket by means of stainless steel screws and an O-ring seal. Also, there is a O-ring compression seal around the exit pipe of the calorimeter and the lid of the jacket to prevent leakage from the thermal ballast tank into the air jacket. Finally, four 12 in. long polyvinyl chloride legs are mounted on the base of the air jacket to support it and the calorimeter.

e) Internal Heat Exchanger (Figs. 3 & 7)

The internal heat exchanger provides a means of finally equilibrating the inflowing oil from the external circulating system with the

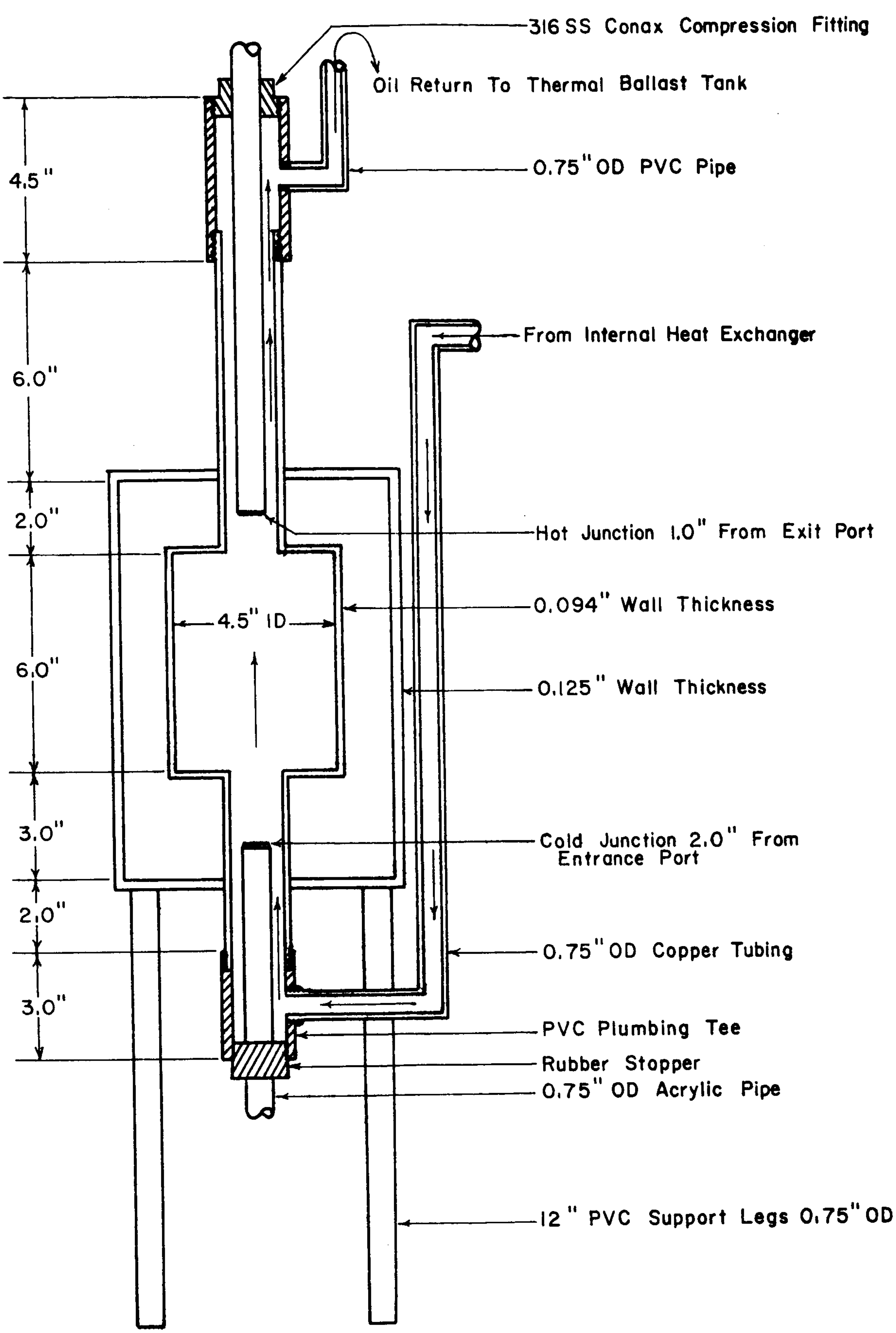


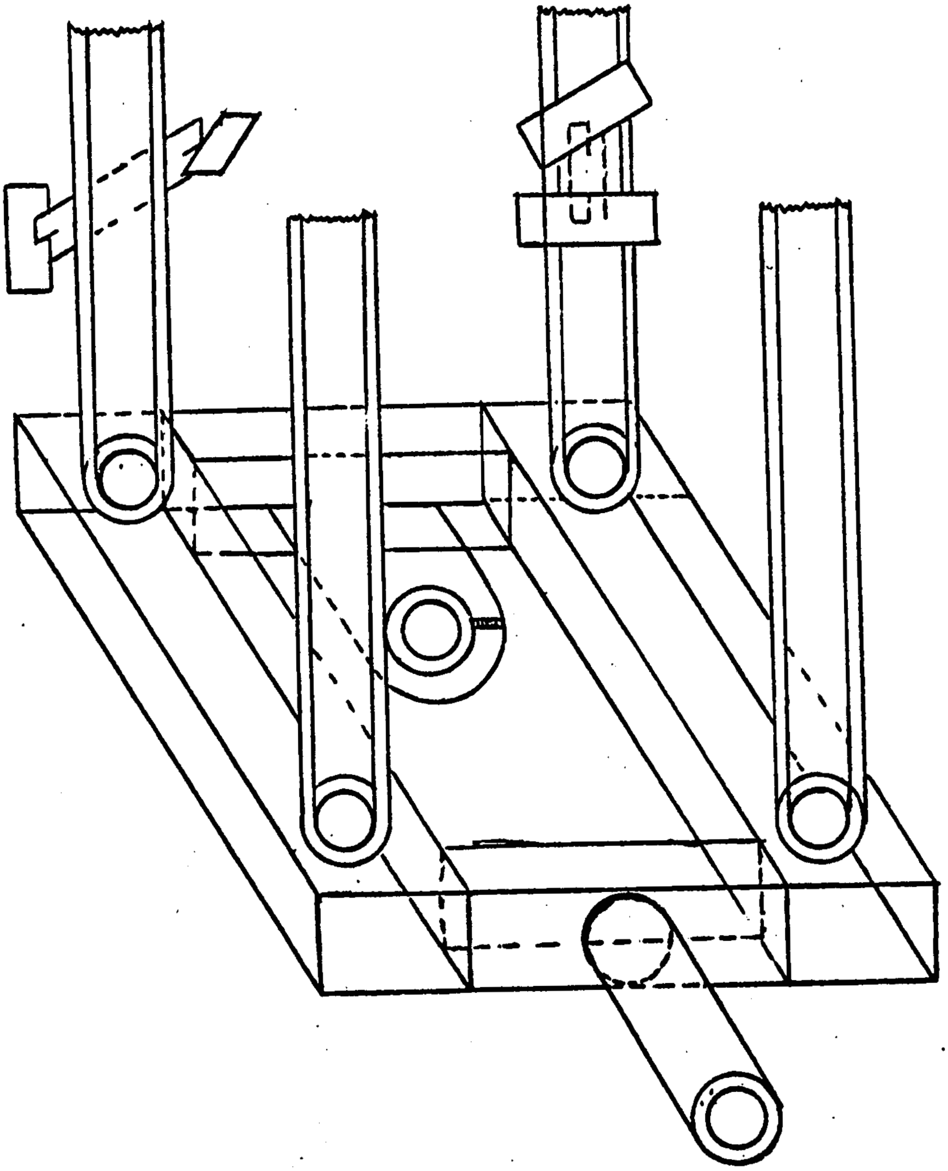
FIGURE 6 CALORIMETER AND AIR JACKET (~ 1/4 scale)

oil in the thermal ballast tank before it enters the calorimeter. The heat exchanger was constructed by placing four 0.875 in. diameter copper tubes into two copper manifolds (Fig. 7). The bottom manifold is connected to the external circulating system by a polyvinyl chloride pipe which passed through the thermal ballast tank wall. The top manifold is connected to the calorimeter by a copper tube coupling device. The four copper tubes of the heat exchanger had 0.25-in. holes drilled through them at 90° angles and 1.0 in. apart; 0.25 in. by 0.25 in. solid copper rods which are notched at both ends and inserted through these holes, passing through the tubes and having the notched ends exposed on both sides of the tube. This arrangement serves to baffle any oil being drawn up externally to the heat exchanger by the action of the stirrer thus eliminating streamers of hot and cold oil throughout the thermal ballast tank.

f) Stirrer (Fig. 3)

The stirrer is powered by 1/10 h.p. variable speed electric motor which is mounted on the super structure of the console. A V-shaped rubber belt passes between the motor and a wheel which is mounted on a bearing housing. The bearing shaft is made of Bakelite and is coupled to a 0.50 in. diameter stainless steel stirrer shaft which passes through the center of the heat exchanger. On the bottom manifold of the heat exchange there is a bronze bearing through which the shaft passes thus eliminating whiplash. At the end of the stirrer shaft is mounted a small brass propeller.

FIGURE 7. INTERNAL HEAT EXCHANGER (Ref. 9)



4. External Circulating System

a) Pump (Fig. 3)

The oil is drawn off at the lower left side of the thermal ballast tank (fig. 3) and passes through 0.75 in. diameter polyvinyl chloride pipe to a pump. A 1/2 h.p. Milton Roy controlled volume pump was used to circulate the oil through the system at a specified rate. The capacity of the pump ranged up to 4400 cc/min and was adjustable by varying the stroke of the plunger. Because this pump operated on a 70 cycle frequency it was possible to eliminate the constant level reservoir which was previously used by Caulder[9] in conjunction with the pump to deliver a constant volume of liquid through the system.

b) Constant Temperature Bath

An Aminco Wide-Range Laboratory Bath was used because of its wide temperature range capabilities ($-29^{\circ}C$ to $+71^{\circ}C$). This bath could be maintained within $\pm 0.01^{\circ}C$. The oil passed from it through a polyvinyl chloride pipe to the manifold of internal heat exchanger in the thermal ballast tank where the final temperature equilibrating occurred.

c) External Heat Exchanger

By external is meant external to the thermal ballast tank. This heat exchanger is located in the Aminco Wide-Range Laboratory Bath and it equilibrates the oil to the approximate temperature of the experiment before it enters the thermal ballast tank. It consists of 12 ft. of 0.75 in. copper tubing sectioned into two ft. lengths which are connected by a series of elbows to form a path through which the oil flows while in the Aminco Bath.

5. Electrical System

The electrical system is divided into two main systems: a) the thermal measuring circuit and b) the calibration and cell testing circuit.

a) Thermal Measuring Circuit

The thermal measuring circuit consists of a 25-junction thermopile, a microvolt amplifier (L & N Stabilized D-C Microvolt Amplifier #9835-B) and a recorder (L & N Speedomax Type "G"). The function of this circuit is to measure and record any changes in the temperature of the oil flowing through the calorimeter. A 25-junction copper-constantan thermopile was constructed using 60-in. lengths of No. 30 wire which were coated with enamel and encased in fiberglass insulation (L & N #30-55-1 Cu -Const.). The construction of this thermopile proved to be time consuming. In figure 8 is presented a diagram of the final system which has been in operation for three continual months. Teflon "spaghetti" was used to reinforce the wire and to protect it both mechanically and chemically. The entire bundle of 25 junctions was placed in 12-in. lengths of 0.75 diameter acrylic pipe and liquid Armstrong C-7 epoxy was injected between each wire to fix its position. The elaborate device was necessary in order to know the exact position of the junction with reference to the calorimeter and to insure that the junctions do not short circuit with themselves or the sides of the stainless steel calorimeter. The emf. of the junction is 41.3 microvolts per degree centrigrade per couple - this gives 1032 $\mu v^{o}C^{-1}$ for 25 couples. The L & N microvolt amplifier is capable of detecting 1 microvolt, thus enabling one to measure a difference of 0.0010 degree between junctions.

