# EXPERIMENTAL APPARATUS FOR THE MEASUREMENT OF THE ENTHALPY OF COAL DERIVED LIQUIDS

By

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A Thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science.

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# ABSTRACT

An experimental apparatus capable of making accurate measurements of enthalpy differences was designed, constructed, and tested. The basic unit is a Freon 11, $CFCl_3$, boil off calorimeter using three chambers; a vacuum chamber, a freon heat shield, and an inner measurement chamber.

Temperatures were measured with platinum resistance thermometers, calibrated against a standard Leeds and Northrup platinum thermometer. Resistances were measured with a Fluke multimeter.

Step by step operating procedures for all the equipment and instruments are presented for use by future operators. After further testing, future operators will use samples of coal derived liquids supplied by Bartlesville Energy Research Center, Bartlesville Oklahoma.

Enthalpy differences for water were measured for several points over the operating range of the equipment. Conditions were selected to best indicate the type of errors present in the measurements.

Steps were taken to decrease the error to within the allowed one $Btu/lb_m$ limit. Although the accuracy was achieved on a few runs, modifications of the equipment and procedures will be required.

## ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks for support from the Energy Research and Development Administration, and the Colorado School of Mines Office of Research Services.

Grateful appreciation is extended to Professors Arthur J. Kidnay and Victor F. Yesavage, thesis co-advisors, who gave valuable guidance during this study. Sincere thanks is extended to the Master of Science Committee members: Professors A. J. Kidnay, V. F. Yesavage, E. D. Sloan, and A. L. Hines.

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# INTRODUCTION

Coal derived liquids are a new and vital class of industrial compounds, but have thermodynamic properties that are largely unknown and, presently, unpredictable. This information of thermodynamic properties is needed to make more efficient design calculations of equipment using these new liquids. Enthalpy measurements offer a greater amount of information to the design engineer than other thermodynamic properties since they can be used directly in the determination of process heat loads.

The purpose of this project was to design and construct an experimental apparatus capable of making enthalpy measurements accurate to within one $Btu/lb_m$. The apparatus was tested by measuring the enthalpy of water over the pressure range of 500-1500 psi and a temperature range of 150-550$^{o}$ F and comparing the data obtained with that in the literature (1). Water was chosen for comparison purposes because it is readily available and realiable enthalpy data is available.

In the future this apparatus will undergo further testing with water before undergoing tests with n-pentane. Upon completion of the n-pentane tests, the apparatus will then be used on coal derived liquid samples supplied by the Energy Research and Development Administration, Bartlesville Energy Research Center, Bartlesville, Oklahoma.

This thesis presents a complete description of how the apparatus was constructed along with design information. Included are test run results describing operating characteristics, and accuracy of the measurements made. The thesis also contains complete calibration data for the platinum resistance thermometers, pressure gauge, and pressure transducers, and complete operating instructions for the apparatus and instruments.

## PROCESS SELECTION

A review of the calorimetric methods and interpretation of experimental results for the enthalpy of fluid mixtures under pressure has been presented recently (2). Flow calorimetry is best suited for measurement of enthalpy since, unlike batch calorimetry, enthalpy is obtained directly without the need for extensive volumetric data. The first law of thermodynamics applied to a flow calorimeter with negligible potential and kinetic energy effects is:

$$(H_{T_2,P_2} - H_{T_1,P_1})_x = \frac{\dot{Q} - \dot{W}}{F} \qquad (1)$$

where $H_{T_2,P_2}$ and $H_{T_1,P_1}$ represent the enthalpies per unit mass of the fluid at outlet and inlet conditions respectively; $\dot{Q}$ is the net rate of heat transfer to the fluid; $\dot{W}$ is the net rate of work input; F is the mass flow rate; and x represents a constant overall composition. Flow calorimeters can be used to measure the variation of enthalpy with temperature and pressure depending upon the manner in which temperature and pressure are controlled.

The two major kinds of methods used to determine enthalpies of fluids by flow calorimetry are the direct measurement where a known quantity of energy is added to the fluid under study, and comparative measurement where a knowledge of the specific heat or latent heat of a reference fluid is used to determine the energy input (2). The comparative method or more specifically a reference fluid boil off calorimeter similar to that originally developed by Nelson and Holcomb (3) was selected to be used in this study. In such a calorimeter energy is added to the fluid under study by heat transfer to a boiling fluid. The amount of energy added is determined from a knowledge of the latent heat of vaporization and the quantity of reference material boiled away.

The reasons for selecting a boil off calorimeter for this study are the following:

1) Boil off calorimeters are more suited for the measurement of enthalpy differences over large temperature ranges than direct measurement methods which are more suitable for determining heat capacities. For this apparatus large temperature differences are required since the processing of liquid fuels generally involves temperature changes of process streams of between room temperature to at least 700° F.

2) Boil off calorimeter systems are generally simpler, less costly, and less subject to equipment failures.

3) Although less accurate than direct calorimeters, boil off calorimeters can be developed with an accuracy of

about 1 $Btu/lb_m$ (3) which is within the accuracy of engineering process design calculations.

In all calorimetry programs the major concerns in obtaining accurate experimental data generally are the minimization of heat losses from the calorimeter and the accurate measurement of flow rate. The basic relation for a flow calorimeter, equation 1, when applied to a boil off calorimeter becomes:

$$(H_{T_2,P_2} - H_{T_1,P_1})_x = \frac{F_r\lambda_r}{F} + \frac{q}{F} \tag{2}$$

where $F_r$ is the mass rate of reference fluid boiling off, $\lambda_r$ is the latent heat of reference fluid, and q is the heat loss from the calorimeter-reference fluid system which in general must be estimated and represents a limitation in the accuracy of a measurement. The above relation is obtained since for boil off calorimeters:

$$\dot{Q} = F_r\lambda_r + q \quad \text{and} \qquad \dot{W} = 0. \tag{2a}$$

From equation 2, one can see that the heat loss error term is q/F and is thus inversely proportional to flow rate. Furthermore, as flow rate decreases, the accurate measurement of flow rate becomes more difficult. Thus, most calorimetry facilities, as with this one, have been developed to operate at flow rates in the order of one gallon per hour to minimize heat loss effects and to obtain accurate flow rate measurements (3,4).

The enthalpy differences are obtained at constant total composition between a given temperature and the reference fluid boiling point temperature. Freon 11, $CFCl_3$, is used as the reference fluid in this apparatus since it boils around room temperature (3). The calorimeter was constructed to operate at essentially constant pressure. Thus, the final results will consist of enthalpy differences at constant pressure levels between different temperatures and room temperature. To obtain the effect of pressure on enthalpy at any temperature it is necessary to tie in the data to results for enthalpy as a function of pressure for at least one isotherm. This can be done at room temperature for the liquid sample by integrating the relation:

$$\left(\frac{\partial H}{\partial P}\right)_T = V - T \left(\frac{\partial V}{\partial T}\right)_P \qquad (3)$$

using measured values of the sample volume at room temperature. Since the effect of pressure on enthalpy is small for liquid hydrocarbons, generally of the order of 5 $Btu/lb_m$ over a pressure range of 2000 psi (2), accurate values of volume are not required to determine the effect of pressure on enthalpy to within one $Btu/lb_m$.

In the two phase region the determined enthalpy values represent the total enthalpy of a vapor-liquid mixture with a combined composition equal to that of the original sample. Such results are required to determine heat loads for heat transfer equipment; however, for phase separation equipment a knowledge of vapor-liquid equilibria is required.

# EQUIPMENT DESIGN

Since the development of the original boil off calorimeter by Nelson and Holcomb (3), boil off calorimeters of numerous designs have been used under a variety of conditions, and their capabilities are well documented. Table 1 presents a listing of the boil off calorimeters that have been used, and the conditions under which they were operated. The design incorporated in this apparatus was developed after careful study of the ones listed in Table 1.

## Calorimeter

The actual design work for the calorimeter was done by Dr. A. J. Kidnay and Dr. V. F. Yesavage in consultation with Cryogenic Engineering Incorporated, the fabricator. Figure 1 shows a scale drawing of the calorimeter design used in the apparatus. All calculations were based on a maximum change in enthalpy of 800 Btu/$lb_m$.

The calorimeter is constructed of 304 stainless steel except where it is in contact with the sample oil, where 316 stainless steel is used. The inner chamber constitutes the boiling bath. The 35 foot long coil of 1/8 inch outside diameter stainless stell tubing provides more than adequate heat transfer area to cool the sample

Table 1

Boil-Off Calorimeter Facilities

| Authors | Reference Fluid | System Fluid | Type of Data |
|---|---|---|---|
| Nelson & Holcomb (3) | Freon 11 | Polar Liquids | Constant P |
| Jenkins & Berwaldt (5) | Liq. Nitrogen | Fixed Gases | Constant P |
| Sahyal et al (6) | Liq. Nitrogen | Fixed Gases | Constant P |
| Wiener (7) | Freon 11 | Gases & Liquids | Pressure Drop |
| Lenoir & Hipkin (4) | Freon 11 | Liquids | Constant P |
| Laverman & Selcukoglee (8) | Liq. Nitrogen | Fixed Gases | Constant P |
| Dolan et al (9) | Liq. Nitrogen | Fixed Gases | Constant P & Pressure Drop |
| Banks & Haselden (10) | Liq. Nitrogen | Fixed Gases | Constant P |
| Eakin et al (11) | Freon 11 | Gases & Liquids | Constant P & Pressure Drop |
| Thinh et al (12) | Freon 11 | Liquids | Constant P |
| Brewer (13) | Freon 11 | Gases | Constant P |

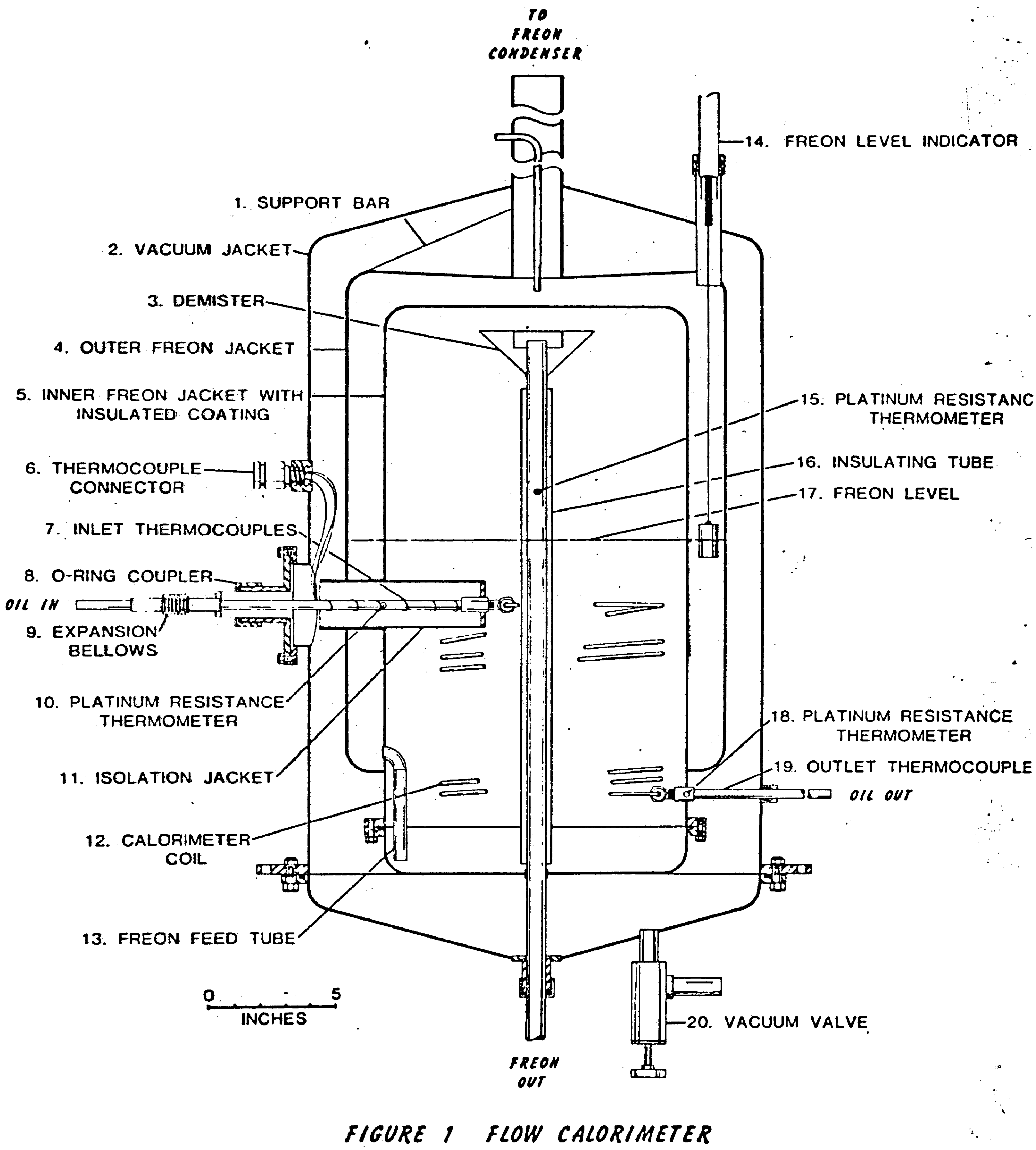



*FIGURE 1 FLOW CALORIMETER*

oil down to within 1° F of the freon bath.