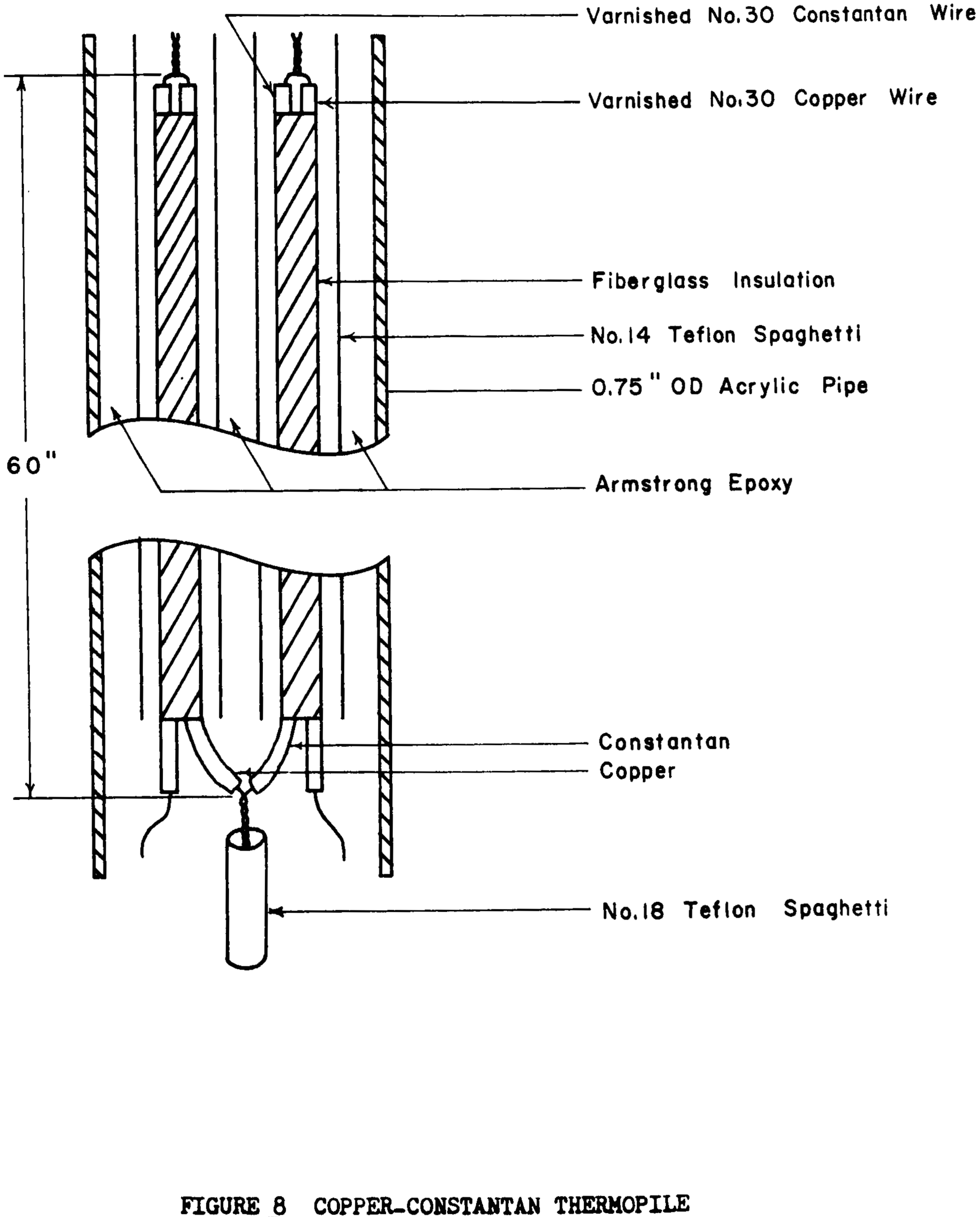
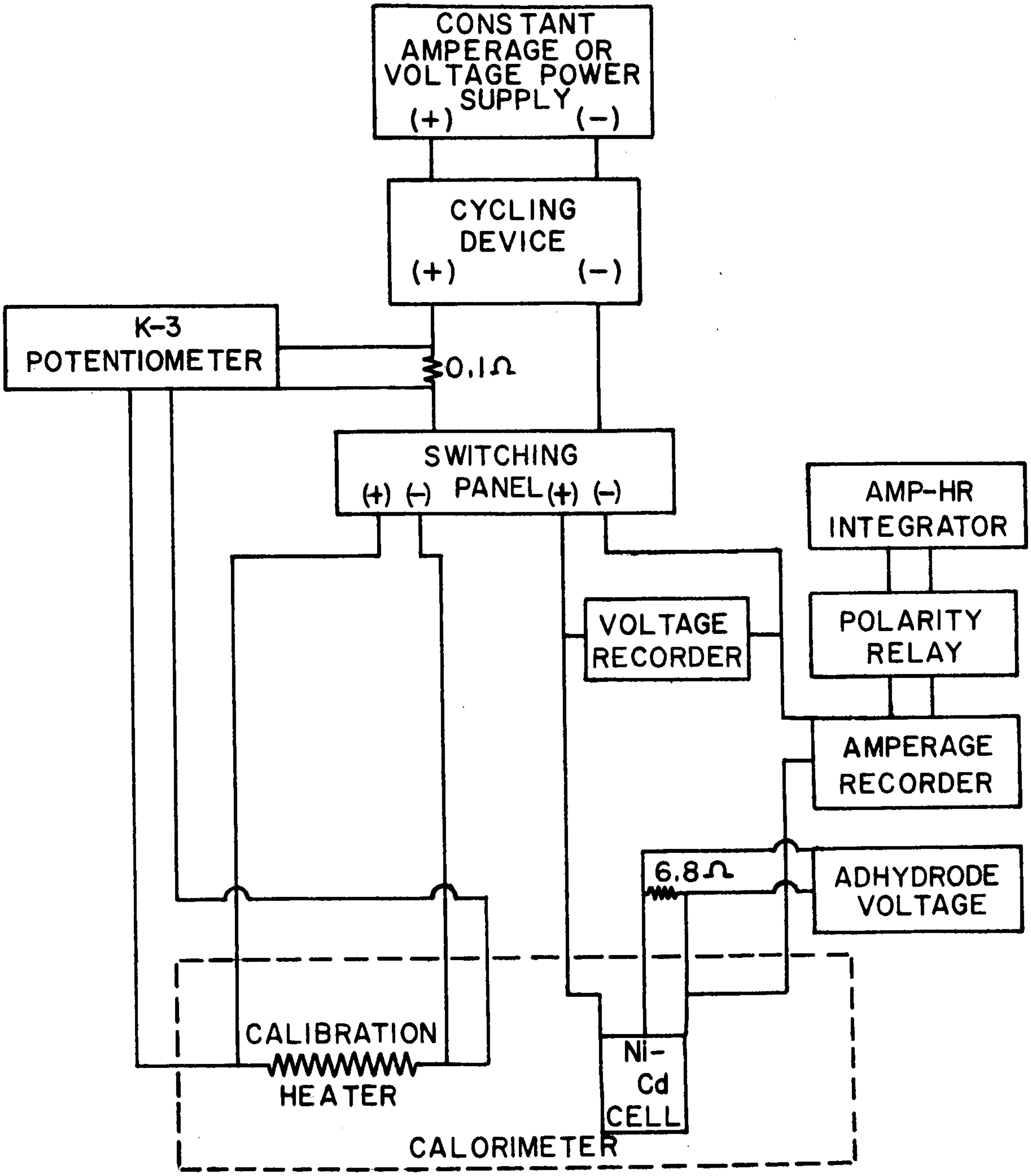


FIGURE 8 COPPER-CONSTANTAN THERMOPILE

b) Calibration & Cell Testing Circuit

The calibration and cell testing circuits (Fig. 9) jointly share a constant current-constant voltage power supply (Kepco #CK 18-3M), an automatic cycling device, and a millivolt potentiometer (L & N #7553-5). The Kepco power supply is capable of maintaining a constant current setting to 0.1% of its value. The power supply is then remotely programmed through the automatic cycling device Figure 10. This device facilitates the charging of the cell at constant current or constant voltage and the discharging of the cell at constant current or constant load. A K-3 microvolt potentiometer is used to measure accurately the current as a function of the voltage drop across a 0.1 ohm resistor. From this point the current proceeds through a switching panel to either the calibration circuit or the cell testing circuit. The current is carried by #16 polyvinyl chloride coated copper wires to a calibration heater which is constructed from manganin wire and held in position by the Lucite fixture shown in Figure 2. Manganin wire is used because of its fairly constant resistance between 15°C and 35°C. In this range it has a temperature coefficient of resistance of $1.0 \times 10^{-5} oC^{-1}$. Finally two more #16 polyvinyl chloride insulated copper wires are attached to the heater for measuring the voltage drop across the heater. These voltage measuring leads are then connected to the K-3 potentiometer. No. 16 polyvinyl chloride coated copper leads are also used for the current carrying and voltage measuring leads in this part of the circuit. The voltage and amperage are recorded on a pair of Honeywell Electronik #17 Recorders. The amperage recorder has attached to it a polarity switching relay device which switches the direction of current going to an

FIGURE 9. CALIBRATION AND CELL TESTING CIRCUIT



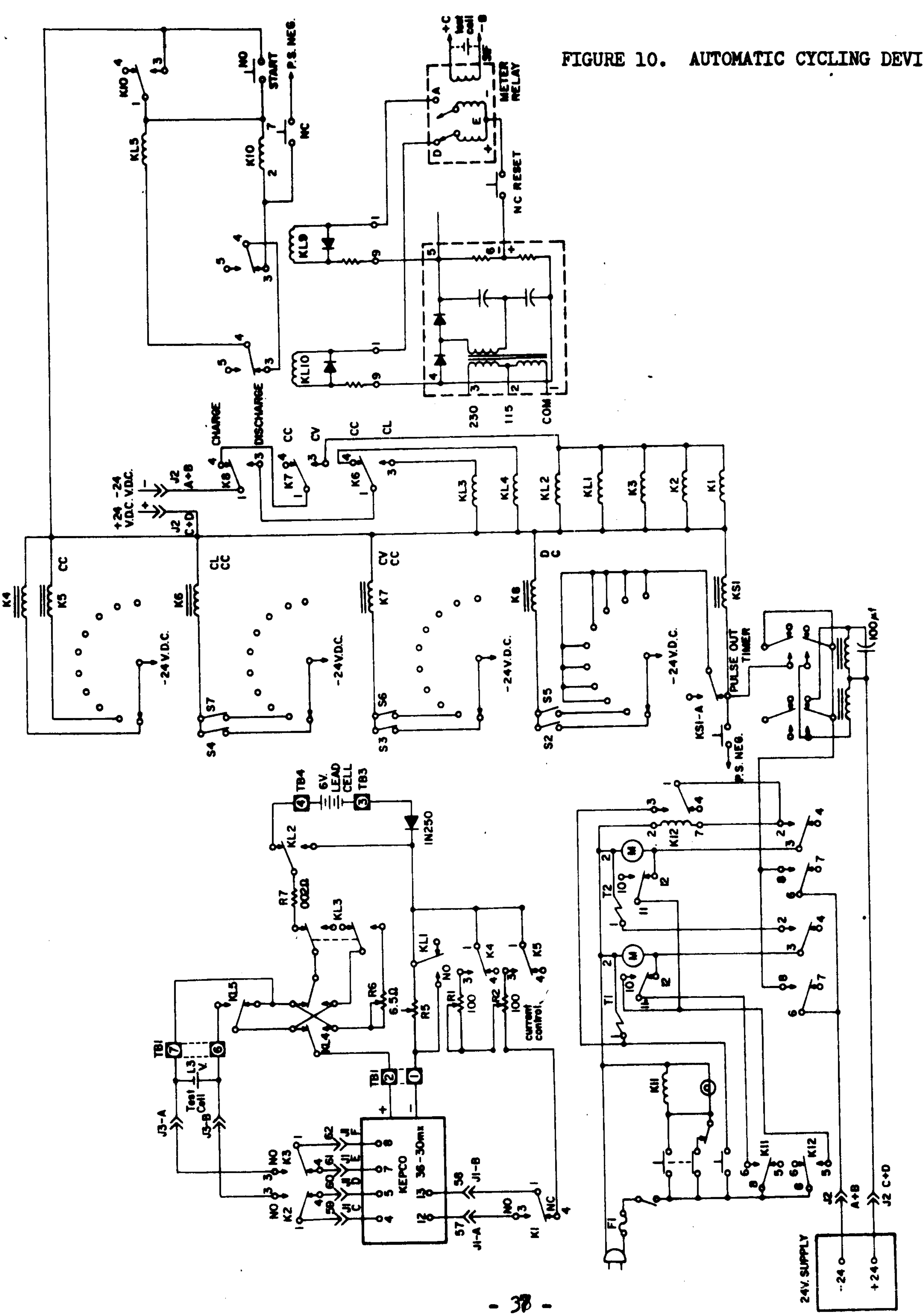


FIGURE 10. AUTOMATIC CYCLING DEVICE

ampere-hour integrator. The integrator is attached to a printer which prints out the number of ampere-hours passing through the cell during each charge and discharge cycle. A Mosely Autograph #680 millivolt recorder is used to measure the voltage drop across a 6.8 ohm resistor which is placed between the Adhydrode and negative terminal of the Ni-Cd cell. This voltage signal is a direct indication of the oxygen pressure in the cell.[12] Finally, the automatic cycling device (Fig. 10) through a series of relays connects to electric timers which control the length of time of the charge and discharge cycles. Also, contained in the cycling device is a voltage meter relay which could be programmed to trip the cell out of the circuit when a certain voltage limit is reached.

IV. EXPERIMENTAL PROCEDURE

1. Calibration Experiments

In order to establish the ability of the continuous flow calorimeter described in Section III to detect the heat liberated or absorbed by a cell, the instrument was calibrated in the region of 0.10 to 1.00 watt, which region corresponds to the heat liberated by a Ni-Cd battery under typical orbital conditions. The experimental sequence was initiated by placing a 6 AH Gulton Prismatic Battery in the Lucite fixture (Figure 2) which also contains the manganin calibration heater. The entire fixture was placed in the calorimeter and allowed to equilibrate for at least 16 hours before the first measurement is made. A one ohm resistor was placed across the terminal of the cell external of the calorimeter. Then, a constant current from the Kepco Power Supply was directed through the switching panel to the calibration heater. This current was measured as the potential drop across a 0.1 ohm resistor by the K-3 potentiometer. The wattage (W) generated by the calibration heater was determined by

$$W = I^2R$$

or, by multiplying the current by the voltage drop across the heater as measured by the K-3 potentiometer.