The freon vapors that boil off from the inner chamber travel through the demister before leaving the calorimeter. The demister removes all forms of liquid from the exit stream allowing only the vapor to leave.

The middle chamber contains boiling freon. It acts as an insulating barrier by eliminating any temperature difference between the inner chamber and its surroundings. It also increases the capacity of the calorimeter for holding freon since the two chambers are connected by the freon feed tube.

The outer chamber is evacuated by the vacuum system to provide another insulating barrier. To be effective, the vacuum has to be less than $7 \times 10^{-4}$ millimeters to increase the mean free path (14) until the distance is that equal to the widest distance of the chamber.

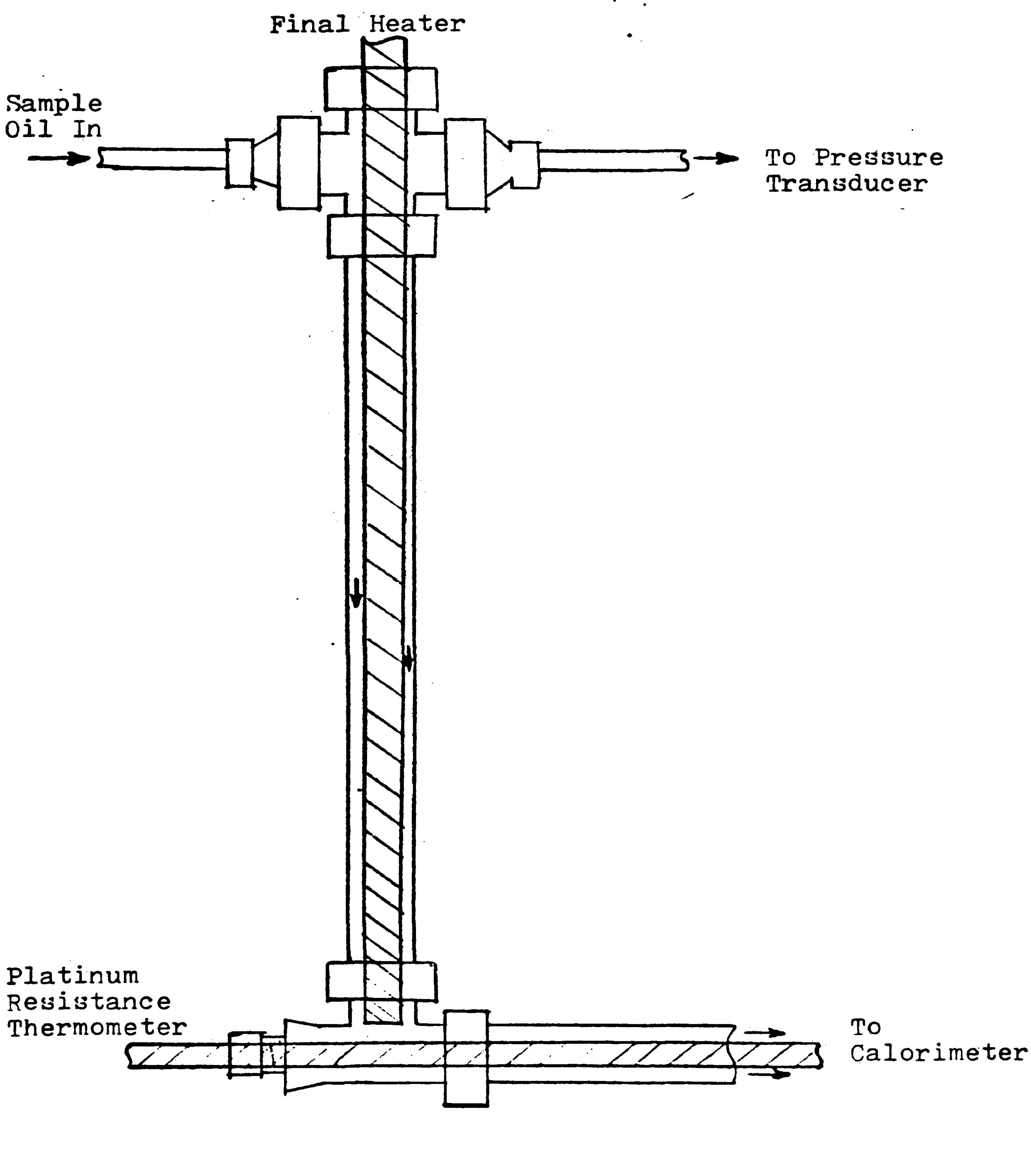
## Heating System

To avoid hot spots in the sample oil lines, a gradual heating of the sample is desired. This is accomplished through the use of a fluidized bath containing a 25 foot coil to gradually heat the sample. An electric final heater is used to achieve the final temperature desired before entering the calorimeter.

The location of the final heater is shown in figure 2. The final heater is a 350 watt, two conducter element,

FIGURE 2

Inlet Tube Assembly



cartridge heater manufactured by Control Products Corporation. It is capable of heating the sample oil approximately 100° F. It is to be used to adjust the temperature for several points while the preheater bath temperature remains constant.

Pumping System

A Milton Roy dual diaphragm pump is used to deliver the sample oil through the system at the desired pressure. A Grove back-pressure regulator, dome loaded type, is located at the outlet of the calorimeter to set and maintain the pressure of the system.

To alleviate the problem of surges caused by the pump, a Greer bladder accumulator was installed in the system prior to the preheater bath. The bladder accumulator introduces a gas, nitrogen, into the system to absorb the energy of the pump strokes. The nitrogen, which is separated from the system by a barrier, releases the absorbed energy between strokes of the pump to stabilize the flow. The static pressure of the nitrogen in the bladder is set equal to the pressure of the system at the location at which it is connected.

Condensers

Based on a one cubic centimeter per second flow of sample oil, the condensers were sized using heat transfer correlations for condensing freon (15). The temperature of the coolant for the condensers was selected to be 30° F for the calculations.

The main condenser has an area of 9.1 square feet while the small one has an area of 2.1 square feet. Both are manufactured by American Standard. The small one is mounted as a reflux condenser with the top vented to the atmosphere. The larger one is mounted as a counter flow condenser to allow for sub-cooling of the freon. All vents are connected to a dryer to prevent water from collecting in the freon system through the condensers.

## Collection System

The collecting tubes for the sample oil and freon are 3 inches in diameter and 15 inches long. Samples collected in the tubes are kept below 2000 grams total to allow them to be weighed on the single pan balance, manufactured by Mettler. This eliminates the use of volumetric information and determines the mass directly.

## Refrigeration System

The refrigeration unit was selected, based on the maximum heat load possible. It is a 13,000 Btu/hour water chiller manufactured by Dunham-Bush and greatly exceeds the value of 6000 Btu/hour calculated to be needed. Flowmeters controlling the flow to the condensers are located to the left of the unit.

### Vacuum System

To obtain the vacuum necessary, a diffusion pump is needed. A portable unit with gauge was assembled by Remanufactured Vacuum Products to fit the needs of the apparatus.

## PROCESS FLOW

A schematic diagram of the experimental apparatus is presented in figure 3. It illustrates the positions of the different streams and the support equipment involved to operate the apparatus.

The layout of the equipment was dictated by the requirements made necessary by the samples to be handled. The initial layout was made using the calorimeter as a reference with an effort to minimize size and maximize ease of access.

The possibility of two-phase flow developing in the sample line after heating determined the layout of the piping. This consisted of a constant downward movement of the stream once the heating process began to prevent trapping of the liquid in a low spot and vapor in a high spot. Eliminating the availability of traps allows for a more uniform flow without separation of the phases.

Another factor considered in the sample line layout was the expected small amount of some of the samples. This called for the shortest possible piping between equipment located in the sample stream.

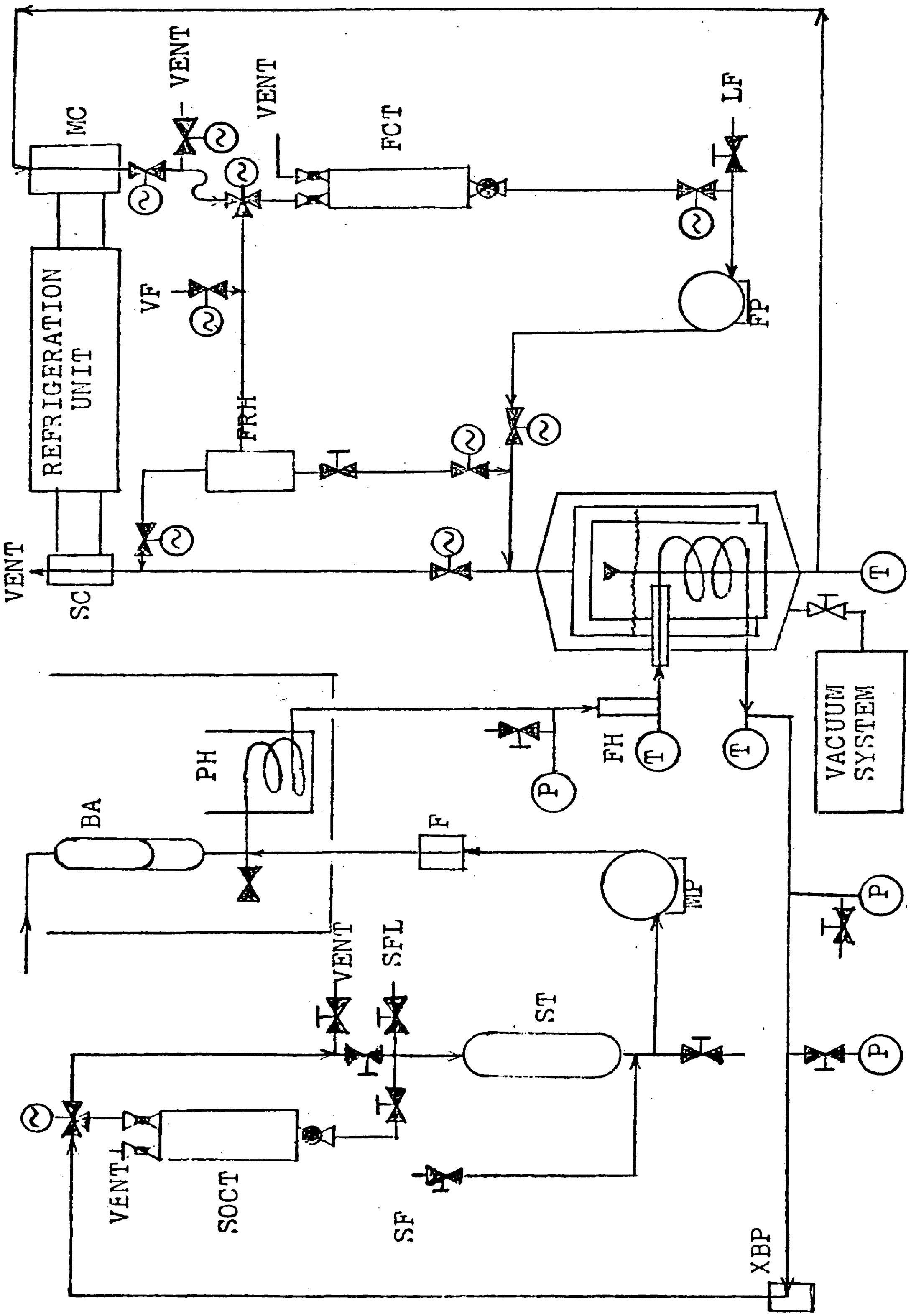
Factors influencing the layout of Freon 11, $CFCl_3$, lines included the gravity forced flow from the large condenser; minimizing length of lines; the low boiling point, approxi-

## SYMBOL INDEX FOR FIGURE 3

| | |
|---|---|
| BA | Bladder Accumulator |
| F | In-line Filter |
| FCT | Freon Collection Tube |
| FH | Final Heater |
| FP | Freon Pump |
| FRH | Freon Return Heater |
| LF | Liquid Fill |
| MC | Main Condenser |
| MP | Main Pump |
| P | Pressuring Indicating Device |
| PH | Preheater |
| SC | Small Condenser |
| SF | Sample Fill |
| SFL | Sample Flush |
| SOCT | Sample Oil Collection Tube |
| ST | Surge Tank |
| T | Temperature Indicating Device |
| VF | Vapor Fill |
| XBP | Back Pressure Regulater |

Figure 3

Experimental Apparatus for the Measurement of the Enthalpy of Coal Derived Liquids Schematic Diagram



mately 65$^{o}$ F, at this altitude; and the size allowed by room dimensions.

Gravity forced flow from the large condenser dictated its position above the collection tubes and at a height determined by the size of equipment required between the two. The compactness of the equipment was again necessary to maintain the length of lines as short as possible and also due to limited ceiling height in the laboratory. The low boiling point of the freon called for special measures to be taken in the handling to prevent excessive loss during filling and draining as well as during operation.

The actual equipment is mounted on a frame of slotted angle steel 8 feet wide, 4 feet deep, and 10 feet high, with a 2 1/2 foot extension on the front for the control panels. Aluminum panels were used to mount the controls and to construct the safety shielding around the preheater bath.

Sample System

The sample system is mainly made of 316 stainless steel to handle the corrosiveness of liquids derived from coal. The main lines are 1/16 inch inside diameter and 1/8 inch outside diameter and the connecting lines around the surge tank are 3/8 inch outside diameter. The surge tank is made of 304 stainless steel, has a capacity of 2.25 liters, and is mounted vertically. Manufactured by Hoke, it is a high pressure sample cylinder with 1/2 inch NPT openings at both ends.

The fill port connects with the lower opening of the surge tank to allow air to escape out the vent, which is connected to the upper opening, without being trapped by the sample as it flows in. A drain valve is connected to the lower opening where the feed line to the main pump originates.

The main pump is a Milton Roy dual diaphragm metering pump, capable of capacities of up to two gallons per hour and of pressures up to 1800 psi. The dual diaphragm pump was selected for its ability to level out the pulsating in the flow with its double action.

An in-line filter was included after the pump to remove particles from the stream. If allowed to stay in the stream, small particles could collect in a stagnant corner created by change in tubing diameter, and dislodge and travel down stream to plug up the small diameter tubing. The filter elements are compressed stainless steel with 60 micron sized openings.

Before the preheater, a tee is located in the line to allow for the installation of a bladder accumulator to stabilize the pressure. The bladder accumulator, manufactured by Greer, incorporates a nitrogen filled bag to absorb the force gen filled bag to absorb the force of the pump stroke.

of the pump stroke. This acts as a cushion for the liquid sample system which is unable to react to the pump's stroke without pressure surges.

The preheater, manufactured by Techne, is a fluidized bath. Air is injected into the bath at the bottom to agitate the fused alumina sand to produce a safe heat transferring medium. A coil made of a 25 foot length of tubing was installed into the bath to provide an adequate heat transferring area.

The final equipment assembly before the sample stream enters into the calorimeter contains a water-cooled pressure transducer by Precise Sensors, the final heater by Control Products Corporation, and a platinum resistance thermometer, in that order. The pressure transducer is water-cooled to hold the temperature of the sensor within the limits of the transducer. The final heater is a rod-type, controlled by a Honeywell three mode controller.

After leaving the calorimeter, the sample line contains a platinum resistance thermometer to accurately measure temperature. This is followed by a pressure transducer and a Heise bourdon tube gauge to measure pressure. A back pressure regulator, made by Grove, is next in the line to maintain the systems pressure. The regulator is dome loaded with the pressure being set by pressurized nitrogen. The sample is then sent back to the surge tank or to the collecting tube by a three way solenoid valve.

Freon System

The calorimeter's two inner chambers hold approximately twelve gallons of Freon 11, $CFCl_3$. The measurement is made with the boil off freon from the inner chamber. The outer chamber of Freon 11 acts as insulation and a surge tank to increase the capacity to better maintain the level during long running periods.

The boil off from the inner chamber which is used for the actual measurement, passes through a mist trap to allow only the vapor to exit. The vapor then passes a platinum resistance thermometer which measures the temperature before entering a heated tube leading to the large condenser. The tube is heated to prevent condensing of the vapor before it reaches the condenser. Once the vapor condenses in the large condenser, it flows past a vent, through a vapor trap, to three-way valve. The three-way valve directs flow to either the recycle or the collection tube.

The recycle line goes to a return heater. The return heater is a heated glass flask that is vented to a location below the small condenser and drains through a metering valve into the outer Freon 11, $CFCl_3$, chamber of the calorimeter. The return heater is used to heat the subcooled liquid freon to the saturation point before allowing it to enter the calorimeter. This is done by allowing the freon to boil before opening the metering valve.

The outer chamber of Freon 11 is used as insulation and a surge tank. Its boil off is caused by heat transferred from the outside of the calorimeter. The vapor then travels to the small condenser, which is vented to the atmosphere, to condense and fall back to the outer layer at the saturation temperature.

# INSTRUMENTATION AND MEASUREMENT

## Temperature

Enthalpy measurement is highly sensitive with respect to temperature. Small errors in the temperature measurement cannot be overlooked. Temperature measurements that are not directly involved in the enthalpy calculations are measured with iron-constant thermocouples connected to an Omega digital readout. The temperatures at the locations of the thermocouples are excellent indicators as to how the equipment is operating.

At locations requiring more accurate measurement, 100 ohm platinum resistance thermometers are used. They are sheathed in 316 stainless steel and are located in the sample inlet and outlet of the calorimeter and in the Freon 11 outlet of the calorimeter.

A digital volt/ohm meter, manufactured by John Fluke Company, provides accurate measurement of the resistance thermometers output. The meter incorporates a four lead connection to duplicate the type of readings available from a mueller bridge, but with greater speed.

To check for temperature gradients in the sample stream at the calorimeter inlet, several thermocouples are located on the sample inlet tube. They are spaced one inch apart on the outside of the tube. To magnify even the slightest gradient, the digital volt/ohm meter is used along with a cold junction compensator.

Pressure

Sample system pressure is measured at both the inlet and outlet of the calorimeter to obtain operating pressure as well as the pressure drop across the calorimeter coil. The pressure drop is measured with two pressure transducers, one at the inlet and one at the outlet to the calorimeter. A Hewlett-Packard D.C. power supply is used to input the 10 volt signal necessary for the transducers. The Fluke meter is used to measure the output signal which is then converted to pressure.

The bourdon tube gauge is located at the outlet and measures the pressure directly. It is also used as a standard when calibrating the pressure transducers.

## CONTROLS

The most used controls are located on the front panels with lesser used controls located throughout the equipment. The right front panel, Figure 4, is the main control panel. Several remote valves are electrically operated and are controlled from this panel as well as most of the measurement readouts. Also located on this panel are the power switches for most of the equipment, final heater controller, run switch, timer, Fluke meter, temperature indicator, and D.C. power supply. Switches to change the input to the Fluke meter and temperature are located on the lower portion of the right panel.

The middle panel houses the collection tubes. Drains for both tubes are located on their respective sides. The return flow metering valve for the freon return heater is mounted on the upper left corner of the middle panel. Coolant control valve on the upstream side of the collection tube for the freon, is located to the right of the collection tube.

The left panel, figure 5, contains the Heise bourdon tube gauge, cooling water and air flow meters, preheater controller unit, and variacs. The air flow meter controls the flow to the preheater bath to fluidize it. The water flow meter adjusts the flow of cooling water to the inlet

## SYMBOL INDEX FOR FIGURE 4

1. SCR indicating light

2. Vacuum system power switch

3. Main pump power switch

4. Main electric control panel (Switches)

   a) Blank
   b) Blank
   c) Blank
   d) Blank
   e) Solenoid Group A
   f) Solenoid Group B
   g) Solenoid Group C
   h) Solenoid Group D
   i) Freon pump
   j) Spare
   k) Spare
   l) Blank
   m) Fluke multimeter
   n) Temperature indicator
   o) D.C. power supply
   p) Final heater temperature controller