The difference in temperature between the inflowing and outflowing oil from the calorimeter produced by the calibration heater was detected by the 25-junction thermopile. The output of the thermopile was fed into the D. C. microvolt amplifier which, in turn, was fed into 0-20 mv. range (L & N) Speedomax G recorder.

A plot of watts vs. microvolts was obtained by performing a series of these experiments in the range of 0.0 to 1.0 watt. Some of the variables which effect the magnitude of this signal are (a) the position of the thermopile, (b) the rate of flow of oil, and (c) the duration of time the system has been seeking equilibrium. A detailed discussion of these variables appears in the "results" section of the report.

2. Cell Conditioning

The cells were received from the manufacturer with a short circuit strap across the terminals. The short circuit strap was removed and the cells were conditioned as follows:

a) charged at $\frac{C}{10}$ or 0.6 amp for 16 hours;

b) discharged at $\frac{C}{2}$ or 3.0 amps until a terminal voltage of 1.0 was reached;

c) short circuited through a 1.0 ohm resistor for a minimum of 2 hours;

d) repeated step a, b, and c;

e) charge at $\frac{C}{10}$ or 0.6 amps for 16 hours.

At this point the cell is ready to start the cycling experiments with the first step being a discharge cycle. The discharge step (b above) in the cell conditioning served as a capacity check on the cell. A cell was considered acceptable if it maintained a capacity in excess of 7.0 A-H.

3. Cycling of Ni-Cd Cell in the Calorimeter

A previously conditioned cell was subjected to a series of experiments which varied in depth of discharge, percentage recharge and number of cycles. They were as follows:

a) Experimental Series A: The cell was discharged at 3.0 amps for 30 min. or 25% depth. The cell was then charged at 1.65 amps for 60 minutes or to 110% recharge. This was repeated for 79 cycles.

b) Experimental Series B: The cell was discharged at 1.8 amps for 30 minutes or to a 15% depth. The cell was then charged at 0.99 amp for 62 min. or to 114% recharge. This was repeated for 74 cycles.

c) Experimental Series C: The cell was discharged at 3.0 amps for 30 min. or to a 25% depth. The cell was then charged at 1.65 amps for 62 min. or 114% recharge. This was repeated for 93 cycles.

As a part of each experimental series a capacity check was run during the last discharge cycle. The cell was discharged until a terminal voltage of 1.0 V. was observed. Finally a 1 ohm resistor was held across the cell terminals for at least 2 hours. Then, before beginning the next experimental series the cell was recharged for 16 hours at $\frac{C}{10}$ or 0.6 amp.

4. Determination of the Enthalpy Change (ΔH) of a Ni-Cd Cell

It is possible to determine the enthalpy change (ΔH) of the Ni-Cd cell as noted before. Since the reaction is conducted in a hermatically sealed cell then no PΔV work is done and if a time in the reaction is chosen such that no gas is being evolved then no VΔP work is performed. Under the above conditions of VΔP and PΔV equalling zero then by definition ΔE = ΔH or

$$\Delta H = q - w$$

where w represents only electrical work and q the heat liberated or absorbed. The electrical work done on or by the cell equals (I)(V) watts, where V is the voltage across the cell and I is the current through it. The heat liberated or absorbed during the cell reaction is recorded as microvolts through the thermopile and these data are converted to watts through the calibration curves. Finally, the rate of reaction is IF^{-1}

equiv/sec, where F is the Faraday in amp.-sec/equiv. Thus, during discharge

$$\Delta H = \frac{[q - (w)]F}{4.18 \times 10^{3} \cdot I} = K \text{ cal equiv}^{-1}$$

with the use of the above equations it is possible to calculate the enthalpy change (ΔH) for the cell reaction during either charging or discharging. These equations must be modified to include a $V\Delta P$ term if the calculations are performed during the evolution or reaction of oxygen.

5. Determination of Oxygen Pressure During Cell Cycling

Using the work of Sizemore[12] with the third electrode cell it is possible to continually monitor the oxygen pressure in the cell. Sizemore with the aid of a piezo-resistive pressure tranducer was able to correlate the millivolt signal of the Adhydrode across a 6.8 ohm resistor with the oxygen-pressure in the cell. The results of this testing appears in the following table for the purpose of correlation.

TABLE IV

Adhydrode Signal vs. Oxygen Pressure

Voltage (mv.)	Oxygen Press. (P.S.I.A.)	Voltage (mv.)	Oxygen Press. (P.S.I.A.)
6.25	0.63	100.00	11.50
12.50	1.25	106.25	12.50
18.75	1.75	112.50	13.50
25.00	2.50	118.75	14.60
31.25	3.13	125.00	15.25
37.50	3.75	131.25	16.25
43.75	4.75	137.50	17.50
50.00	5.13	143.75	18.75
56.25	6.13	150.00	20.00
62.50	6.85	156.25	21.20
68.75	7.50	162.50	22.90
75.00	8.50	168.75	24.75
81.25	9.00	175.00	26.30
87.50	10.00	181.25	28.70
93.75	11.00		

Conditions: Temperature 25°C and Resistance 6.8 Ohms.

V. RESULTS AND CONCLUSIONS

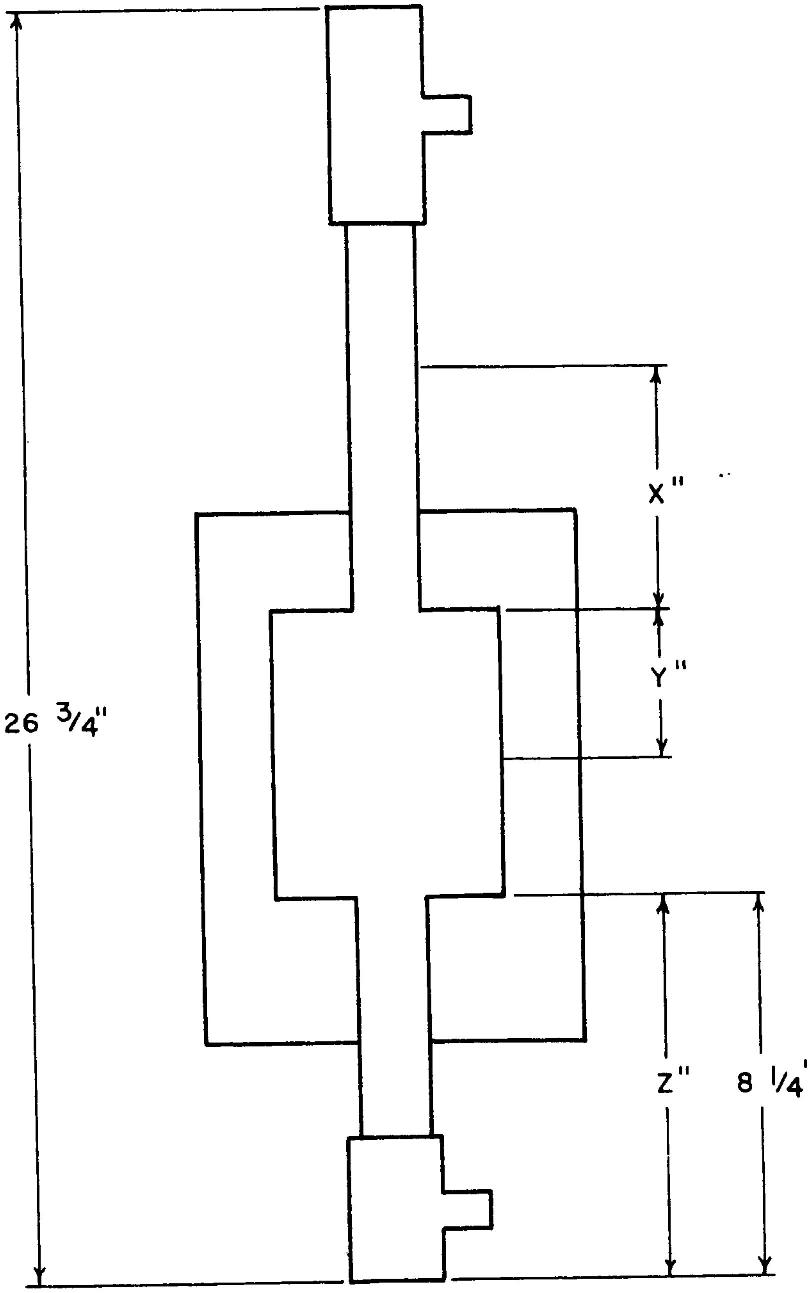
1. Calibration Experiments

Prior to the calibration experiments a considerable effort was devoted to the physical design of the thermopile, calibration heater and the positioning of each. The major difficulty involved was the elimination of electrical short circuits produced in the heater and the thermopile by the elements of each making contact with themselves or the walls of the calorimeter. The final versions of these devices appear in Figures 2 and 8. Both the thermopile and calibration heater have been in continual successful service for several months. With everything in working order, there were three remaining variables to be investigated during the course of the experiments:

a) the position of the thermopile;
b) the flow rate of the oil; and
c) the length of time required for equilibrium to be established.

A system of reference distances was used to evaluate the positions of the thermopile and heater as indicated in Figure 11. It was found that "y," the distance of the heater from the top of the calorimeter did not affect the signal from the thermopile. Distance "x," however, was very critical and if it were more than several inches from the top of the calorimeter, the thermopile would start sensing changes in the laboratory such as the cycling of the air conditioner. Position "z" was the least critical since this was the position of the cold junction of the thermopile which was in equilibrium with the entire system. The final positions which were used for all measurements appearing in this report are:

a) $x = 1"$
b) $y = 5\frac{1}{2}"$
c) $z = 2"$



X" = Distance Of Thermojunction From Top Of Calorimeter
Y" = Distance Of Heater Down From Top Of Calorimeter
Z" = Distance Of Thermojunction From Bottom Of Calorimeter

FIGURE <u>11</u> REFERENCE DIAGRAM FOR LOCATING POSITION OF THERMOPILE AND CALIBRATION HEATER

The flow rate of the Marcol 70 Oil through the calorimeter was varied by changing the length of stroke of the piston of the Milton Roy Constant Volume Metering Pump. A 20% stroke produces a 1000 cc/min. flow rate, while a 40% stroke produces a 2000 cc/min. flow rate. In Table IV are the results of these two flow rates. As would be expected, the slower flow rate of 1000 cc/min. produces almost double the signal of the fast flow rate of 2000 cc/min. A plot of the first four columns of Table IV yields a straight line demonstrating the linearity of response from 0.0 to 1.0 watt. However, these same graphs would also show that this line does not intercept the origin. The deviation from the origin and the lack of exact agreement between the signal from day to day was an indication that complete equilibrium had not yet been established. The system used to obtain the data in the first four columns was allowed to equilibrate for 16 hours, whereas the system used to obtain data for columns 5 and 6 was allowed to equilibrate for the better part of a week before the data was collected. A graph of the data appearing in column 6 appears in Figure 12. In Figure 13, the base line signal of the thermopile before the experimental series 8-24-40 was begun is represented. The periodic fluctuations were the result of the external heating and cooling of the Aminco Constant Temperature Bath. These fluctuations are constant and predictable and do not interfere with the interpretation of the results in any way. In Figure 14, the heat profile curve for the experimental series 8-24-40 when the calibration heat generated 0.4 watts of energy is presented. The response time, that is, the time for the full signal to be registered once the heater has been activated, appears in Table V.

TABLE V.

CALIBRATION DATA

Heater (watts)	Signal (microvolt)	Signal (microvolt)	Signal (microvolt)	Signal (microvolt)	Signal (microvolt)	Signal (microvolt)
	7-10-40	7-11-20	7-14-40	7-15-20	8-23-40	8-24-40
Oil	11	24	12	23	10	10
0.2	22	48	24	48	20	19
0.3	33	70	33	70	30	30
0.4	43	90	44	94	40	40
0.5	56	115	55	113	50	51
0.6	67	140	66	140	60	59
0.7	78	155	76	158	70	70
0.8	90	175	88	175	80	81
0.9	103	200	95	193	90	91
1.0	113	220	105	213	100	100

Experimental Number: 1st digit is the month
2nd digit is the day
3rd digit is the % stroke

20% stroke = 1000 cc/min.
40% stroke = 2000 cc/min.