5. Final heater temperature controller

6. Run Switch

7. Timer

8. Fluke multimeter

9. Temperature Indicator

10. D.C. power supply

11. Pressure transducer input voltage control switch

12. Fluke multimeter input switch

13. Thermocouple switch (Fluke multimeter)

14. Thermocouple switch (Temperature indicator)

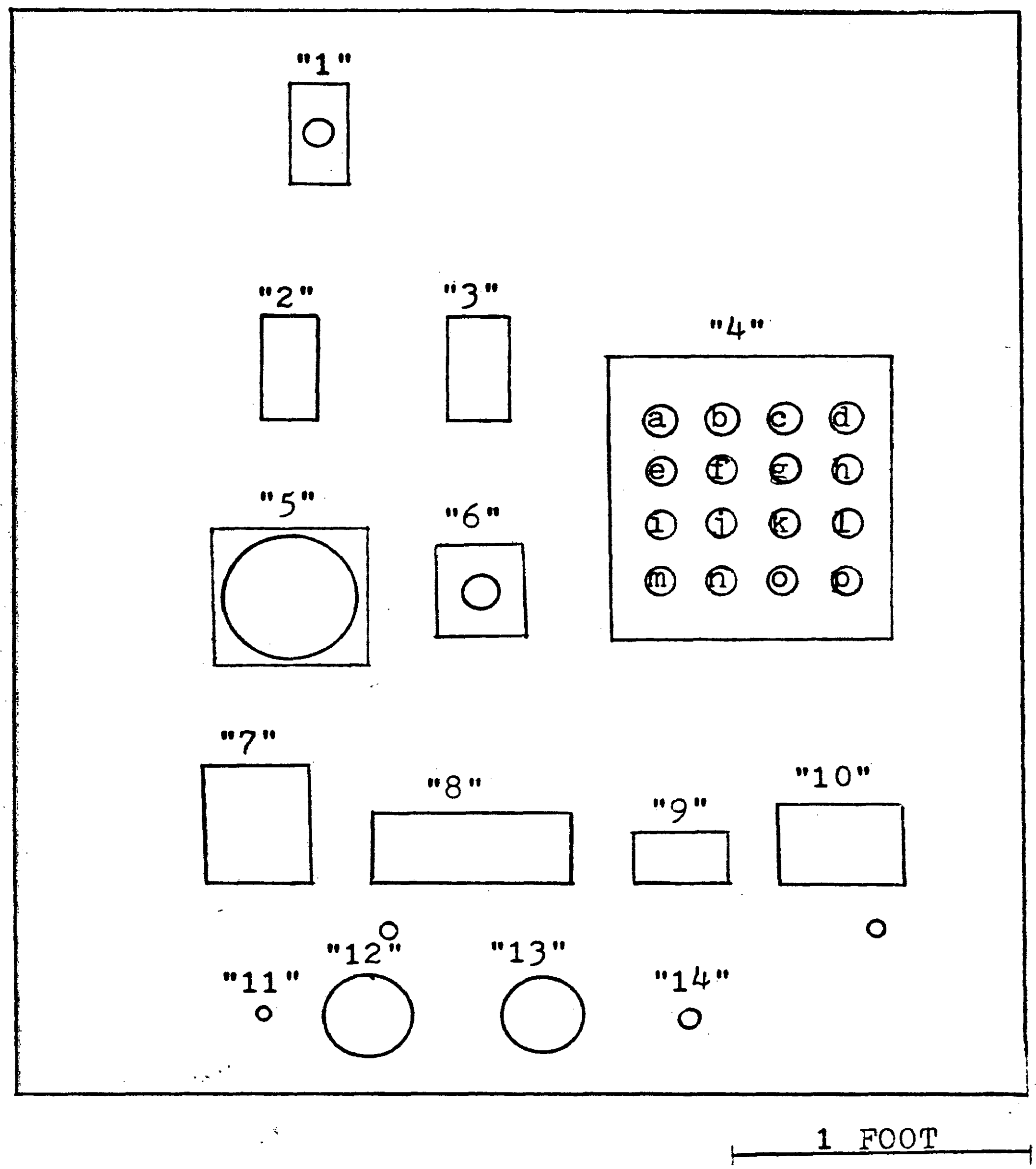



**Figure 4**

RIGHT MAIN CONTROL PANEL

## SYMBOL INDEX FOR FIGURE 5

1. Heise bourdon tube pressure gauge
2. Air flow meter for preheater
3. Preheater temperature controller
4. Heise gauge disconnect valve.
5. Water coolant flow meter for inlet pressure transducer
6. Variac for freon return heater
7. Variac for freon outlet line heater

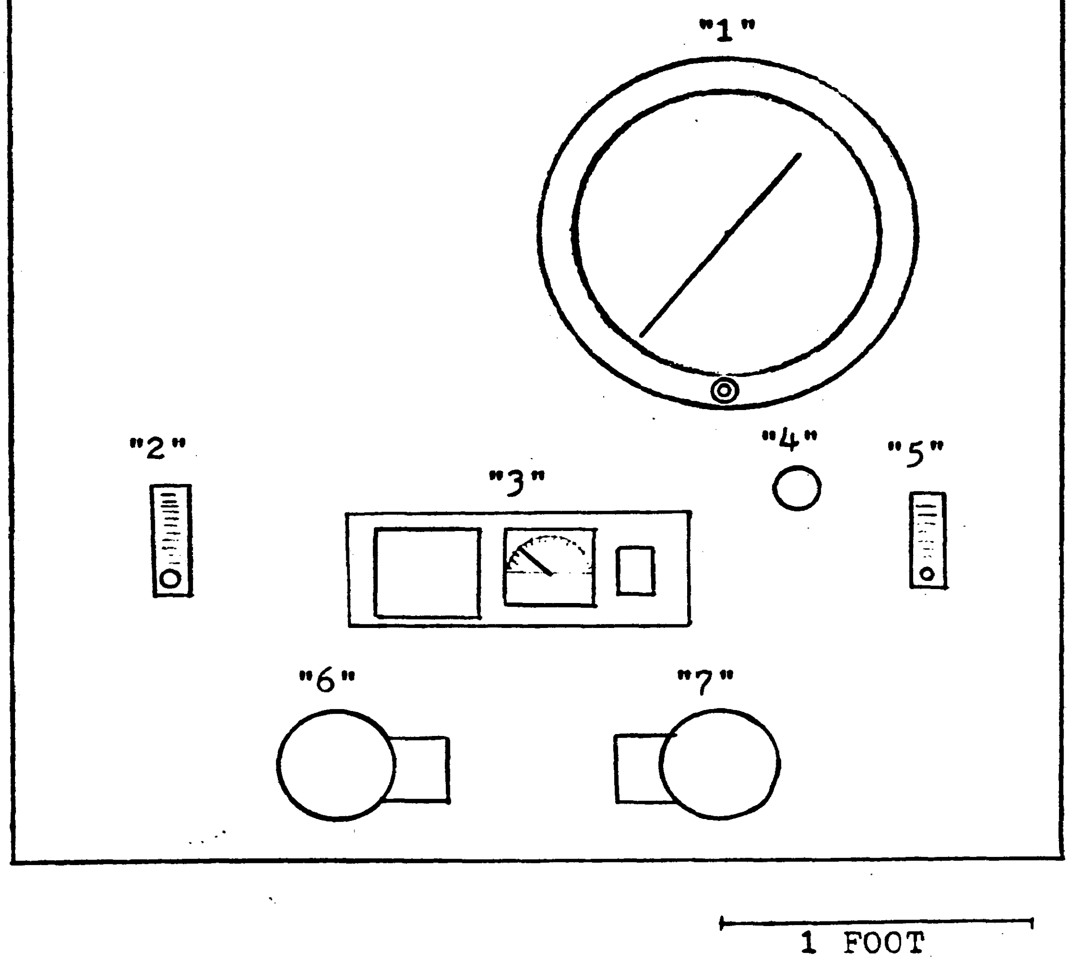



Figure 5

LEFT MAIN CONTROL PANEL

pressure transducer. One variac controls the freon return heater and the other controls the freon line to the large condenser. The valve below the Heise gauge separates the bourdon tube from the system to protect it when the system fluctuates. It should be closed during start up and shut down of the pump as well as when the system's pressure surges, to prevent damage to the bourdon tube.

The nitrogen regulators located on the cylinders to the right of the control panels are used to control the system's pressure. The left cylinder supplies the bladder accumulator which stabilizes pressure. The right regulator supplies the back pressure regulator and is used to set the operating pressure.

Between the refrigeration unit and the nitrogen cylinder rack is a small panel located on the main frame. This panel contains control valves for nitrogen flow and for coolant flow for the freon collection tube. The large valve is located downstream from the collection tube in the coolant line. It is used in conjunction with the upstream valve to isolate the tygon tubing used. The small valve on the left is located between the nitrogen regulator and the bladder accumulator to close off the system from regulator fluctuations. The three remaining valves are connected to the nitrogen regulator for the back-pressure regulator. The left valve of the three, connects the cylinder to the back pressure regulator. The top one connects the cylinder to the sample surge tank for flushing the system. The right valve is a vent to release pressure of either the flush line or back-pressure regulator line.

Other controls are located throughtout the apparatus on the equipment they control. The equipment which have controls on them are the main pump, preheater bath, vacuum system and refrigeration system. These controls, along with valves not mentioned in the discussion of the controls, are mentioned in the operation of the particular item.

# EXPERIMENTAL PROCEDURE

The following section describes the experimental procedure used in operating the equipment, given for a totally shut down apparatus. The purpose of this section is to describe what was done and to give a step by step procedure to be used by future operators.

## Preparation

1) Fill the calorimeter with Freon-11 until the float level is approximately level with the slotted angle steel through which the float travels.
2) Connect two nitrogen gas cylinders to the regulators to the right of the control panel. Cylinders should have a pressure of at least 100 psi greater than the system pressure to be maintained during operation.
3) Fill the refrigeration unit with a 50-50 mixture by volume, of distilled water and ethylene glycol. The fill is located on the front panel above the level sight glass, which has a vent at the top to be opened only during filling. Liquid will flow out of the vent when the holding tank is full.
4) Fill the preheater with fused alumina sand to

within three inches from the top.

5) Fill surge tank with approximately 1.5 to 2.0 liters of sample to be tested.

Daily Start-up

1) Turn on refrigeration unit to cool the condensers.

2) Turn on vacuum system to evacuate the outer chamber of the calorimeter.

3) Turn on air flow to preheater bath and adjust the flow to 120 cubic feet per hour. Turn on preheater controller and adjust to desired temperature.

4) Turn on instruments, including the temperature indicator, DC power supply, and Fluke multimeter.

5) Activate solenoid group A when refrigeration outlet temperature drops below $30^{\circ}$ F to open the freon system.

6) Adjust pressure transducer water coolant flow rate to 3.5 gallons per hour. Open valve to allow Heise gauge to read pressure. At zero gauge pressure, measure the output of the inlet pressure transducer with a 10 volt input. Record this value for later calculations.

7) Close the valve to the Heise gauge. Turn on the main pump and set its stroke metering to obtain

a one cubic centimeter per second flow rate. Set the back pressure regulator at approximately 100 psi greater than the desired system pressure to pressurize the system.

8) After allowing the pump to run for 20 to 30 seconds, pressurize the bladder accumulator to a pressure approximately 20 to 40 psi greater than the system pressure. Gradually open the valve to the Heise gauge. If fluctuations in pressure occur, adjust the pressure of the bladder accumulator to minimize pump surges.

9) Turn on the variac that controls the heat to the freon outlet line. Set dial reading to 30.

10) Close off metering valve for freon return heater until the liquid level is visible from a position in front of the control panel. Turn on the variac that controls the heat to the return heater and adjust metering valve to keep the level constant.

11) Adjust the final heater controller to the desired temperature and turn on.

Collecting Data

1) Allow time to reach steady state and record temperatures and pressures to monitor the system's conditions.

3) The vacuum in the jacket should be below 0.7 microns to be effective. Check to make sure it has had time to reach this condition.

4) Once the temperature and pressure have stabalized, the equipment is ready to operate at the conditions set.

5) To collect the fluids (the sample flowing through the calorimeter and the freon that has boiled off), push the run button on the right panel. This activates the timer and three-way solenoid valves. (A manual valve was used in the freon line. A solenoid valve is being sought to replace the manual valve at a future date.) Once the system is collecting, temperatures and pressures are recorded to make required calculations and to check stability during the run. The level of the float must remain constant during the run to maintain a steady state.

6) To end the run, the run button is pushed again to de-energize the three-way solenoids and stop the timer. The collection tubes are weighed to determine the amounts collected.

7) The tube located on the left side of the center front panel is then connected to drain the sample

into the surge tank.

8) The tube located on the right side of the center front panel is then connected to drain the freon back to the calorimeter. Solenoid groups C and D and the freon pump are turned on to drain the collection tube.

9) After draining, replace the collection tubes with clean ones that have been weighed. Then repeat the steps of collecting data for the conditions of the next run.

Daily Shut-down

1) Turn off freon return heater variac and open the freon return metering valve completely.

2) Turn off the final heater controller and pre-heater controller, leaving the air supply to the preheater on.

3) Turn off the vacuum system, allowing time for the diffusion pump to cool.

4) Allow time for the preheater to cool to below 180° F before turning off its air supply.

5) After cooling off the preheater, turn off the main pump and remove the pressure from the back-pressure regulator and then from the bladder accumulator.

6) Turn off the freon outlet variac, Fluke meter, temperature indicator, and D.C. power supply.

7) When flow stops through the return heater, turn off solenoid group A. At this time the refrigeration usit can be shut off. If a run is to be made the next day, it is advisable to leave it on.

Freon Filling and Draining

1) Connect the Freon 11 barrel to filling lines located directly behind the calorimeter. The refrigeration unit must be on and cooled to operation temperature before filling or draining.

2) Open the valves on the barrel and on the apparatus.

3) Turn on the solenoid group D and and freon pump to fill the calorimeter. Solenoid group A must be open to allow the two freon chambers to be at the same pressure. The calorimeter is full when the float is approximately six inches high in its guide tube.

4) Once the calorimeter is filled, the freon pump and solenoid group D are turned off, and the valves are closed that connect the barrel to the apparatus.

5) Solenoid group B controls the vapor fill. This is to be open to transfer vapor from the barrel to the calorimeter through the condenser. This is used to decrease pressure in the barrel and to empty it as far as possible.

6) To empty the calorimeter, the barrel must be connected and valves open to permit evacuation.

7) The apparatus needs to be set up to run hot fluid through the calorimeter coil and set in the run position.

8) Open solenoid group C and stop cock at the bottom of the collection tube to allow flow through to the barrel. Pressure in the barrel is released by turning on solenoid group B, allowing vapor flow into the calorimeter.

9) This is continued until the outlet sample stream from the calorimeter starts increasing in temperature to a value of $80^{\circ}$ F. The main pump and the heat controllers are then turned off.

10) When the flow of freon from the calorimeter stops, solenoid group C is closed along with the connecting valves to the barrel. The calorimeter is then dismantled to remove the remaining freon.

# TEST RUN RESULTS

A total of twenty test runs were made with distilled water to determine the accuracy of the equipment. The equipment was modified when the data indicated an equipment or design failure. Values of enthalpy differences measured were compared to values published (1). Table 2 list the results of the last ten runs. They were made after the last corrective measure was made during the twenty test runs.

## Corrective Measures

Test runs one and two were invalid due to a faulty valve. The three-way valve for the Freon 11 system was not capable of handling the freon and deteriorated to the point of not changing the flow completely.

Test runs three through seven indicated a restriction of the flow to the freon collection tube. The quick-disconnect that was being used in that line was replaced by tubing of a larger inside diameter.

During test run ten a leak developed inside the calorimeter and made necessary its dismantling. Data collected on runs eight through ten were disallowed due to the corrections made on the system after run ten.

TABLE 2

| Run | Flow Rate cc/sec | Pressure psia | Temp. °F | Enthalpy (Determined) Btu/lb | Enthalpy (Literature) Btu/lb |
|---|---|---|---|---|---|
| 11 | 1.16 | 564 | 256.2 | 182.6 | 190.7 |
| 12 | 1.24 | 565 | 254.2 | 182.7 | 188.9 |
| 13 | | Leakage | Through | Collection Tube | |
| 14 | .73 | 1418 | 174.5 | 102.8 | 107.5 |
| 15 | .72 | 1430 | 175.5 | 105.1 | 109.2 |
| 16 | .70 | 1526 | 547.6 | 485.2 | 507.3 |
| 17 | .67 | 1517 | 515.0 | 447.7 | 461.3 |
| 18 | .43 | 546 | 275.1 | 202.9 | 210.2 |
| 19 | .95 | 565 | 277.3 | 209.1 | 212.5 |
| 20 | 1.93 | 600 | 274.5 | 208.3 | 209.3 |

Indications

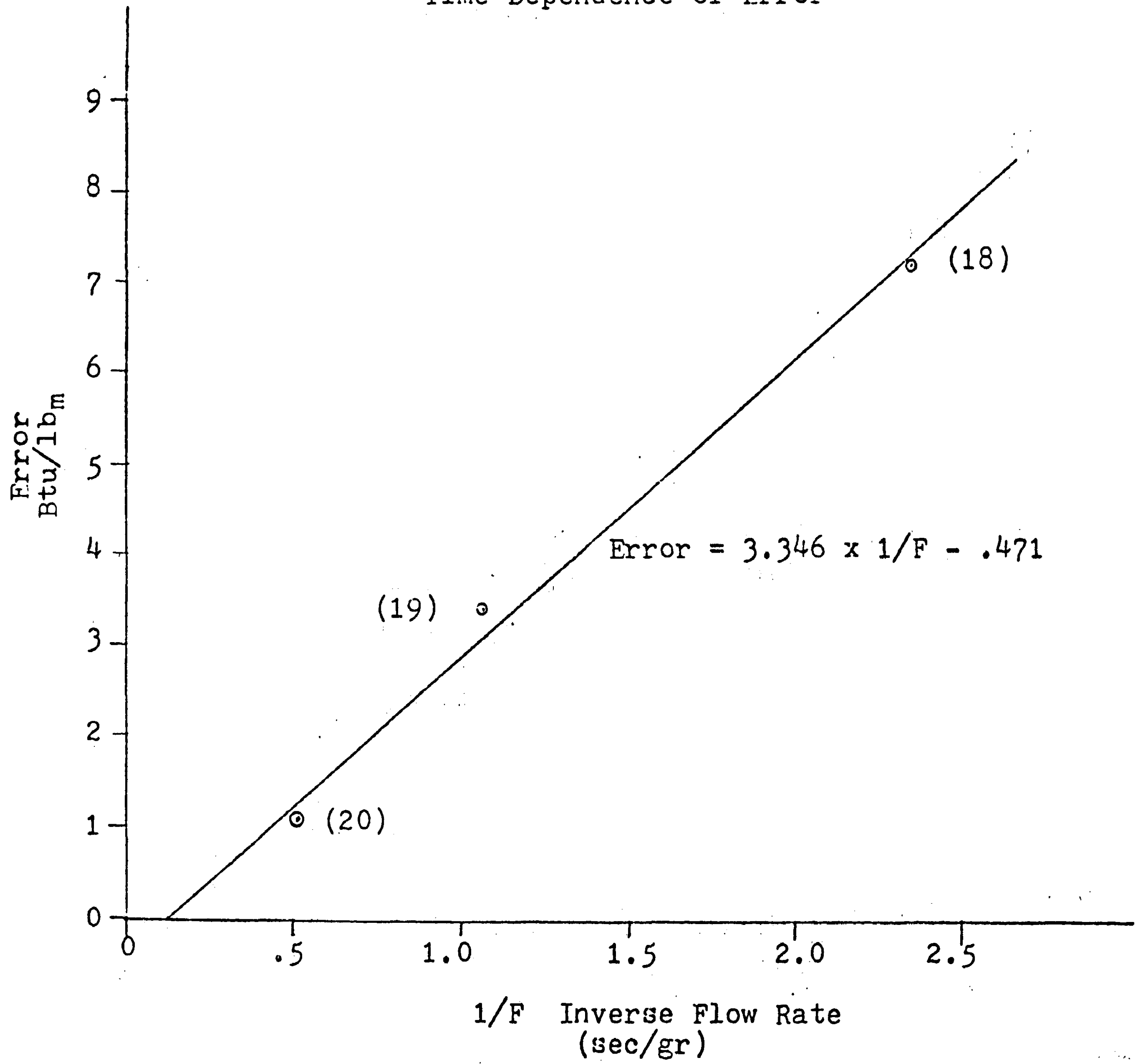
The results of the following runs were then used to determine the type of errors still remaining in the equipment. Graphs one and two illustrate the trends in the measurements taken.

Graph one indicates a heat leak that is dependent on time. The error values are shown to be inversely proportional to the flow rate. As the length of the run is increases, the error in measurement is increased by the constant heat flux from the boil off chamber of freon in the calorimeter to its surroundings. The middle chamber of freon was found to be at a lower temperature than the inner chamber. This would cause the type of error realized. To compensate for this, the freon from the small condenser needs to be heated to its saturation temperature before entering the outer chamber.

Graph two indicates a conduction heat leak, since the error is proportional to the inlet temperature of the sample. This would point to a path for conduction from the inlet tube assembly to the outer chamber of freon. the inlet thermocouples were removed to eliminate any possible path for conduction.

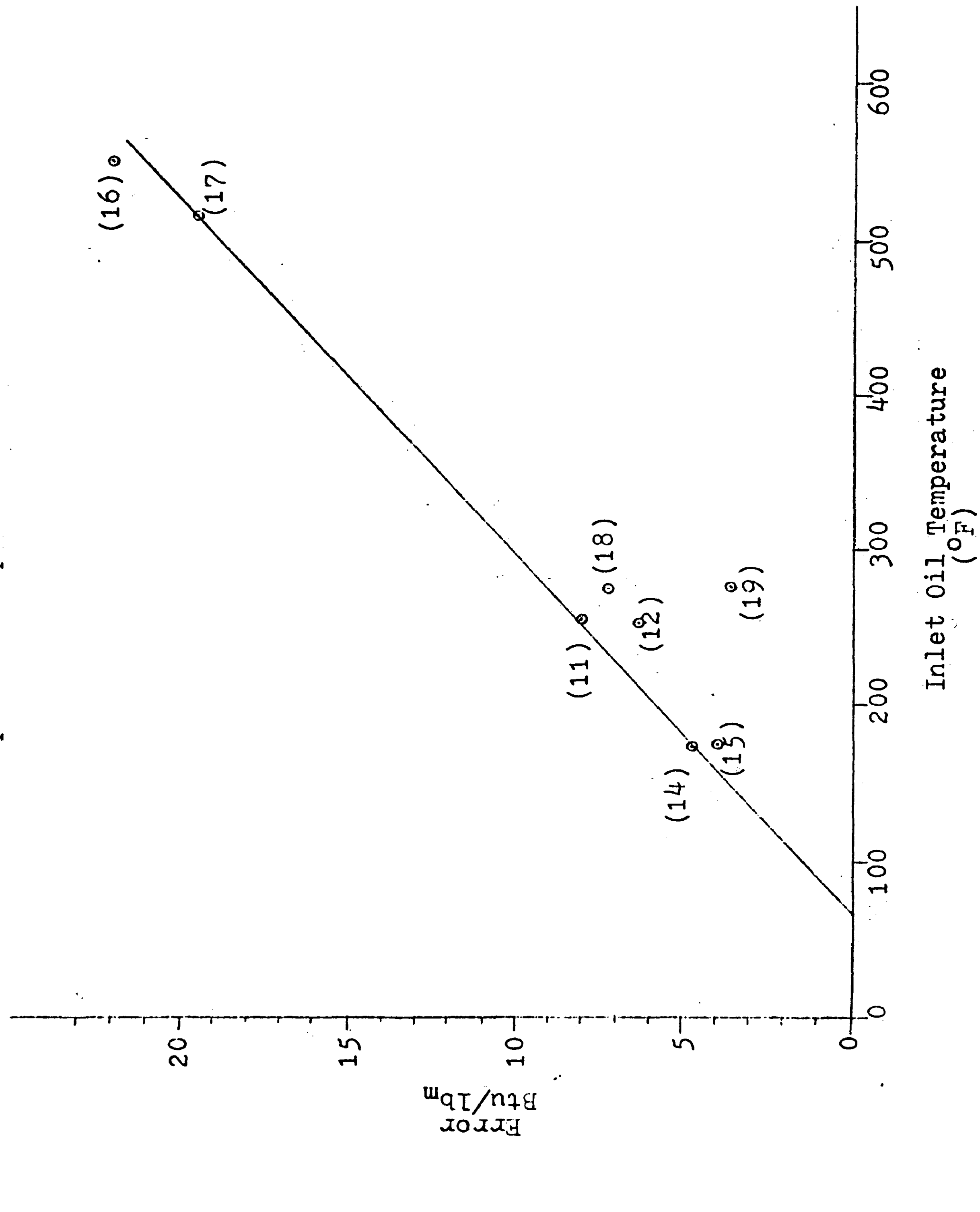
GRAPH 1

Time Dependence of Error



GRAPH 2

Temperature Dependnece of Error



## CONCLUSIONS

Although several faults in the equipment were corrected during the first twenty test runs, it is necessary to make more test runs to see if any more errors exist. The runs should be made using distilled water and then n-pentane with data points covering the full range of the calorimeter capabilites

# RECOMMENDATIONS

1. Replace inlet thermocouples with a better set-up to eliminate any form of heat loss.
2. Reroute the return flow from the small condenser through an apparatus similiar to the return heater before allowing it to enter the calorimeter.
3. Replace the drain lines for the freon collection tube with 3/8 inch copper tubing that is insulated.
4. Modify the freon collection lines to establish 1/4 inch as a minimum inside diameter.

# APPENDIX A

## Platinum Resistance Thermometer Calibration

The Report of Calibration from Leeds and Northrup Company for the calibrated thermometer is presented in this appendix. The report is followed by information on the calibration of the 100-ohm platinum resistance thermometers used in the system, including calibration procedures, results, and the method to determine the results from the raw data.

LEEDS & NORTHRUP COMPANY Sumneytown Pike • North Wales, Pennsylvania 19454

**REPORT OF CALIBRATION**

**FOR**

**8167-25-B PLATINUM RESISTANCE THERMOMETER**

**SERIAL NO.** 1835855

-oOo-

The above designated platinum resistance thermometer was calibrated in October, 1975 for use with continuous current of 1.0 milliamp through the thermometer.