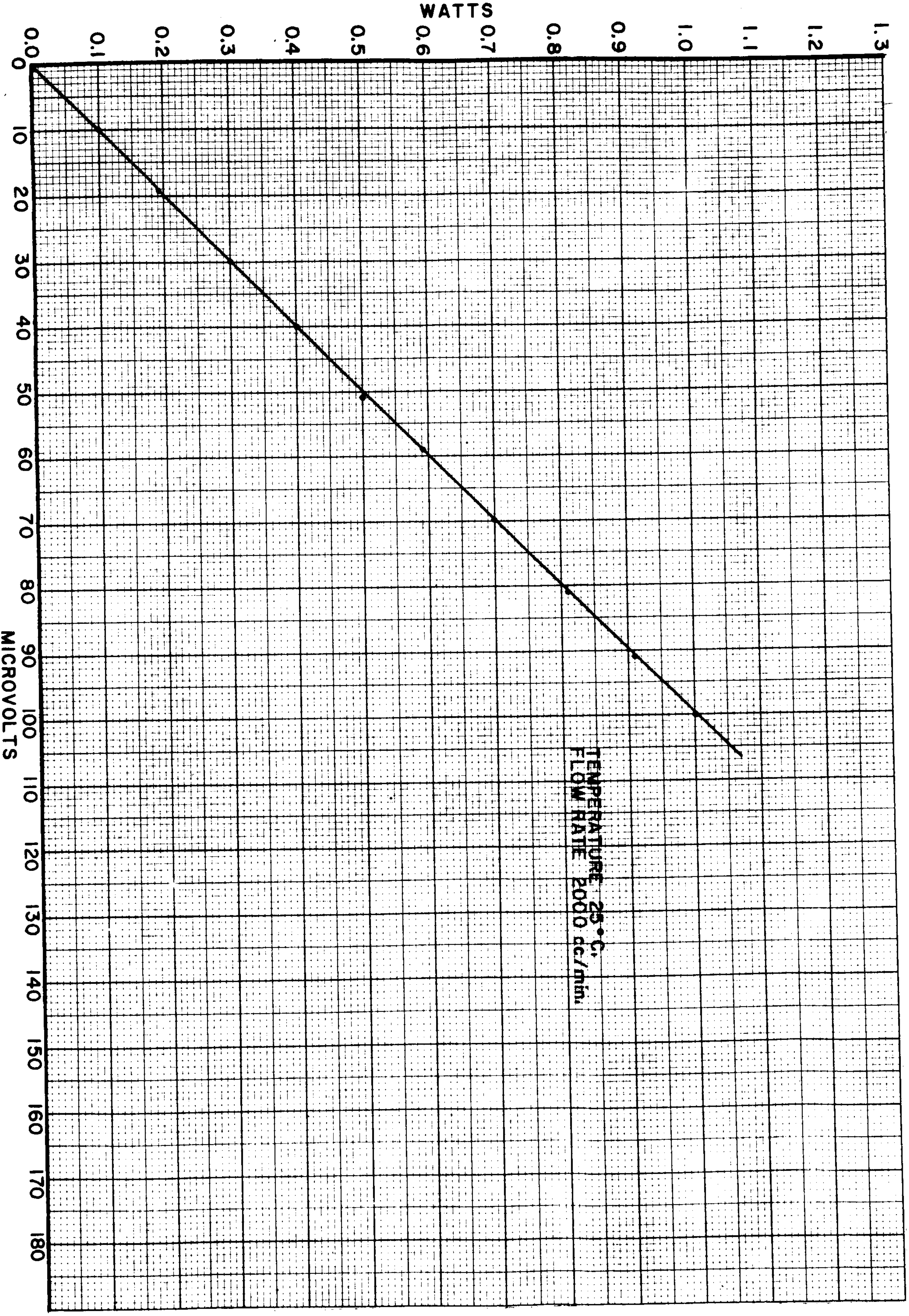


FIGURE 12 CALIBRATION CURVE FOR 40% STROKE

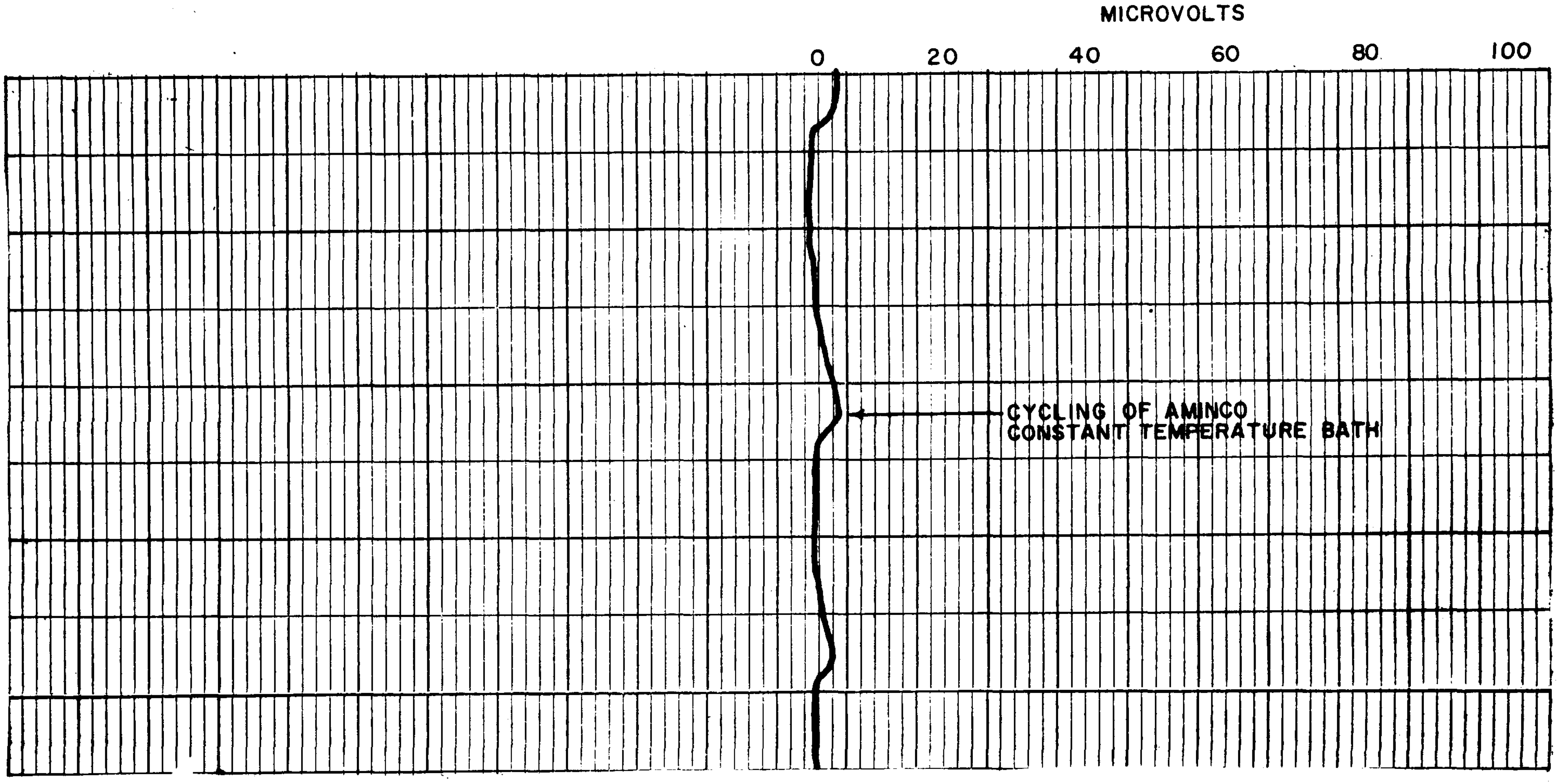


FIGURE 13 BASE LINE SIGNAL OF THERMOPILE

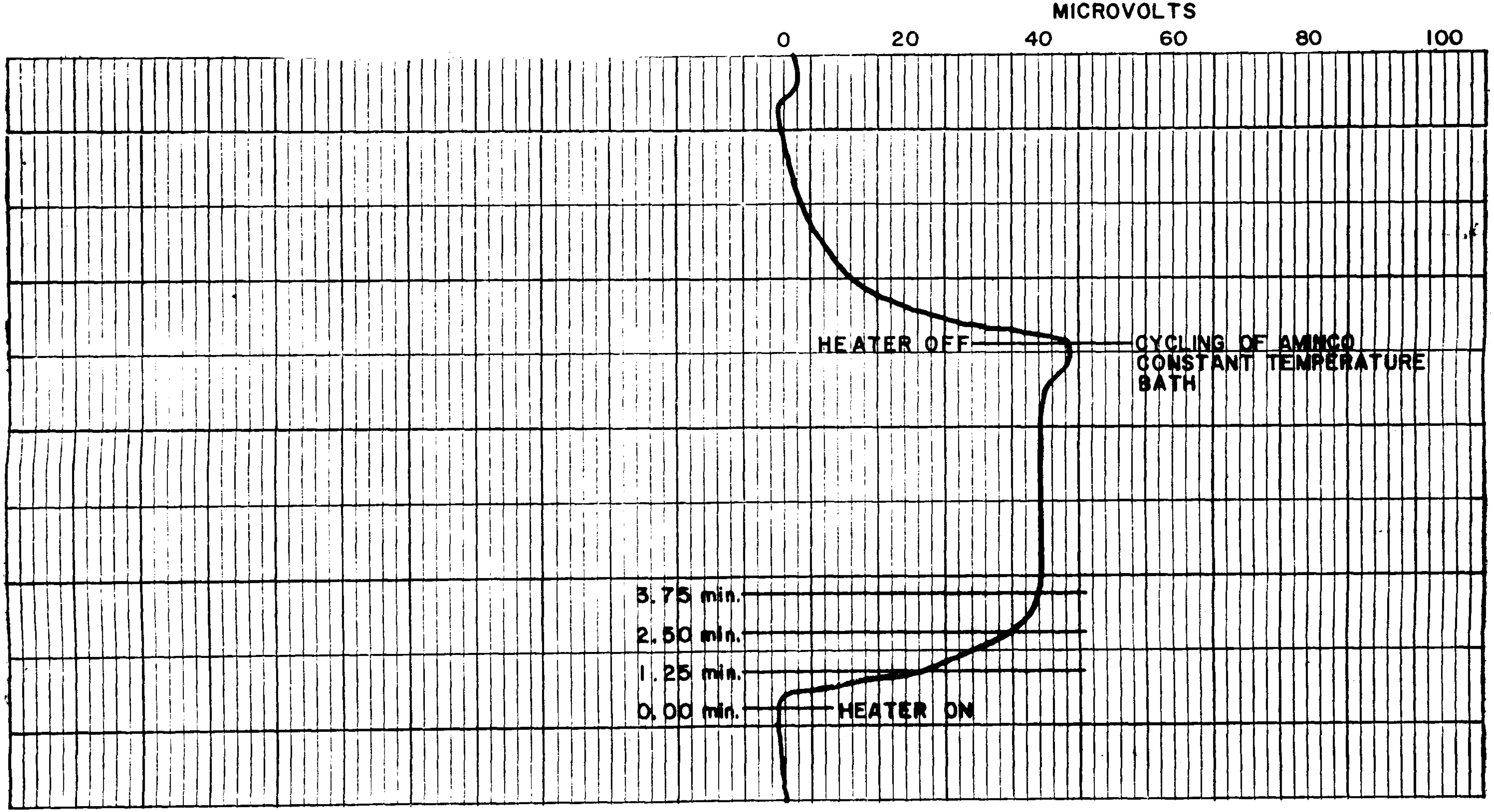


FIGURE 14 HEAT PROFILE FOR 0.4 WATTS

TABLE VI- RESPONSE TIME

Time (min.)	Signal (microvolts)	% of Total
1.25	20 μv	50%
2.50	34 μv	85%
3.75	40 μv	100%

2. Cycling Experiments

Table VI gives the oxygen pressure, change in enthalpy, and thermal data at specific times during the 18th orbit of each experimental series. This Table is a condensed form of the Tables appearing in the Appendix which contain calculations of the above data at each five minute interval in the cycle. The 18th orbit was chosen because this occurs approximately 24 hours after the series was initiated, which time was sufficient for a steady state condition to be established in the cell. The steady state condition was substantiated by the data for the 50th, 60th and 70th orbits appearing in the Appendix, which varied only slightly with that of the 18th orbit.

The thermal data were accumulated by converting the microvolt signal of the thermopile to watts by means of the calibration curve presented in Figure 12. The oxygen pressure was obtained by converting the millivolt signal of the Adhydrode to pressure (p.s.i.a.) by means of the data appearing in Table III. The enthalpy changes (ΔH) were calculated as discussed above. In these calculations no provision was made for oxygen evolution or reaction, i.e. no $V\Delta P$ term. Therefore, only that calculation made during the minimum point of the oxygen pressure can have any thermodynamic significance. This point occurs approximately 35 minutes into the charge cycle when the pressure has dropped to 2.0 p.s.i.a. This residual oxygen pressure does not enter into the thermodynamic calculations since it is oxygen which was generated during the overcharge portion of the previous cycle and has not yet diffused to a reaction site on the nickel or Adhydrode electrode. It exists in the cell at this point as an unreactive species which is neither being generated or consumed. Further substantiation of this phenomena occurs

TABLE VII- Comparison of Thermal Enthalpy and Oxygen Pressure Data.

Condition	Time (min.)	Heat (watts)	ΔH (kcal/equiv)	O_2 Pressure (PSIA)	
Discharge	5	-.58	-35.58	15.3	Experimental Series A Orbit 18 (25% Depth of D.C., 110% Recharge)
Discharge	30	-.59	-33.70	4.1	
Charge	5	-.38	+24.66	3.5	
Charge	35	+.10	+33.67	1.5	
Charge	60	-.23	+31.43	13.1	
Discharge	5	-.40	-36.48	13.1	Experimental Series B Orbit 18 (15% Depth of D.C., 114% Recharge)
Discharge	30	-.32	-33.38	3.2	
Charge	5	-.18	+26.25	3.0	
Charge	35	+.07	+33.68	1.2	
Charge	60	-.16	+29.93	10.4	
Discharge	5	-.74	-36.58	>29.0	Experimental Series C Orbit 18 (25% Depth of D.C., 114% Recharge)
Discharge	30	-.60	-33.66	6.5	
Charge	5	-.38	+25.12	6.0	
Charge	35	+.10	+33.44	2.1	
Charge	60	-.34	+29.36	22.0	

during the cell conditioning experiments where, after discharging a cell for several hours to a terminal voltage of 1.0, an oxygen pressure of approximately 2 p.s.i.a. was detectable. It was in fact, present for several hours after a one ohm resistor had been placed across the cell terminals. If the cell was left in this condition for 16 hours, then the Adhydrode signal would finally indicate zero oxygen pressure. From a thermodynamic standpoint, the charge process can be represented by the reaction:

$$Cd\ (OH)_2(s) + 2\ Ni\ (OH)_2\ (s) = Cd\ (s) + 2\ Ni\ (OH)_3(s)$$

Using the literature values for the standard molar heats of formation of the reactants and products, i.e. -128.6, -133.3, 0.0, and -162.1 kcal mole^{-1}, the ΔH of the charging reaction is +66.3 kcal mole^{-1} or +33.1 kcal equiv.$^{-1}$. There is excellent agreement between the calculated value of 33.1 kcal equiv.$^{-1}$ and the experimental obtained at the time intervals of 30 and 35 minutes into the charge cycle which appears in the appendix of this report. Typical values obtained are +33.24, +33.32, +33.44, and +33.68 kcal equiv.$^{-1}$.Variations in a tenth of a kcal equiv.$^{-1}$ are to be expected and are within the accuracy of the experiment. The remaining enthalpy calculations though thermodynamically questionable, are indicative of the changes in the energy content of systems related to the evolution or reaction of oxygen.

The peak of the exothermic reaction occurs approximately ten minutes into the discharge cycle while the height of the endothermic reaction occurs approximately thirty-five minutes into the charging reaction.

Oxygen generation begins as soon as the overcharging state is reached, i.e. 55 minutes into the charging cycle. The greatest oxygen pressure recorded for experimental series C (25% Depth of D.C., 114% Recharge) at 62 minutes into the charge cycle with a pressure in excess of 29.0 p.s.i.a.

In Table VII appears a comparison of the maximum thermal data and oxygen pressure for each experimental series. It may be noted that a greater thermal effect is produced by the depth of discharge used here than by the percentage recharge. Also, in the case of two similar depths of discharge the one with the highest recharge percentage will have the greatest thermal effect.

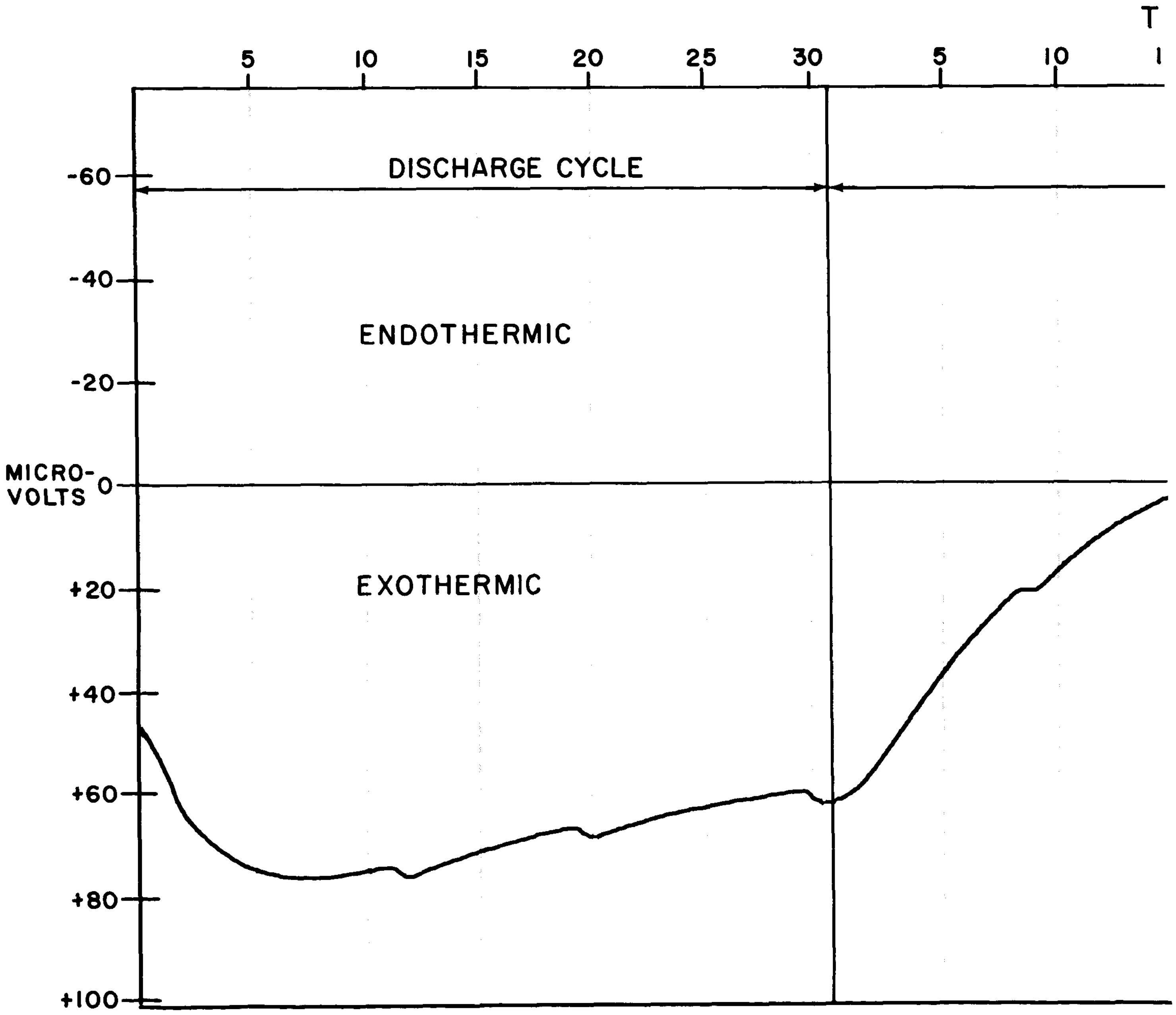
A heat profile curve obtained for the 20th cycle of experimental series "C" is presented in Figure 15. This curve is typical in profile for all of the cyclic experiments appearing in the appendices with only the magnitude of the thermal effect increasing or decreasing with the corresponding change in the percentage recharge and depth of discharge. That is, every battery experiences an exothermic reaction during discharge and overcharge, and an endothermic reaction during charging.

TABLE VIII

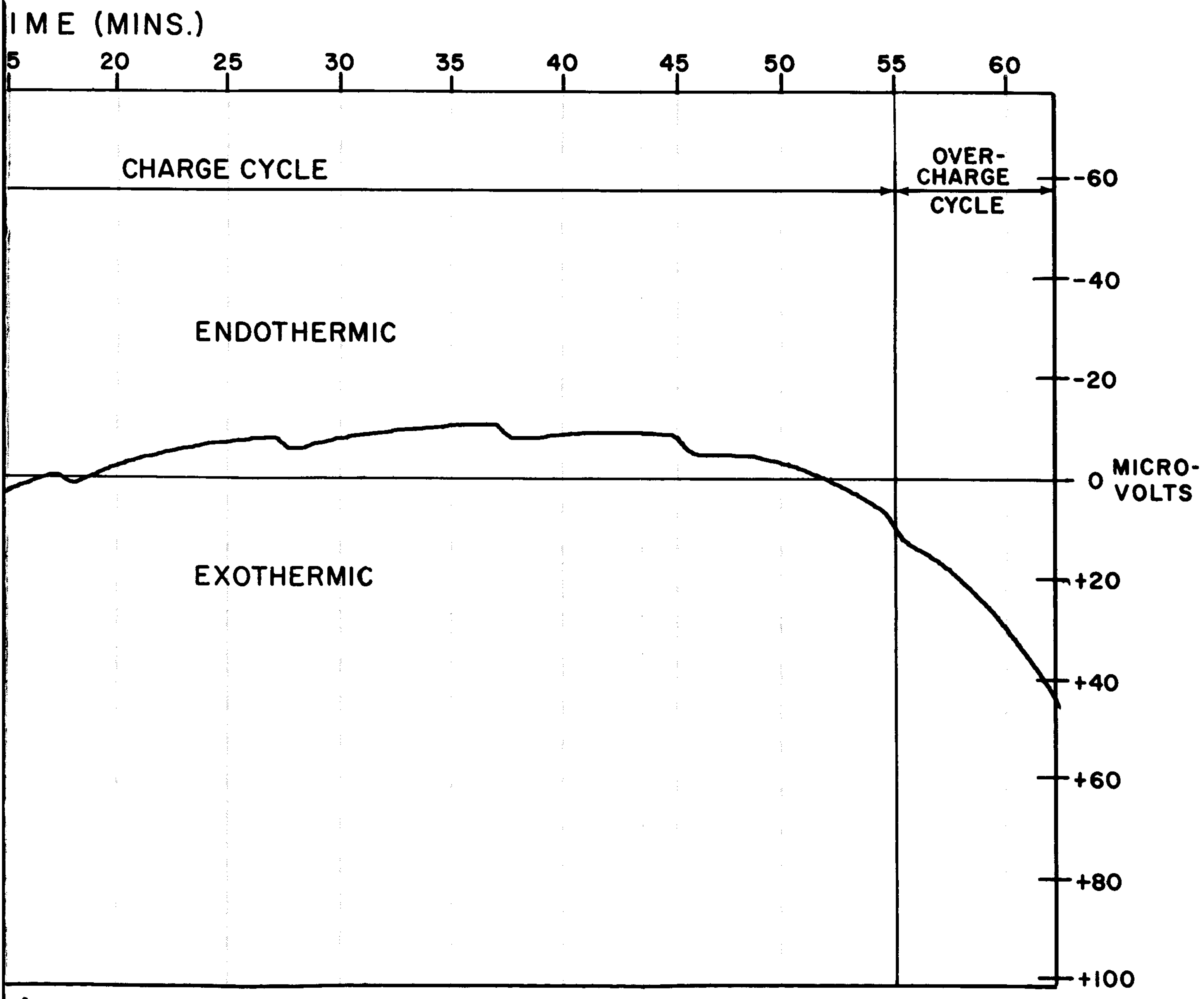
Comparison of Maximum Thermal Data and O_2 Pressure

	Max. Heat Liberated	Max. Heat Absorbed	Max. O_2 Press.
Exp. Series A (25% D.C. 110% Recharge)	-.66 Watts	+.11 Watts	16.1 p.s.i.a.
Exp. Series B (15% D.C. 114% Recharge)	-.44 Watts	+.08 Watts	12.6 p.s.i.a.
Exp. Series C (25% D.C. 114% Recharge)	-.77 Watts	+.10 Watts	>29.0 p.s.i.a.

FIGURE 15. HEAT PROFILE CURVE F
25% DEPTH DISCHARGE



OR 6-AH Ni-Cd BATTERY EXPERIENCING
AND 114% RECHARGE. (See p. 79)



VI. FUTURE WORK

Following a discussion with the Technical Officer, Mr. Floyd Ford, it was decided to perform only two more types of experiments with the six ampere-hour battery before going on to the twelve ampere-hour battery. These experiments are as follows:

(1) Subject the battery to at least 70 cycles involving a 40% depth of discharge and a 110% recharge rate.

(2) Investigate the effect of varying the charge rate ($\frac{C}{10}$, $\frac{C}{8}$, $\frac{C}{6}$, $\frac{C}{4}$, $\frac{C}{2}$, & C) on the efficiency of the battery using the Adhydrode signal of 100 mv. to terminate each experiment.

As before, all data such as oxygen pressure and the rate of heat generation will be recorded and the changes in enthalpy (ΔH) for the system undergoing the various processes will be calculated.

VII. ACKNOWLEDGEMENT

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4) Mr. Floyd Ford (NASA Goddard Space Flight Center) for his valuable suggestions and discussions.