The following values were found for constants in the formulas given in the International Practical Temperature Scale of 1968 (IPTS-68):

| | |
|---|---|
| Alpha ($\alpha$) = 0.003926573 | $A_4$ = $6.063 \times 10^{-7}$ |
| Delta ($\delta$) = 1.496340 | $C_4$ = $2.122 \times 10^{-14}$ |

The pertinent International Practical Temperature Scale formulas are given in the discussion on the following pages.

The resistance at 0° C was found to be 25.5104 ohms.

The values given were determined from measurements at the triple point of water, tin point, zinc point and the boiling point of oxygen.

All observations were made by comparison with platinum resistance thermometer reference standards calibrated at regular intervals by the National Bureau of Standards. The most recent reference standard calibration is dated October, 1974; N. B. S. Test No. 211432.

For the Vice President-Instruments & Products Group

R. H. Verity
Manager, Standards Laboratory

October 21, 1975

LEEDS & NORTHRUP COMPANY Sumneytown Pike • North Wales, Pennsylvania 19454

## TEMPERATURE RANGE: 0° TO 630.74° C

Temperatures between 0° C and 630.74° C on the new International Practical Temperature Scale of 1968 (IPTS-68) are defined by the indications (resistance values) of standard platinum resistance thermometers and the following expressions:

$$t = t' + M(t') \qquad (1)$$

$$t' = \frac{1}{\alpha}\left(\frac{R_t}{R_o} - 1\right) + \delta\left(\frac{t'}{100} - 1\right)\frac{t'}{100} \qquad (2)$$

$$M(t') = .045\left(\frac{t'}{100}\right)\left(\frac{t'}{100} - 1\right)\left(\frac{t'}{419.58} - 1\right)\left(\frac{t'}{630.74} - 1\right) \qquad (3)$$

where t is the temperature, at the outside of the tube protecting the platinum resistor, in ° C on the International Practical Temperature Scale of 1968, and $R_t$ and $R_o$ are the resistances of the platinum resistor at t° and 0° C respectively, measured with a continuous current through the platinum resistor. The value of this current and the values of the constants $\alpha$ and $\delta$ found for this thermometer are given on the previous page. The value of M(t'), given by expression (3), is the same for all thermometers and is a function only of the quantity t'. The addition of the small value represented by (3) serves to make the IPTS-68 conform more closely to the thermodynamic scale than can be done with only the simple quadratic of expression (2).

An alternate form which is completely equivalent to expression (2) is

$$R_t = R_o\,(1 + At' + Bt'^2) \qquad (4)$$

In some instances expression (4) is less difficult to calculate than (2). The constants A and B used in (4) are related directly to $\alpha$ and $\delta$.

$$A = \alpha\,(1 + \delta/100) \qquad (5)$$

$$B = -\alpha\delta/10^4 \qquad (6)$$

CAUTION: THE VALUES OF A, B, AND $\delta$ ON THE NEW 1968 SCALE ARE DISTINCTLY DIFFERENT FROM THE CORRESPONDING VALUES ON THE OLD 1948 OR 1927 SCALE. THE VALUES OF $\alpha$ AND $R_o$ ARE ALSO DIFFERENT BUT ONLY TRIVIALLY SO.

LEEDS & NORTHRUP COMPANY Sumneytown Pike • North Wales, Pennsylvania 19454

## TEMPERATURE RANGE: -182.962° C TO 0° C (90.188K TO 273.15K)

Temperatures below 0° C on the new 1968 scale are calculated using a standard reference table which gives values of $R_t/R_o$ for a fictitious "mean" standard thermometer. This reference table and a specified deviation equation are combined to give the values for a particular thermometer. The standard reference table used for IPTS-68 is referred to as the "CCT-68" table. It is convenient to use the symbol $W_t$ in place of $R_t/R_o$. For the special reference values of $R_t/R_o$ tabulated in CCT-68 the designation $W_t$(CCT-68) is used. The table giving values of $W_t$ for a particular thermometer from 0° C down to -182.962° C (90.188K) may be calculated from the following expressions,

$$W_t = W_t(\text{CCT-68}) + \Delta W_t \qquad (7)$$

$$\Delta W_t = A_4 t + C_4 t^3 (t - 100) \qquad (8)$$

Expression (8) is the specified deviation equation in the range 0° C to -182.962° C. The constants $A_4$ and $C_4$ to be used in expression (8) for this particular thermometer are given on the first page.

## CALIBRATION TABLE

A table calculated from the constants for this thermometer is on the following pages. The first column of the table gives values of temperature. Unless a different function is requested, the second column gives $R_t/R_o$ (i.e. the ratio of the resistance at the stated temperature to the resistance at the ice point). The third column gives the inverse (reciprocal) of the difference between successive values in the second column. These reciprocal first differences are included to facilitate interpolation. The error introduced by using the linear interpolation will be less than 0.0001° C.

The resistance at the ice point should be determined with the bridge which is used with the thermometer.

This table was computed and printed by machine. Although it has been made with care, a complete check of every value actually printed has not been made.

6167-25-B PLATINUM RESISTANCE THERMOMETER 1835855 T.C. 1 M.A.
(IPTS - 68) OCTOBER 1975

| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| | | | -150.0 | 0.385453 | 235.20 |
| | | | -149.0 | 0.389702 | 235.37 |
| | | | -148.0 | 0.393947 | 235.54 |
| | | | -147.0 | 0.398190 | 235.71 |
| | | | -146.0 | 0.402429 | 235.88 |
| | | | -145.0 | 0.406666 | 236.04 |
| | | | -144.0 | 0.410899 | 236.21 |
| | | | -143.0 | 0.415130 | 236.37 |
| | | | -142.0 | 0.419358 | 236.53 |
| | | | -141.0 | 0.423582 | 236.69 |
| | | | -140.0 | 0.427804 | 236.85 |
| | | | -139.0 | 0.432024 | 237.01 |
| | | | -138.0 | 0.436240 | 237.17 |
| | | | -137.0 | 0.440454 | 237.32 |
| | | | -136.0 | 0.444665 | 237.48 |
| | | | -135.0 | 0.448873 | 237.63 |
| | | | -134.0 | 0.453079 | 237.78 |
| -183.0 | 0.243560 | | -133.0 | 0.457281 | 237.93 |
| -182.0 | 0.247399 | 230.45 | -132.0 | 0.461482 | 238.08 |
| -181.0 | 0.252238 | 230.51 | -131.0 | 0.465680 | 238.22 |
| -180.0 | 0.256574 | 230.59 | -130.0 | 0.469875 | 238.37 |
| -179.0 | 0.260909 | 230.68 | -129.0 | 0.474067 | 238.51 |
| -178.0 | 0.265242 | 230.78 | -128.0 | 0.478258 | 238.65 |
| -177.0 | 0.269573 | 230.89 | -127.0 | 0.482445 | 238.79 |
| -176.0 | 0.273903 | 231.00 | -126.0 | 0.486631 | 238.93 |
| -175.0 | 0.278229 | 231.12 | -125.0 | 0.490813 | 239.07 |
| -174.0 | 0.282553 | 231.25 | -124.0 | 0.494994 | 239.21 |
| -173.0 | 0.286875 | 231.39 | -123.0 | 0.499172 | 239.34 |
| -172.0 | 0.291194 | 231.53 | -122.0 | 0.503348 | 239.47 |
| -171.0 | 0.295511 | 231.68 | -121.0 | 0.507521 | 239.61 |
| -170.0 | 0.299824 | 231.82 | -120.0 | 0.511692 | 239.74 |
| -169.0 | 0.304135 | 231.98 | -119.0 | 0.515861 | 239.87 |
| -168.0 | 0.308443 | 232.14 | -118.0 | 0.520028 | 239.99 |
| -167.0 | 0.312748 | 232.30 | -117.0 | 0.524193 | 240.13 |
| -166.0 | 0.317050 | 232.46 | -116.0 | 0.528355 | 240.25 |
| -165.0 | 0.321348 | 232.63 | -115.0 | 0.532515 | 240.38 |
| -164.0 | 0.325644 | 232.79 | -114.0 | 0.536673 | 240.50 |
| -163.0 | 0.329937 | 232.96 | -113.0 | 0.540829 | 240.62 |
| -162.0 | 0.334226 | 233.13 | -112.0 | 0.544983 | 240.74 |
| -161.0 | 0.338512 | 233.30 | -111.0 | 0.549135 | 240.86 |
| -160.0 | 0.342795 | 233.47 | -110.0 | 0.553284 | 240.98 |
| -159.0 | 0.347075 | 233.65 | -109.0 | 0.557432 | 241.10 |
| -158.0 | 0.351352 | 233.82 | -108.0 | 0.561576 | 241.21 |
| -157.0 | 0.355626 | 233.99 | -107.0 | 0.565721 | 241.33 |
| -156.0 | 0.359896 | 234.17 | -106.0 | 0.569863 | 241.45 |
| -155.0 | 0.364164 | 234.34 | -105.0 | 0.574003 | 241.56 |
| -154.0 | 0.368428 | 234.51 | -104.0 | 0.578141 | 241.67 |
| -153.0 | 0.372689 | 234.69 | -103.0 | 0.582277 | 241.78 |
| -152.0 | 0.376946 | 234.86 | -102.0 | 0.586411 | 241.90 |
| -151.0 | 0.381201 | 235.03 | -101.0 | 0.590543 | 242.01 |

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| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| -100.0 | 0.594673 | 242.11 | -50.0 | 0.799083 | 246.82 |
| -99.0 | 0.598801 | 242.22 | -49.0 | 0.803133 | 246.90 |
| -98.0 | 0.602928 | 242.33 | -48.0 | 0.807182 | 246.99 |
| -97.0 | 0.607053 | 242.44 | -47.0 | 0.811229 | 247.07 |
| -96.0 | 0.611176 | 242.54 | -46.0 | 0.815275 | 247.15 |
| -95.0 | 0.615297 | 242.65 | -45.0 | 0.819320 | 247.23 |
| -94.0 | 0.619416 | 242.75 | -44.0 | 0.823364 | 247.32 |
| -93.0 | 0.623534 | 242.86 | -43.0 | 0.827406 | 247.40 |
| -92.0 | 0.627650 | 242.96 | -42.0 | 0.831446 | 247.48 |
| -91.0 | 0.631764 | 243.06 | -41.0 | 0.835486 | 247.56 |
| -90.0 | 0.635877 | 243.17 | -40.0 | 0.839524 | 247.65 |
| -89.0 | 0.639987 | 243.26 | -39.0 | 0.843560 | 247.73 |
| -88.0 | 0.644096 | 243.36 | -38.0 | 0.847596 | 247.80 |
| -87.0 | 0.648204 | 243.46 | -37.0 | 0.851630 | 247.89 |
| -86.0 | 0.652310 | 243.56 | -36.0 | 0.855663 | 247.96 |
| -85.0 | 0.656414 | 243.66 | -35.0 | 0.859694 | 248.05 |
| -84.0 | 0.660516 | 243.76 | -34.0 | 0.863724 | 248.13 |
| -83.0 | 0.664617 | 243.86 | -33.0 | 0.867753 | 248.21 |
| -82.0 | 0.668716 | 243.95 | -32.0 | 0.871781 | 248.29 |
| -81.0 | 0.672813 | 244.05 | -31.0 | 0.875807 | 248.37 |
| -80.0 | 0.676909 | 244.15 | -30.0 | 0.879832 | 248.45 |
| -79.0 | 0.681004 | 244.24 | -29.0 | 0.883856 | 248.53 |
| -78.0 | 0.685096 | 244.34 | -28.0 | 0.887878 | 248.60 |
| -77.0 | 0.689188 | 244.43 | -27.0 | 0.891899 | 248.68 |
| -76.0 | 0.693277 | 244.52 | -26.0 | 0.895919 | 248.76 |
| -75.0 | 0.697365 | 244.62 | -25.0 | 0.899938 | 248.84 |
| -74.0 | 0.701452 | 244.71 | -24.0 | 0.903955 | 248.92 |
| -73.0 | 0.705537 | 244.80 | -23.0 | 0.907971 | 249.00 |
| -72.0 | 0.709620 | 244.89 | -22.0 | 0.911986 | 249.07 |
| -71.0 | 0.713702 | 244.98 | -21.0 | 0.916000 | 249.15 |
| -70.0 | 0.717782 | 245.08 | -20.0 | 0.920012 | 249.23 |
| -69.0 | 0.721861 | 245.16 | -19.0 | 0.924023 | 249.30 |
| -68.0 | 0.725939 | 245.26 | -18.0 | 0.928033 | 249.38 |
| -67.0 | 0.730015 | 245.34 | -17.0 | 0.932042 | 249.49 |
| -66.0 | 0.734089 | 245.44 | -16.0 | 0.936049 | 249.54 |
| -65.0 | 0.738162 | 245.52 | -15.0 | 0.940055 | 249.62 |
| -64.0 | 0.742233 | 245.61 | -14.0 | 0.944060 | 249.69 |
| -63.0 | 0.746303 | 245.70 | -13.0 | 0.948064 | 249.78 |
| -62.0 | 0.750372 | 245.79 | -12.0 | 0.952066 | 249.84 |
| -61.0 | 0.754439 | 245.87 | -11.0 | 0.956067 | 249.93 |
| -60.0 | 0.758504 | 245.97 | -10.0 | 0.960067 | 250.00 |
| -59.0 | 0.762569 | 246.05 | -9.0 | 0.964066 | 250.08 |
| -58.0 | 0.766631 | 246.14 | -8.0 | 0.968064 | 250.15 |
| -57.0 | 0.770693 | 246.22 | -7.0 | 0.972060 | 250.23 |
| -56.0 | 0.774753 | 246.31 | -6.0 | 0.976055 | 250.31 |
| -55.0 | 0.778811 | 246.40 | -5.0 | 0.980049 | 250.38 |
| -54.0 | 0.782868 | 246.48 | -4.0 | 0.984041 | 250.46 |
| -53.0 | 0.786924 | 246.56 | -3.0 | 0.988033 | 250.54 |
| -52.0 | 0.790978 | 246.65 | -2.0 | 0.992023 | 250.62 |
| -51.0 | 0.795031 | 246.73 | -1.0 | 0.996012 | 250.69 |

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| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| 0.0 | 1.000000 | 250.75 | 50.0 | 1.197833 | 254.65 |
| 1.0 | 1.003987 | 250.85 | 51.0 | 1.201759 | 254.73 |
| 2.0 | 1.007972 | 250.92 | 52.0 | 1.205684 | 254.80 |
| 3.0 | 1.011956 | 251.00 | 53.0 | 1.209607 | 254.88 |
| 4.0 | 1.015939 | 251.08 | 54.0 | 1.213529 | 254.96 |
| 5.0 | 1.019920 | 251.15 | 55.0 | 1.217450 | 255.04 |
| 6.0 | 1.023901 | 251.23 | 56.0 | 1.221370 | 255.12 |
| 7.0 | 1.027880 | 251.31 | 57.0 | 1.225289 | 255.19 |
| 8.0 | 1.031858 | 251.39 | 58.0 | 1.229206 | 255.27 |
| 9.0 | 1.035834 | 251.46 | 59.0 | 1.233122 | 255.35 |
| 10.0 | 1.039810 | 251.54 | 60.0 | 1.237037 | 255.43 |
| 11.0 | 1.043784 | 251.62 | 61.0 | 1.240951 | 255.51 |
| 12.0 | 1.047757 | 251.70 | 62.0 | 1.244864 | 255.59 |
| 13.0 | 1.051729 | 251.77 | 63.0 | 1.248775 | 255.66 |
| 14.0 | 1.055700 | 251.85 | 64.0 | 1.252685 | 255.74 |
| 15.0 | 1.059669 | 251.93 | 65.0 | 1.256594 | 255.82 |
| 16.0 | 1.063637 | 252.01 | 66.0 | 1.260502 | 255.90 |
| 17.0 | 1.067604 | 252.08 | 67.0 | 1.264409 | 255.98 |
| 18.0 | 1.071570 | 252.16 | 68.0 | 1.268314 | 256.06 |
| 19.0 | 1.075535 | 252.24 | 69.0 | 1.272218 | 256.13 |
| 20.0 | 1.079498 | 252.31 | 70.0 | 1.276121 | 256.21 |
| 21.0 | 1.083460 | 252.39 | 71.0 | 1.280023 | 256.29 |
| 22.0 | 1.087421 | 252.47 | 72.0 | 1.283924 | 256.37 |
| 23.0 | 1.091380 | 252.55 | 73.0 | 1.287823 | 256.45 |
| 24.0 | 1.095339 | 252.62 | 74.0 | 1.291721 | 256.53 |
| 25.0 | 1.099296 | 252.70 | 75.0 | 1.295618 | 256.61 |
| 26.0 | 1.103252 | 252.78 | 76.0 | 1.299514 | 256.68 |
| 27.0 | 1.107207 | 252.86 | 77.0 | 1.303409 | 256.76 |
| 28.0 | 1.111161 | 252.93 | 78.0 | 1.307302 | 256.84 |
| 29.0 | 1.115113 | 253.01 | 79.0 | 1.311195 | 256.92 |
| 30.0 | 1.119064 | 253.09 | 80.0 | 1.315086 | 257.00 |
| 31.0 | 1.123014 | 253.17 | 81.0 | 1.318976 | 257.08 |
| 32.0 | 1.126963 | 253.25 | 82.0 | 1.322864 | 257.16 |
| 33.0 | 1.130910 | 253.32 | 83.0 | 1.326752 | 257.23 |
| 34.0 | 1.134857 | 253.40 | 84.0 | 1.330638 | 257.31 |
| 35.0 | 1.138802 | 253.48 | 85.0 | 1.334523 | 257.39 |
| 36.0 | 1.142746 | 253.56 | 86.0 | 1.338407 | 257.47 |
| 37.0 | 1.146688 | 253.63 | 87.0 | 1.342290 | 257.55 |
| 38.0 | 1.150630 | 253.71 | 88.0 | 1.346171 | 257.63 |
| 39.0 | 1.154570 | 253.79 | 89.0 | 1.350052 | 257.71 |
| 40.0 | 1.158509 | 253.87 | 90.0 | 1.353931 | 257.79 |
| 41.0 | 1.162447 | 253.95 | 91.0 | 1.357809 | 257.87 |
| 42.0 | 1.166384 | 254.02 | 92.0 | 1.361686 | 257.95 |
| 43.0 | 1.170319 | 254.10 | 93.0 | 1.365561 | 258.02 |
| 44.0 | 1.174253 | 254.18 | 94.0 | 1.369436 | 258.10 |
| 45.0 | 1.178186 | 254.26 | 95.0 | 1.373309 | 258.18 |
| 46.0 | 1.182118 | 254.33 | 96.0 | 1.377181 | 258.26 |
| 47.0 | 1.186049 | 254.41 | 97.0 | 1.381052 | 258.34 |
| 48.0 | 1.189978 | 254.49 | 98.0 | 1.384922 | 258.42 |
| 49.0 | 1.193906 | 254.57 | 99.0 | 1.388790 | 258.50 |

8167-25-R PLATINUM RESISTANCE THERMOMETER 1835855 T.C. 1 M.A.
(IPTS - 68) OCTOBER 1975

| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| 100.0 | 1.392657 | 258.58 | 150.0 | 1.584516 | 262.58 |
| 101.0 | 1.396523 | 258.66 | 151.0 | 1.588324 | 262.66 |
| 102.0 | 1.400388 | 258.74 | 152.0 | 1.592130 | 262.74 |
| 103.0 | 1.404252 | 258.82 | 153.0 | 1.595934 | 262.82 |
| 104.0 | 1.408115 | 258.90 | 154.0 | 1.599738 | 262.90 |
| 105.0 | 1.411976 | 258.98 | 155.0 | 1.603541 | 262.99 |
| 106.0 | 1.415836 | 259.05 | 156.0 | 1.607342 | 263.07 |
| 107.0 | 1.419695 | 259.13 | 157.0 | 1.611142 | 263.15 |
| 108.0 | 1.423553 | 259.21 | 158.0 | 1.614941 | 263.23 |
| 109.0 | 1.427410 | 259.29 | 159.0 | 1.618739 | 263.31 |
| 110.0 | 1.431265 | 259.37 | 160.0 | 1.622535 | 263.39 |
| 111.0 | 1.435119 | 259.45 | 161.0 | 1.626331 | 263.47 |
| 112.0 | 1.438972 | 259.53 | 162.0 | 1.630125 | 263.55 |
| 113.0 | 1.442824 | 259.61 | 163.0 | 1.633918 | 263.63 |
| 114.0 | 1.446675 | 259.69 | 164.0 | 1.637710 | 263.72 |
| 115.0 | 1.450525 | 259.77 | 165.0 | 1.641501 | 263.80 |
| 116.0 | 1.454373 | 259.85 | 166.0 | 1.645291 | 263.88 |
| 117.0 | 1.458220 | 259.93 | 167.0 | 1.649079 | 263.96 |
| 118.0 | 1.462066 | 260.01 | 168.0 | 1.652866 | 264.04 |
| 119.0 | 1.465911 | 260.09 | 169.0 | 1.656653 | 264.12 |
| 120.0 | 1.469755 | 260.17 | 170.0 | 1.660438 | 264.20 |
| 121.0 | 1.473597 | 260.25 | 171.0 | 1.664221 | 264.29 |
| 122.0 | 1.477438 | 260.33 | 172.0 | 1.668004 | 264.37 |
| 123.0 | 1.481278 | 260.41 | 173.0 | 1.671785 | 264.45 |
| 124.0 | 1.485117 | 260.49 | 174.0 | 1.675566 | 264.53 |
| 125.0 | 1.488955 | 260.57 | 175.0 | 1.679345 | 264.61 |
| 126.0 | 1.492792 | 260.65 | 176.0 | 1.683123 | 264.70 |
| 127.0 | 1.496627 | 260.73 | 177.0 | 1.686899 | 264.78 |
| 128.0 | 1.500461 | 260.81 | 178.0 | 1.690675 | 264.86 |
| 129.0 | 1.504294 | 260.89 | 179.0 | 1.694449 | 264.94 |
| 130.0 | 1.508126 | 260.97 | 180.0 | 1.698223 | 265.02 |
| 131.0 | 1.511957 | 261.05 | 181.0 | 1.701995 | 265.10 |
| 132.0 | 1.515786 | 261.13 | 182.0 | 1.705766 | 265.19 |
| 133.0 | 1.519615 | 261.21 | 183.0 | 1.709535 | 265.27 |
| 134.0 | 1.523442 | 261.29 | 184.0 | 1.713304 | 265.35 |
| 135.0 | 1.527268 | 261.37 | 185.0 | 1.717071 | 265.43 |
| 136.0 | 1.531093 | 261.45 | 186.0 | 1.720838 | 265.52 |
| 137.0 | 1.534916 | 261.53 | 187.0 | 1.724603 | 265.60 |
| 138.0 | 1.538739 | 261.61 | 188.0 | 1.728367 | 265.68 |
| 139.0 | 1.542560 | 261.69 | 189.0 | 1.732130 | 265.76 |
| 140.0 | 1.546380 | 261.77 | 190.0 | 1.735891 | 265.84 |
| 141.0 | 1.550199 | 261.85 | 191.0 | 1.739652 | 265.93 |
| 142.0 | 1.554017 | 261.93 | 192.0 | 1.743411 | 266.01 |
| 143.0 | 1.557833 | 262.02 | 193.0 | 1.747169 | 266.09 |
| 144.0 | 1.561649 | 262.10 | 194.0 | 1.750926 | 266.17 |
| 145.0 | 1.565463 | 262.18 | 195.0 | 1.754682 | 266.26 |
| 146.0 | 1.569276 | 262.26 | 196.0 | 1.758436 | 266.34 |
| 147.0 | 1.573088 | 262.34 | 197.0 | 1.762190 | 266.42 |
| 148.0 | 1.576899 | 262.42 | 198.0 | 1.765942 | 266.50 |
| 149.0 | 1.580708 | 262.50 | 199.0 | 1.769693 | 266.59 |