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IX. APPENDICES

1. Experimental Series A (25% depth d.c., 110% recharge)
2. Experimental Series B (15% depth d.c., 114% recharge)
3. Experimental Series C (25% depth d.c., 114% recharge)

EXPERIMENTAL SERIES "A"

25°C Orbit #17 July 28, 1966

Orbital Conditions:

1.) 30 mins. d c at 3.00 amps for 25% Depth of d c

2.) 62 mins. c at 1.65 amps for 110% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	H (watt-sec)	H (kcal/equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.32	1.50	4.50	-4.82	-37.04	100	11.5
5	-.62	1.34	4.02	-4.64	-35.66	130	16.1
10	-.66	1.32	3.96	-4.62	-35.50	100	11.5
15	-.66	1.30	3.90	-4.56	-35.04	78	8.8
20	-.63	1.28	3.84	-4.47	-34.35	60	6.5
25	-.61	1.27	3.81	-4.42	-33.96	50	5.1
30	-.58	1.27	3.81	-4.39	-33.74	40	4.1
CHARGE							
5	-.38	1.32	2.18	+1.80	+25.14	35	3.5
10	-.15	1.34	2.21	+2.06	+28.78	30	3.0
15	-.02	1.35	2.23	+2.21	+30.87	22	2.2
20	+.04	1.36	2.24	+2.28	+31.85	20	2.0
25	+.08	1.37	2.26	+2.34	+32.69	16	1.6
30	+.10	1.38	2.28	+2.38	+33.24	16	1.6
35	+.10	1.40	2.31	+2.41	+33.67	14	1.4
40	+.09	1.41	2.33	+2.42	+33.80	14	1.4
45	+.09	1.42	2.34	+2.43	+33.95	15	1.5
50	+.05	1.44	2.38	+2.43	+33.95	22	2.2
55	-.02	1.46	2.41	+2.39	+33.39	50	5.1
60	-.23	1.50	2.48	+2.25	+31.43	110	13.1
62	-.30	1.50	2.48	+2.18	+30.45	130	16.1

EXPERIMENTAL SERIES "A"

25°C Orbit #18 July 28, 1966

Orbital Conditions:

1.) 30 mins. d c at 3.00 amps for 25% Depth of d c

2.) 62 mins. c at 1.65 amps for 110% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	H (watt-sec)	H (kcal/ equiv)	Adhy- drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.30	1.50	4.50	-4.80	-36.88	100	11.5
5	-.58	1.35	4.05	-4.63	-35.58	125	15.3
10	-.66	1.32	3.96	-4.62	-35.50	100	11.5
15	-.65	1.30	3.90	-4.55	-34.97	75	8.5
20	-.64	1.28	3.84	-4.48	-34.42	60	6.5
25	-.60	1.265	3.795	-4,395	-33.78	50	5.1
30	-.59	1.265	3.795	-4.385	-33.70	40	4.1
CHARGE							
5	-.38	1.30	2.145	+1.765	+24.66	35	3.5
10	-.14	1.33	2.195	+2.055	+28.71	30	3.0
15	-.02	1.34	2.211	+2.191	+30.61	25	2.5
20	+.06	1.36	2.244	+2.304	+32.33	20	2.0
25	+.06	1.37	2.261	+2.321	+32.42	15	1.5
30	+.10	1.385	2.285	+2.385	+33.32	15	1.5
35	+.10	1.40	2.310	+2.410	+33.67	15	1.5
40	+.11	1.40	2.310	+2.420	+33.81	15	1.5
45	+.09	1.42	2.343	+2.433	+33.99	15	1.5
50	+.06	1.44	2.376	+2.436	+34.03	25	2.5
55	-.05	1.46	2.409	+2.359	+32.96	50	5.1
60	-.26	1.48	2.442	+2.182	+30.48	110	13.1
62	-.32	1.50	2.475	+2.155	+30.11	120	14.9

EXPERIMENTAL SERIES "A"

$25^{\circ}C$ Orbit #19 July 28,1966

Orbital Conditions:

1.) 30 mins. D.C. at 3.00 amps for 25% Depth of D.C.

2.) 62 mins. C. at 1.65 amps for 110% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	H (watt-sec)	H (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.32	1.50	4.50	-4.82	-37.04	100	11.5
5	-.61	1.35	4.05	-4.66	-35.81	130	15.3
10	-.66	1.32	3.96	-4.62	-35.50	100	11.5
15	-.65	1.30	3.90	-4.55	-34.97	75	8.5
20	-.64	1.28	3.84	-4.48	-34.43	60	6.5
25	-.60	1.27	3.81	-4.41	-33.89	50	5.1
30	-.60	1.26	3.78	-4.38	-33.66	40	4.1
CHARGE							
5	-.36	1.32	2.178	+1.818	+25.40	35	3.5
10	-.14	1.32	2.178	+2.038	+28.47	30	3.0
15	-.02	1.34	2.211	+2.191	+30.61	25	2.5
20	+.04	1.35	2.227	+2.267	+31.67	20	2.0
25	+.08	1.36	2.244	+2.324	+32.47	15	1.5
30	+.08	1.38	2.277	+2.357	+32.93	15	1.5
35	+.10	1.40	2.310	+2.410	+33.67	15	1.5
40	+.10	1.40	2.310	+2.410	+33.67	15	1.5
45	+.10	1.42	2.343	+2.443	+34.13	15	1.5
50	+.04	1.44	2.376	+2.416	+33.75	25	2.5
55	-.04	1.46	2.409	+2.369	+33.09	50	5.1
60	-.26	1.48	2.442	+2.182	+30.37	110	13.1
62	-.32	1.50	2.475	+2.155	+30.11	130	16.1

EXPERIMENTAL SERIES "A"

25°C Orbit #20 July 28, 1966

Orbital Conditions:

1.) 30 mins. D.C. at 3.00 amps for 25% Depth of D.C.

2.) 62 mins. C. at 1.65 amps for 110% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	H (watt-sec)	H (kcal/equiv)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.32	1.50	4.50	-4.82	-37.04	100	11.5
5	-.58	1.35	4.05	-4.63	-35.58	128	15.7
10	-.66	1.32	3.96	-4.66	-35.81	100	11.5
15	-.64	1.30	3.90	-4.54	-34.89	75	8.5
20	-.63	1.28	3.84	-4.47	-34.35	60	6.5
25	-.60	1.27	3.81	-4.41	-33.89	50	5.1
30	-.58	1.26	3.78	-4.36	-33.51	40	4.1
CHARGE							
5	-.37	1.32	2.178	+1.808	+25.26	35	3.5
10	-.13	1.34	2.211	+2.081	+29.07	30	3.0
15	-.04	1.35	2.227	+2.187	+30.55	22	2.2
20	+.05	1.36	2.244	+2.294	+32.05	20	2.0
25	+.06	1.38	2.277	+2.337	+32.65	15	1.5
30	+.10	1.39	2.294	+2.394	+33.44	15	1.5
35	+.09	1.40	2.310	+2.400	+33.53	15	1.5
40	+.11	1.40	2.310	+2.420	+33.81	15	1.5
45	+.09	1.42	2.343	+2.433	+33.99	15	1.5
50	+.06	1.44	2.376	+2.436	+34.03	25	2.5
55	-.04	1.46	2.409	+2.369	+33.09	50	5.1
60	-.24	1.48	2.442	+2.202	+30.76	110	13.1
62	-.33	1.50	2.475	+2.145	+29.97	130	16.1

EXPERIMENTAL SERIES "A"

25°C Orbit #21 July 28, 1966

Orbital Conditions:

1.) 30 mins. D.C. at 3.00 amps for 25% Depth of D.C.

2.) 62 mins. C. at 1.65 amps for 110% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	H (watt-sec)	H (kcal/ equiv)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.32	1.50	4.50	-4.82	-37.04	100	11.5
5	-.60	1.34	4.02	-4.62	-35.50	130	16.1
10	-.66	1.32	3.96	-4.62	-35.50	100	11.5
15	-.64	1.30	3.90	-4.54	-34.89	75	8.5
20	-.62	1.28	3.84	-4.46	-34.28	60	6.5
25	-.60	1.27	3.81	-4.41	-33.89	50	5.1
30	-.58	1.27	3.81	-4.39	-33.74	40	4.1
CHARGE							
5	-.34	1.32	2.178	+1.838	+25.68	35	3.5
10	-.10	1.34	2.211	+2.111	+29.49	30	3.0
15	-.02	1.34	2.211	+2.191	+30.61	25	2.5
20	+.06	1.35	2.228	+2.288	+31.96	20	2.0
25	+.08	1.37	2.260	+2.340	+32.69	15	1.5
30	+.11	1.38	2.277	+2.387	+33.34	15	1.5
35	+.10	1.40	2.310	+2.410	+33.67	15	1.5
40	+.10	1.40	2.310	+2.410	+33.67	15	1.5
45	+.10	1.42	2.343	+2.443	+34.13	15	1.5
50	+.02	1.44	2.376	+2.396	+33.47	25	2.5
55	-.06	1.46	2.409	+2.349	+32.82	60	6.6
60	-.32	1.48	2.442	+2.122	+29.64	110	13.1
62	-.36	1.50	2.475	+2.115	+29.55	130	16.1

EXPERIMENTAL SERIES "B"

25°C Orbit #18 Aug. 4, 1966

Orbital Conditions:

1.) 30 mins. d c. at 1.80 amps for 15% Depth of d c

2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.22	1.47	2.646	-2.866	-36.71	85	9.6
5	-.40	1.36	2.448	-2.848	-36.48	110	13.1
10	-.39	1.34	2.412	-2.802	-35.89	90	10.4
15	-.38	1.32	2.376	-2.656	-34.02	70	7.7
20	-.36	1.30	2.340	-2.600	-33.31	55	6.0
25	-.33	1.28	2.304	-2.534	-32.46	42	4.6
30	-.32	1.27	2.286	-2.606	-33.38	32	3.2
CHARGE							
5	-.18	1.32	1.307	+1.127	+26.25	30	3.0
10	-.07	1.33	1.317	+1.247	+29.04	23	2.3
15	+.01	1.34	1.327	+1.337	+31.14	20	2.0
20	+.05	1.35	1.337	+1.387	+32.30	18	1.8
25	+.04	1.36	1.346	+1.386	+32.28	15	1.5
30	+.08	1.38	1.366	+1.446	+33.68	12	1.2
35	+.07	1.39	1.376	+1.446	+33.68	12	1.2
40	+.06	1.40	1.386	+1.446	+33.68	14	1.4
45	+.06	1.42	1.406	+1.466	+34.14	20	2.0
50	+.02	1.44	1.426	+1.446	+33.68	29	2.9
55	+.04	1.45	1.436	+1.396	+32.51	50	5.1
60	-.16	1.46	1.445	+1.285	+29.93	90	10.4
62	-.22	1.46	1.445	+1.225	+28.53	107	12.6

EXPERIMENTAL SERIES "B"

25°C   Orbit #19   Aug. 4, 1966

Orbital Conditions:

1.) 30 mins. d c. at 1.80 amps for 15% Depth of d c

2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.22	1.46	2.628	-2.848	-36.48	107	12.6
5	-.40	1.36	2.448	-2.848	-36.48	110	13.1
10	-.40	1.34	2.412	-2.812	-36.02	90	10.4
15	-.38	1.31	2.358	-2.738	-35.07	70	7.7
20	-.34	1.30	2.340	-2.680	-34.33	55	6.0
25	-.33	1.28	2.304	-2.634	-33.74	42	4.6
30	-.32	1.26	2.268	-2.588	-33.15	35	3.5
CHARGE							
5	-.18	1.32	1.307	+1.127	+26.25	30	3.0
10	-.07	1.32	1.307	+1.237	+28.81	25	2.5
15	+.00	1.34	1.327	+1.327	+30.91	20	2.0
20	+.04	1.35	1.337	+1.347	+31.37	19	1.9
25	+.04	1.36	1.346	+1.386	+32.28	15	1.5
30	+.08	1.37	1.356	+1.436	+33.44	12	1.2
35	+.06	1.38	1.366	+1.426	+33.21	12	1.2
40	+.08	1.40	1.386	+1.466	+34.14	13	1.3
45	+.06	1.42	1.406	+1.466	+34.14	20	2.0
50	+.01	1.44	1.426	+1.436	+33.44	28	2.8
55	+.04	1.45	1.436	+1.396	+32.51	49	5.0
60	-.16	1.46	1.445	+1.285	+29.93	85	9.7
62	-.21	1.46	1.445	+1.235	+28.76	100	11.5

EXPERIMENTAL SERIES "B"

25°C　　Orbit #20　　Aug. 4, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 1.80 amps for 15% Depth of d.c.
2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.21	1.46	2.628	-2.838	-36.35	100	11.5
5	-.39	1.36	2.448	-2.838	-36.35	107	12.6
10	-.40	1.34	2.412	-2.812	-36.02	88	10.0
15	-.38	1.32	2.376	-2.756	-35.30	69	7.5
20	-.34	1.30	2.340	-2.680	-34.33	55	6.0
25	-.32	1.28	2.304	-2.604	-33.36	42	4.6
30	-.34	1.26	2.268	-2.608	-33.40	32	3.2
CHARGE							
5	-.18	1.32	1.307	+1.127	+26.25	30	3.0
10	-.08	1.32	1.307	+1.227	+28.58	24	2.4
15	+.00	1.34	1.327	+1.327	+30.91	20	2.0
20	+.04	1.35	1.337	+1.377	+32.07	18	1.8
25	+.05	1.36	1.346	+1.396	+32.51	15	1.5
30	+.08	1.37	1.356	+1.436	+33.44	15	1.5
35	+.06	1.38	1.366	+1.426	+33.21	15	1.5
40	+.06	1.40	1.386	+1.446	+33.68	15	1.5
45	+.06	1.42	1.406	+1.462	+34.05	19	1.9
50	+.02	1.44	1.426	+1.446	+33.68	28	2.8
55	+.03	1.45	1.436	+1.406	+32.75	50	5.1
60	-.16	1.46	1.445	+1.285	+29.93	85	9.6
62	-.21	1.46	1.445	+1.235	+28.76	102	11.8

EXPERIMENTAL SERIES "B"

25°C Orbit #21 Aug. 4, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 1.80 amps for 15% Depth of d.c.
2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.21	1.46	2.628	-2.838	-36.35	102	11.8
5	-.38	1.36	2.448	-2.828	-36.22	110	13.1
10	-.43	1.34	2.412	-2.842	-36.41	90	10.4
15	-.37	1.31	2.358	-2.728	-34.95	70	7.7
20	-.37	1.30	2.340	-2.710	-34.72	52	5.4
25	-.32	1.28	2.304	-2.624	-33.61	42	4.6
30	-.32	1.27	2.286	-2.606	-33.38	32	3.2
CHARGE							
5	-.21	1.32	1.307	+1.097	+25.55	30	3.0
10	-.06	1.32	1.307	+1.247	+29.04	25	2.5
15	+.02	1.34	1.327	+1.347	+31.37	20	2.0
20	+.04	1.35	1.337	+1.377	+32.07	18	1.8
25	+.06	1.36	1.346	+1.406	+32.75	15	1.5
30	+.05	1.37	1.356	+1.406	+32.75	15	1.5
35	+.08	1.39	1.376	+1.456	+33.91	15	1.5
40	+.06	1.40	1.386	+1.446	+33.67	15	1.5
45	+.07	1.42	1.406	+1.476	+34.38	19	1.9
50	+.02	1.44	1.426	+1.446	+33.67	19	1.9
55	+.06	1.45	1.436	+1.376	+32.05	50	5.1
60	-.16	1.46	1.445	+1.285	+29.93	90	10.4
62	-.25	1.46	1.445	+1.195	+27.83	105	12.3

EXPERIMENTAL SERIES "B"

25°C Orbit #22 Aug. 4, 1966

Orbital Conditions

1.) 30 mins. d c at 1.80 amps for 15% Depth of d c
2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy- drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.25	1.46	2.628	-2.878	-36.87	105	12.3
5	-.38	1.36	2.448	-2.828	-36.23	110	13.1
10	-.42	1.32	2.376	-2.796	-35.81	90	10.4
15	-.38	1.31	2.358	-2.738	-35.07	70	7.7
20	-.35	1.30	2.340	-2.690	-34.45	55	6.0
25	-.32	1.28	2.304	-2.624	-33.61	42	4.6
30	-.31	1.27	2.286	-2.596	-33.25	32	3.2
CHARGE							
5	-.20	1.32	1.307	+1.107	+25.78	30	3.0
10	-.06	1.32	1.307	+1.247	+29.04	25	2.5
15	+.00	1.34	1.327	+1.327	+30.91	20	2.0
20	+.03	1.35	1.337	+1.367	+31.84	18	1.8
25	+.06	1.36	1.346	+1.406	+32.75	15	1.5
30	+.05	1.38	1.366	+1.416	+32.98	15	1.5
35	+.08	1.39	1.376	+1.456	+33.91	15	1.5
40	+.08	1.40	1.386	+1.466	+34.14	15	1.5
45	+.06	1.42	1.406	+1.466	+34.14	20	2.0
50	+.04	1.44	1.426	+1.466	+34.14	30	3.0
55	+.06	1.45	1.436	+1.376	+32.05	50	5.1
60	-.15	1.46	1.445	+1.295	+30.16	90	10.4
62	-.23	1.46	1.445	+1.215	+28.30	105	12.3

EXPERIMENTAL SERIES "B"

25°C Orbit #30 Aug. 4, 1966

Orbital Conditions

1.) 30 mins. d c at 1.80 amps for 15% Depth of d c
2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy- drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.22	1.47	2.646	-2.866	-36.71	80	8.9
5	-.38	1.35	2.430	-2.810	-36.00	108	12.8
10	-.42	1.34	2.412	-2.832	-36.28	85	9.6
15	-.36	1.31	2.358	-2.718	-34.82	65	7.1
20	-.34	1.30	2.340	-2.680	-34.33	52	5.3
25	-.34	1.28	2.304	-2.644	-33.87	40	4.1
30	-.30	1.26	2.268	-2.568	-32.90	32	3.2
CHARGE							
5	-.18	1.32	1.307	+1.127	+26.25	30	3.0
10	-.08	1.32	1.307	+1.227	+28.58	25	2.5
15	+.02	1.34	1.327	+1.347	+31.37	20	2.0
20	+.04	1.35	1.337	+1.377	+32.07	15	1.5
25	+.06	1.36	1.346	+1.406	+32.75	15	1.5
30	+.09	1.37	1.356	+1.446	+33.67	15	1.5
35	+.08	1.38	1.366	+1.446	+33.67	15	1.5
40	+.10	1.40	1.386	+1.486	+34.61	15	1.5
45	+.07	1.42	1.406	+1.476	+34.38	20	2.0
50	+.04	1.44	1.426	+1.466	+34.14	28	2.8
55	+.03	1.45	1.436	+1.406	+32.75	50	5.1
60	-.14	1.46	1.445	+1.305	+30.39	90	10.4
62	-.20	1.46	1.445	+1.245	+29.00	102	11.8

EXPERIMENTAL SERIES "B"

25°C Orbit #40 Aug. 4, 1966

Orbital Conditions:

1.) 30 mins. d c at 180 amps for 15% Depth of d c
2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.22	1.42	2.556	-2.776	-35.56	80	8.9
5	-.38	1.36	2.448	-2.828	-36.23	108	12.8
10	-.41	1.34	2.412	-2.822	-36.15	85	9.6
15	-.38	1.31	2.358	-2.738	-35.07	65	7.1
20	-.34	1.30	2.340	-2.680	-34.33	50	5.1
25	-.32	1.28	2.304	-2.624	-33.61	40	4.1
30	-.32	1.26	2.268	-2.588	-33.15	32	3.2
CHARGE							
5	-.16	1.32	1.307	+1.147	+26.71	30	3.0
10	-.06	1.33	1.317	+1.257	+29.28	25	2.5
15	+.00	1.34	1.327	+1.327	+30.91	20	2.0
20	+.04	1.36	1.346	+1.386	+32.28	15	1.5
25	+.07	1.36	1.346	+1.416	+32.98	15	1.5
30	+.06	1.38	1.366	+1.426	+33.21	15	1.5
35	+.09	1.39	1.376	+1.466	+34.14	15	1.5
40	+.08	1.40	1.386	+1.466	+34.14	15	1.5
45	+.06	1.42	1.406	+1.466	+34.14	20	2.0
50	+.01	1.44	1.426	+1.436	+33.44	30	3.0
55	+.03	1.45	1.436	+1.406	+32.75	50	5.1
60	-.16	1.46	1.445	+1.285	+29.93	90	10.4
62	-.22	1.46	1.445	+1.225	+28.53	102	11.8

EXPERIMENTAL SERIES "B"

25°C Orbit #50 Auh. 4, 1966

Orbital Conditions:

1.) 30 mins. d c at 1.80 amps for 15% Depth of d c

2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.25	1.42	2.556	-2.806	-35.94	80	8.9
5	-.40	1.36	2.448	-2.848	-36.48	108	12.8
10	-.42	1.34	2.412	-2.832	-36.28	88	10.0
15	-.41	1.31	2.358	-2.768	-35.46	69	7.5
20	-.36	1.29	2.322	-2.682	-34.36	51	5.2
25	-.36	1.28	2.304	-2.664	-34.13	40	4.1
30	-,32	1.26	2.268	-2.588	-33.15	32	3.2
CHARGE							
5	-.20	1.32	1.307	+1.107	+25.78	30	3.0
10	-.08	1.32	1.307	+1.227	+28.58	25	2.5
15	+.00	1.34	1.327	+1.327	+30.91	20	2.0
20	+.03	1.35	1.337	+1.367	+31.84	15	1.5
25	+.05	1.36	1.346	+1.396	+32.51	15	1.5
30	+.06	1.37	1.356	+1.416	+32.98	15	1.5
35	+.07	1.38	1.366	+1.436	+33.44	15	1.5
40	+.04	1.40	1.386	+1.426	+33.21	15	1.5
45	+.06	1.42	1.406	+1.466	+34.14	20	2.0
50	+.00	1.44	1.426	+1.426	+33.21	28	2.8
55	+.04	1.45	1.436	+1.396	+32.51	48	4.9
60	-.20	1.46	1.445	+1.245	+29.00	85	9.7
62	-.24	1.46	1.445	+1.205	+28.06	101	11.6

EXPERIMENTAL SERIES "B"

25°C Orbit #60 Aug. 4, 1966

Orbital Conditions:

1.) 30 mins. d c at 1.80 amps for 15% Depth of d c

2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv.)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.26	1.42	2.556	-2.816	-36.07	80	8.9
5	-.40	1.36	2.448	-2.848	-36.48	108	12.8
10	-.42	1.34	2.412	-2.832	-36.28	87	10.0
15	-.38	1.31	2.358	-2.738	-35.07	68	7.5
20	-.36	1.30	2.340	-2.700	-34.59	52	5.4
25	-.33	1.28	2.304	-2.634	-33.74	40	4.1
30	-.31	1.27	2.286	-2.596	-33.25	32	3.2
CHARGE							
5	-.20	1.32	1.307	+1.107	+25.78	30	3.0
10	-.06	1.33	1.317	+1.257	+29.28	25	2.5
15	+.00	1.34	1.327	+1.327	+30.91	20	2.0
20	+.04	1.36	1.346	+1.386	+32.28	15	1.5
25	+.06	1.36	1.346	+1.406	+32.75	15	1.5
30	+.07	1.38	1.366	+1.436	+33.44	15	1.5
35	+.08	1.39	1.376	+1.456	+33.91	15	1.5
40	+.06	1.40	1.386	+1.446	+33.67	15	1.5
45	+.06	1.42	1.406	+1.466	+34.14	18	1.8
50	+.00	1.44	1.426	+1.426	+33.21	25	2.5
55	+.04	1.45	1.436	+1.396	+32.51	48	4.9
60	-.18	1.46	1.445	+1.265	+29.46	85	9.7
62	-.24	1.46	1.445	+1.205	+28.06	102	11.6

EXPERIMENTAL SERIES "B"

25°C Orbit #70 Aug. 4, 1966

Orbital Conditions:

1.) 30 mins. d c at 1.80 amps for 15% Depth of d c

2.) 62 mins. c at 0.99 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.22	1.42	2.556	-2.776	-35.56	80	8.9
5	-.40	1.36	2.448	-2.848	-36.48	105	12.3
10	-.42	1.34	2.412	-2.832	-36.28	82	9.0
15	-.38	1.31	2.358	-2.738	-35.07	62	6.8
20	-.38	1.30	2.340	-2.720	-34.84	50	5.1
25	-.33	1.28	2.304	-2.634	-33.74	40	4.1
30	-.33	1.26	2.268	-2.598	-33.28	32	3.2
CHARGE							
5	-.18	1.32	1.307	+1.127	+26.25	29	2.9
10	-.08	1.32	1.307	+1.227	+28.58	22	2.2
15	+.00	1.34	1.327	+1.327	+30.91	20	2.0
20	+.03	1.35	1.337	+1.367	+31.84	15	1.5
25	+.06	1.36	1.346	+1.406	+32.75	15	1.5
30	+.06	1.37	1.356	+1.416	+32.98	12	1.2
35	+.06	1.38	1.366	+1.426	+33.21	12	1.2
40	+.06	1.40	1.386	+1.446	+33.67	15	1.5
45	+.05	1.42	1.406	+1.456	+33.91	18	1.8
50	+.02	1.44	1.426	+1.446	+33.68	25	2.5
55	+.04	1.45	1.436	+1.396	+32.51	45	4.8
60	-.16	1.46	1.445	+1.285	+29.93	80	8.9
62	-.24	1.46	1.445	+1.205	+28.06	95	11.1

EXPERIMENTAL SERIES "C"

25°C Orbit #18 Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.

2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.48	1.48	4.44	-4.92	-37.81	170	25.0
5	-.74	1.34	4.02	-4.76	-36.58	195	>29.0
10	-.76	1.31	3.93	-4.69	-36.04	150	20.0
15	-.72	1.29	3.87	-4.59	-35.27	120	15.0
20	-.68	1.28	3.84	-4.52	-34.74	95	11.2
25	-.62	1.26	3.78	-4.40	-33.81	75	8.5
30	-.60	1.26	3.78	-4.38	-33.66	60	6.5
CHARGE							
5	-.38	1.32	2.178	+1.798	+25.12	55	6.0
10	-.16	1.33	2.195	+2.035	+28.43	45	4.8
15	-.04	1.34	2.211	+2.171	+30.33	35	3.5
20	+.05	1.35	2.228	+2.278	+31.82	30	3.0
25	+.07	1.36	2.244	+2.314	+32.33	25	2.5
30	+.09	1.38	2.277	+2.367	+33.07	22	2.2
35	+.10	1.39	2.294	+2.394	+33.44	21	2.1
40	+.08	1.40	2.310	+2.390	+33.39	21	2.1
45	+.07	1.42	2.343	+2.413	+33.71	27	2.7
50	+.02	1.45	2.393	+2.413	+33.71	40	4.1
55	-.10	1.46	2.409	+2.309	+32.26	80	8.9
60	-.34	1.48	2.442	+2.102	+29.36	160	22.0
62	-.46	1.48	2.442	+1.982	+27.69	195	> 29.0

EXPERIMENTAL SERIES "C"

25°C Orbit #19 Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.
2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.46	1.48	4.44	-4.90	-37.66	195	> 29.0
5	-.75	1.35	4.05	-4.80	-36.89	192	> 29.0
10	-.76	1.31	3.93	-4.69	-36.04	150	20.0
15	-.72	1.30	3.90	-4.62	-35.50	117	14.5
20	-.66	1.28	3.84	-4.50	-34.58	92	10.8
25	-.62	1.27	3.81	-4.43	-34.04	75	8.5
30	-.60	1.26	3.78	-4.38	-33.66	60	6.5
CHARGE							
5	-.36	1.32	2.178	+1.818	+25.40	53	5.6
10	-.18	1.33	2.195	+2.015	+28.15	43	4.7
15	-.02	1.34	2.211	+2.191	+30.61	35	3.5
20	+.01	1.35	2.228	+2.238	+31.26	30	3.0
25	+.07	1.36	2.244	+2.314	+32.33	27	2.7
30	+.08	1.38	2.277	+2.357	+32.93	22	2.2
35	+.10	1.39	2.294	+2.394	+33.44	21	2.1
40	+.10	1.40	2.310	+2.410	+33.67	21	2.1
45	+.08	1.42	2.343	+2.423	+33.85	28	2.8
50	+.01	1.45	2.393	+2.403	+33.57	42	4.6
55	-.13	1.46	2.409	+2.279	+31.84	85	9.6
60	-.34	1.48	2.442	+2.102	+29.36	160	22.0
62	-.48	1.48	2.442	+1.962	+27.41	200	> 29.0

EXPERIMENTAL SERIES "C"

$25^{o}C$ Orbit #20 Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.
2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/equiv)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.48	1.48	4.44	-4.92	-37.81	170	25.0
5	-.75	1.34	4.02	-4.77	-36.66	195	> 29.0
10	-.76	1.31	3.93	-4.69	-36.04	150	20.0
15	-.72	1.29	3.87	-4.59	-35.27	120	15.0
20	-.69	1.28	3.84	-4.53	-34.81	92	10.9
25	-.63	1.26	3.78	-4.41	-33.89	75	8.5
30	-.62	1.26	3.78	-4.40	-33.81	60	6.5
CHARGE							
5	-.36	1.32	2.178	+1.818	+25.40	55	6.0
10	-.16	1.32	2.178	+2.018	+28.19	45	4.8
15	-.02	1.34	2.211	+2.191	+30.61	35	3.5
20	+.03	1.35	2.228	+2.258	+31.54	30	3.0
25	+.07	1.36	2.244	+2.314	+32.33	25	2.5
30	+.08	1.38	2.277	+2.357	+32.93	25	2.5
35	+.10	1.39	2.294	+2.394	+33.44	22	2.2
40	+.08	1.40	2.310	+2.390	+33.39	22	2.2
45	+.08	1.42	2.343	+2.423	+33.85	28	2.8
50	+.02	1.45	2.393	+2.413	+33.71	42	4.6
55	-.12	1.46	2.409	+2.289	+31.98	80	8.9
60	-.33	1.48	2.442	+2.112	+29.50	160	22.0
62	-.46	1.48	2.442	+1.982	+27.69	200	> 29.0

EXPERIMENTAL SERIES "C"

25°C | Orbit #21 | Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.

2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.46	1.48	4.44	-4.90	-37.66	170	25.0
5	-.75	1.34	4.02	-4.77	-36.66	195	> 29.0
10	-.75	1.31	3.93	-4.68	-35.97	150	20.0
15	-.72	1.29	3.87	-4.59	-35.27	118	14.5
20	-.66	1.28	3.84	-4.50	-34.58	92	10.9
25	-.64	1.26	3.78	-4.42	-33.97	75	8.5
30	-.60	1.26	3.78	-4.38	-33.66	60	6.5
CHARGE							
5	-.36	1.32	2.178	+1.818	+25.40	53	5.6
10	-.14	1.32	2.178	+2.038	+28.47	43	4.7
15	-.02	1.34	2.211	+2.191	+30.61	37	3.7
20	+.04	1.35	2.228	+2.268	+31.68	30	3.0
25	+.07	1.36	2.244	+2.314	+32.33	28	2.8
30	+.09	1.38	2.277	+2.367	+33.07	25	2.5
35	+.08	1.39	2.294	+2.374	+33.16	22	2.2
40	+.07	1.40	2.310	+2.380	+33.25	22	2.2
45	+.08	1.42	2.343	+2.423	+33.84	29	2.9
50	+.00	1.44	2.376	+2.376	+33.19	42	4.6
55	-.10	1.46	2.409	+2.309	+32.26	85	9.6
60	-.34	1.48	2.442	+2.102	+29.36	160	22.0
62	-.48	1.48	2.442	+1.962	+27.41	198	> 29.0

EXPERIMENTAL SERIES "C"

25°C Orbit #22 Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.
2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.48	1.48	4.44	-4.92	-37.81	170	25.0
5	-.74	1.35	4.05	-4.79	-36.81	192	> 29.0
10	-.76	1.32	3.96	-4.72	-36.27	150	20.0
15	-.70	1.30	3.90	-4.60	-35.35	120	15.0
20	-.68	1.28	3.84	-4.52	-34.74	95	11.2
25	-.64	1.27	3.81	-4.45	-34.20	75	8.5
30	-.60	1.26	3.78	-4.38	-33.66	60	6.5
CHARGE							
5	-.37	1.32	2.178	+1.808	+25.26	55	6.0
10	-.16	1.33	2.195	+2.035	+28.43	45	4.8
15	-.06	1.34	2.211	+2.151	+30.05	38	3.8
20	+.02	1.36	2.244	+2.264	+31.63	31	3.1
25	+.07	1.36	2.244	+2.314	+32.33	29	2.9
30	+.08	1.38	2.277	+2.357	+32.93	25	2.5
35	+.07	1.39	2.294	+2.364	+33.03	22	2.2
40	+.09	1.40	2.310	+2.400	+33.53	22	2.2
45	+.04	1.42	2.343	+2.383	+33.29	28	2.8
50	+.03	1.44	2.376	+2.406	+33.61	42	4.6
55	-.14	1.46	2.409	+2.269	+31.70	80	8.9
60	-.34	1.48	2.442	+2.102	+29.36	160	22.0
62	-.46	1.48	2.442	+1.982	+27.69	198	> 29.0

EXPERIMENTAL SERIES "C"

25°C Orbit #30 Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.
2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy-drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.48	1.49	4.47	-4.95	-38.04	165	23.5
5	-.74	1.35	4.05	-4.79	-36.81	192	> 29.0
10	-.75	1.31	3.93	-4.68	-35.97	150	20.0
15	-.73	1.30	3.90	-4.63	-35.58	118	14.5
20	-.66	1.28	3.84	-4.50	-34.58	92	10.9
25	-.64	1.27	3.81	-4.45	-34.20	75	8.5
30	-.60	1.26	3.78	-4.38	-33.66	60	6.5
CHARGE							
5	-.36	1.32	2.178	+1.818	+25.40	53	5.6
10	-.14	1.33	2.195	+2.055	+28.71	43	4.7
15	-.03	1.34	2.211	+2.181	+30.47	37	3.7
20	+.01	1.35	2.228	+2.238	+31.26	30	3.0
25	+.07	1.36	2.244	+2.314	+32.33	28	2.8
30	+.09	1.38	2.277	+2.367	+33.07	25	2.5
35	+.10	1.39	2.294	+2.394	+33.44	22	2.2
40	+.08	1.40	2.310	+2.390	+33.39	22	2.2
45	+.08	1.42	2.343	+2.423	+33.85	28	2.8
50	+.01	1.45	2.393	+2.403	+33.57	40	4.1
55	-.12	1.46	2.409	+2.289	+31.97	85	9.6
60	-.34	1.48	2.442	+2.102	+29.36	160	22.0
62	-.45	1.48	2.442	+1.992	+27.83	200	> 29.0

EXPERIMENTAL SERIES "C"

25°C | Orbit #40 | Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.
2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.45	1.49	4.47	-4.92	-37.81	170	25.0
5	-.75	1.34	4.02	-4.77	-36.66	195	> 29.0
10	-.76	1.30	3.90	-4.66	-35.81	155	20.5
15	-.70	1.28	3.84	-4.54	-34.89	120	14.8
20	-.67	1.27	3.81	-4.48	-34.43	95	11.2
25	-.62	1.26	3.78	-4.40	-33.81	75	8.5
30	-.59	1.25	3.75	-4.34	-33.35	62	6.8
CHARGE							
5	-.37	1.31	2.162	+1.792	+25.03	53	5.6
10	-.14	1.32	2.178	+2.038	+28.47	43	4.7
15	-.03	1.34	2.211	+2.181	+30.47	37	3.7
20	+.03	1.35	2.228	+2.258	+31.54	30	3.0
25	+.08	1.36	2.244	+2.324	+32.47	28	2.8
30	+.07	1.37	2.260	+2.330	+32.55	25	2.5
35	+.09	1.38	2.277	+2.367	+33.07	22	2.2
40	+.09	1.40	2.310	+2.400	+33.52	22	2.2
45	+.09	1.42	2.343	+2.433	+33.99	28	2.8
50	+.04	1.44	2.376	+2.416	+33.75	40	4.1
55	-.10	1.46	2.409	+2.309	+32.26	80	8.9
60	-.30	1.48	2.442	+2.142	+29.92	160	22.0
62	-.46	1.48	2.442	+1.982	+27.69	195	> 29.0

EXPERIMENTAL SERIES "C"

25°C — Orbit #50 — Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.
2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/equiv)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.42	1.49	4.47	-4.89	-37.58	165	23.5
5	-.64	1.34	4.02	-4.66	-35.81	195	> 29.0
10	-.68	1.31	3.93	-4.61	-35.42	150	20.0
15	-.64	1.29	3.87	-4.51	-34.66	115	13.9
20	-.59	1.28	3.84	-4.43	-34.04	90	10.4
25	-.56	1.26	3.78	-4.34	-33.35	75	8.5
30	-.53	1.25	3.75	-4.28	-32.89	60	6.5
CHARGE							
5	-.32	1.32	2.178	+1.858	+25.96	53	5.6
10	-.14	1.32	2.178	+2.038	+28.47	43	4.7
15	-.02	1.34	2.211	+2.191	+30.61	35	3.5
20	+.03	1.35	2.228	+2.258	+31.54	30	3.0
25	+.04	1.38	2.277	+2.317	+32.37	28	2.8
30	+.09	1.38	2.277	+2.367	+33.07	25	2.5
35	+.07	1.39	2.294	+2.364	+33.03	22	2.2
40	+.09	1.40	2.310	+2.400	+33.53	22	2.2
45	+.07	1.42	2.343	+2.413	+33.71	28	2.8
50	+.00	1.45	2.393	+2.343	+32.73	40	4.1
55	-.08	1.46	2.409	+2.329	+32.54	82	9.1
60	-.30	1.48	2.442	+2.142	+29.92	160	22.0
62	-.41	1.48	2.442	+2.032	+28.39	200	> 29.0

EXPERIMENTAL SERIES "C"

25°C Orbit #60 Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.

2.) 62 mins. c. at 1.65 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/ equiv)	Adhy- drode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.50	1.49	4.47	-4.97	-38.19	170	25.0
5	-.74	1.35	4.05	-4.79	-36.81	195	> 29.0
10	-.76	1.32	3.96	-4.72	-36.27	152	20.2
15	-.74	1.30	3.90	-4.64	-35.66	120	14.8
20	-.66	1.28	3.84	-4.50	-34.58	93	11.0
25	-.64	1.26	3.78	-4.42	-33.96	75	8.5
30	-.60	1.26	3.78	-4.38	-33.66	60	6.5
CHARGE							
5	-.36	1.32	2.178	+1.818	+25.40	53	5.6
10	-.16	1.32	2.178	+2.018	+28.19	43	4.7
15	-.02	1.34	2.211	+2.191	+30.61	37	3.7
20	+.04	1.35	2.228	+2.268	+31.68	30	3.0
25	+.05	1.36	2.244	+2.294	+32.05	28	2.8
30	+.09	1.38	2.277	+2.367	+33.07	25	2.5
35	+.10	1.39	2.294	+2.394	+33.44	22	2.2
40	+.10	1.40	2.310	+2.410	+33.67	22	2.2
45	+.09	1.42	2.343	+2.433	+33.99	26	2.6
50	+.01	1.45	2.393	+2.403	+33.57	40	4.1
55	-.08	1.46	2.409	+2.329	+32.54	80	8.9
60	-.32	1.48	2.442	+2.122	+29.64	160	22.0
62	-.46	1.48	2.442	+1.982	+27.69	198	> 29.0

EXPERIMENTAL SERIES "C"

25°C Orbit #70 Aug. 8, 1966

Orbital Conditions:

1.) 30 mins. d.c. at 3.00 amps for 25% Depth of d.c.
2.) 62 mins. c. at 165 amps for 114% Recharge Rate

Time (mins.)	q (watts)	E (volts)	W (watts)	ΔH (watt-sec)	ΔH (kcal/equiv)	Adhydrode (mv)	Oxygen Press. (P.S.I.A.)
DISCHARGE							
0	-.48	1.49	4.47	-4.95	-38.04	168	24.6
5	-.76	1.34	4.02	-4.78	-36.73	195	> 29.0
10	-.77	1.31	3.93	-4.70	-36.12	152	20.2
15	-.74	1.30	3.90	-4.64	-35.66	118	14.5
20	-.68	1.28	3.84	-4.52	-34.74	92	10.9
25	-.65	1.26	3.78	-4.43	-34.04	75	8.5
30	-.62	1.26	3.78	-4.40	-33.81	60	6.5
CHARGE							
5	-.36	1.32	2.178	+1.918	+26.79	53	5.6
10	-.18	1.32	2.178	+1.998	+27.91	43	4.7
15	-.02	1.34	2.211	+2.191	+30.61	38	3.8
20	+.02	1.35	2.228	+2.248	+31.40	30	3.0
25	+.08	1.36	2.244	+2.324	+32.47	28	2.8
30	+.08	1.38	2.277	+2.357	+32.93	22	2.2
35	+.10	1.39	2.294	+2.394	+33.44	22	2.2
40	+.09	1.40	2.310	+2.400	+33.52	22	2.2
45	+.06	1.42	2.343	+2.403	+33.57	26	2.6
50	+.03	1.45	2.393	+2.423	+33.85	40	4.1
55	-.11	1.46	2.409	+2.299	+32.12	80	8.9
60	-.32	1.48	2.442	+2.122	+29.64	160	22.0
62	-.50	1.48	2.442	+1.942	+27.13	202	> 29.0

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