8167-25-B PLATINUM RESISTANCE THERMOMETER 1835855 T.C. 1 M.A.
(IPTS - 68) OCTOBER 1975

| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| 200.0 | 1.773443 | 266.67 | 250.0 | 1.959458 | 270.87 |
| 201.0 | 1.777192 | 266.75 | 251.0 | 1.963149 | 270.95 |
| 202.0 | 1.780939 | 266.84 | 252.0 | 1.966838 | 271.04 |
| 203.0 | 1.784686 | 266.92 | 253.0 | 1.970527 | 271.12 |
| 204.0 | 1.788431 | 267.00 | 254.0 | 1.974214 | 271.21 |
| 205.0 | 1.792175 | 267.08 | 255.0 | 1.977900 | 271.29 |
| 206.0 | 1.795918 | 267.17 | 256.0 | 1.981585 | 271.38 |
| 207.0 | 1.799660 | 267.25 | 257.0 | 1.985269 | 271.46 |
| 208.0 | 1.803401 | 267.33 | 258.0 | 1.988951 | 271.55 |
| 209.0 | 1.807140 | 267.42 | 259.0 | 1.992633 | 271.63 |
| 210.0 | 1.810878 | 267.50 | 260.0 | 1.996313 | 271.72 |
| 211.0 | 1.814616 | 267.58 | 261.0 | 1.999992 | 271.81 |
| 212.0 | 1.818352 | 267.67 | 262.0 | 2.003670 | 271.89 |
| 213.0 | 1.822086 | 267.75 | 263.0 | 2.007347 | 271.98 |
| 214.0 | 1.825820 | 267.83 | 264.0 | 2.011022 | 272.06 |
| 215.0 | 1.829553 | 267.92 | 265.0 | 2.014697 | 272.15 |
| 216.0 | 1.833284 | 268.00 | 266.0 | 2.018370 | 272.23 |
| 217.0 | 1.837014 | 268.08 | 267.0 | 2.022042 | 272.32 |
| 218.0 | 1.840743 | 268.17 | 268.0 | 2.025713 | 272.41 |
| 219.0 | 1.844471 | 268.25 | 269.0 | 2.029383 | 272.49 |
| 220.0 | 1.848198 | 268.33 | 270.0 | 2.033052 | 272.58 |
| 221.0 | 1.851923 | 268.42 | 271.0 | 2.036719 | 272.67 |
| 222.0 | 1.855648 | 268.50 | 272.0 | 2.040386 | 272.75 |
| 223.0 | 1.859371 | 268.59 | 273.0 | 2.044051 | 272.84 |
| 224.0 | 1.863093 | 268.67 | 274.0 | 2.047715 | 272.92 |
| 225.0 | 1.866814 | 268.75 | 275.0 | 2.051378 | 273.01 |
| 226.0 | 1.870533 | 268.84 | 276.0 | 2.055039 | 273.10 |
| 227.0 | 1.874252 | 268.92 | 277.0 | 2.058700 | 273.18 |
| 228.0 | 1.877969 | 269.01 | 278.0 | 2.062359 | 273.27 |
| 229.0 | 1.881686 | 269.09 | 279.0 | 2.066018 | 273.36 |
| 230.0 | 1.885401 | 269.17 | 280.0 | 2.069675 | 273.44 |
| 231.0 | 1.889115 | 269.26 | 281.0 | 2.073331 | 273.53 |
| 232.0 | 1.892827 | 269.34 | 282.0 | 2.076985 | 273.62 |
| 233.0 | 1.896539 | 269.43 | 283.0 | 2.080639 | 273.70 |
| 234.0 | 1.900249 | 269.51 | 284.0 | 2.084291 | 273.79 |
| 235.0 | 1.903959 | 269.60 | 285.0 | 2.087943 | 273.88 |
| 236.0 | 1.907667 | 269.68 | 286.0 | 2.091593 | 273.96 |
| 237.0 | 1.911374 | 269.76 | 287.0 | 2.095242 | 274.05 |
| 238.0 | 1.915079 | 269.85 | 288.0 | 2.098889 | 274.14 |
| 239.0 | 1.918784 | 269.93 | 289.0 | 2.102536 | 274.23 |
| 240.0 | 1.922487 | 270.02 | 290.0 | 2.106181 | 274.31 |
| 241.0 | 1.926190 | 270.10 | 291.0 | 2.109826 | 274.40 |
| 242.0 | 1.929891 | 270.19 | 292.0 | 2.113469 | 274.49 |
| 243.0 | 1.933591 | 270.27 | 293.0 | 2.117111 | 274.58 |
| 244.0 | 1.937290 | 270.36 | 294.0 | 2.120752 | 274.66 |
| 245.0 | 1.940987 | 270.44 | 295.0 | 2.124391 | 274.75 |
| 246.0 | 1.944684 | 270.53 | 296.0 | 2.128030 | 274.84 |
| 247.0 | 1.948379 | 270.61 | 297.0 | 2.131667 | 274.93 |
| 248.0 | 1.952073 | 270.70 | 298.0 | 2.135303 | 275.01 |
| 249.0 | 1.955766 | 270.78 | 299.0 | 2.138939 | 275.10 |

8167-25-B PLATINUM RESISTANCE THERMOMETER 1835855 T.C. 1 M.A.
(IPTS - 68) OCTOBER 1975

| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| 300.0 | 2.142572 | 275.19 | 350.0 | 2.322786 | 279.66 |
| 301.0 | 2.146205 | 275.28 | 351.0 | 2.326361 | 279.75 |
| 302.0 | 2.149837 | 275.36 | 352.0 | 2.329934 | 279.84 |
| 303.0 | 2.153467 | 275.45 | 353.0 | 2.333507 | 279.93 |
| 304.0 | 2.157096 | 275.54 | 354.0 | 2.337078 | 280.02 |
| 305.0 | 2.160724 | 275.63 | 355.0 | 2.340648 | 280.11 |
| 306.0 | 2.164351 | 275.72 | 356.0 | 2.344217 | 280.20 |
| 307.0 | 2.167977 | 275.80 | 357.0 | 2.347784 | 280.30 |
| 308.0 | 2.171602 | 275.89 | 358.0 | 2.351351 | 280.39 |
| 309.0 | 2.175225 | 275.98 | 359.0 | 2.354916 | 280.48 |
| 310.0 | 2.178847 | 276.07 | 360.0 | 2.358480 | 280.57 |
| 311.0 | 2.182468 | 276.16 | 361.0 | 2.362043 | 280.66 |
| 312.0 | 2.186088 | 276.25 | 362.0 | 2.365605 | 280.75 |
| 313.0 | 2.189707 | 276.34 | 363.0 | 2.369166 | 280.85 |
| 314.0 | 2.193325 | 276.42 | 364.0 | 2.372725 | 280.94 |
| 315.0 | 2.196941 | 276.51 | 365.0 | 2.376284 | 281.03 |
| 316.0 | 2.200557 | 276.60 | 366.0 | 2.379841 | 281.12 |
| 317.0 | 2.204171 | 276.69 | 367.0 | 2.383397 | 281.21 |
| 318.0 | 2.207784 | 276.78 | 368.0 | 2.386952 | 281.31 |
| 319.0 | 2.211396 | 276.87 | 369.0 | 2.390505 | 281.40 |
| 320.0 | 2.215006 | 276.96 | 370.0 | 2.394058 | 281.49 |
| 321.0 | 2.218616 | 277.05 | 371.0 | 2.397609 | 281.58 |
| 322.0 | 2.222224 | 277.14 | 372.0 | 2.401159 | 281.67 |
| 323.0 | 2.225831 | 277.22 | 373.0 | 2.404709 | 281.77 |
| 324.0 | 2.229437 | 277.31 | 374.0 | 2.408256 | 281.86 |
| 325.0 | 2.233042 | 277.40 | 375.0 | 2.411803 | 281.95 |
| 326.0 | 2.236646 | 277.49 | 376.0 | 2.415349 | 282.05 |
| 327.0 | 2.240248 | 277.58 | 377.0 | 2.418893 | 282.14 |
| 328.0 | 2.243850 | 277.67 | 378.0 | 2.422436 | 282.23 |
| 329.0 | 2.247450 | 277.76 | 379.0 | 2.425978 | 282.32 |
| 330.0 | 2.251049 | 277.85 | 380.0 | 2.429519 | 282.42 |
| 331.0 | 2.254647 | 277.94 | 381.0 | 2.433059 | 282.51 |
| 332.0 | 2.258244 | 278.03 | 382.0 | 2.436597 | 282.60 |
| 333.0 | 2.261839 | 278.12 | 383.0 | 2.440135 | 282.70 |
| 334.0 | 2.265434 | 278.21 | 384.0 | 2.443671 | 282.79 |
| 335.0 | 2.269027 | 278.30 | 385.0 | 2.447206 | 282.88 |
| 336.0 | 2.272619 | 278.39 | 386.0 | 2.450740 | 282.98 |
| 337.0 | 2.276210 | 278.48 | 387.0 | 2.454272 | 283.07 |
| 338.0 | 2.279800 | 278.57 | 388.0 | 2.457804 | 283.16 |
| 339.0 | 2.283388 | 278.66 | 389.0 | 2.461334 | 283.26 |
| 340.0 | 2.286976 | 278.75 | 390.0 | 2.464863 | 283.35 |
| 341.0 | 2.290562 | 278.84 | 391.0 | 2.468391 | 283.45 |
| 342.0 | 2.294147 | 278.93 | 392.0 | 2.471918 | 283.54 |
| 343.0 | 2.297731 | 279.02 | 393.0 | 2.475444 | 283.63 |
| 344.0 | 2.301314 | 279.11 | 394.0 | 2.478968 | 283.73 |
| 345.0 | 2.304895 | 279.20 | 395.0 | 2.482492 | 283.82 |
| 346.0 | 2.308476 | 279.29 | 396.0 | 2.486014 | 283.92 |
| 347.0 | 2.312055 | 279.38 | 397.0 | 2.489535 | 284.01 |
| 348.0 | 2.315633 | 279.48 | 398.0 | 2.493055 | 284.10 |
| 349.0 | 2.319210 | 279.57 | 399.0 | 2.496573 | 284.20 |

8167-25-R PLATINUM RESISTANCE THERMOMETER 1835855 T.C. 1 M.A.
(IPTS - 68) OCTOBER 1975

| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| 400.0 | 2.500091 | 284.29 | 450.0 | 2.674470 | 289.12 |
| 401.0 | 2.503607 | 284.39 | 451.0 | 2.677927 | 289.22 |
| 402.0 | 2.507122 | 284.48 | 452.0 | 2.681384 | 289.32 |
| 403.0 | 2.510636 | 284.58 | 453.0 | 2.684839 | 289.42 |
| 404.0 | 2.514149 | 284.67 | 454.0 | 2.688293 | 289.52 |
| 405.0 | 2.517661 | 284.77 | 455.0 | 2.691746 | 289.62 |
| 406.0 | 2.521171 | 284.86 | 456.0 | 2.695198 | 289.71 |
| 407.0 | 2.524681 | 284.96 | 457.0 | 2.698648 | 289.81 |
| 408.0 | 2.528189 | 285.05 | 458.0 | 2.702097 | 289.91 |
| 409.0 | 2.531696 | 285.15 | 459.0 | 2.705546 | 290.01 |
| 410.0 | 2.535201 | 285.24 | 460.0 | 2.708992 | 290.11 |
| 411.0 | 2.538706 | 285.34 | 461.0 | 2.712438 | 290.21 |
| 412.0 | 2.542210 | 285.43 | 462.0 | 2.715883 | 290.31 |
| 413.0 | 2.545712 | 285.53 | 463.0 | 2.719326 | 290.41 |
| 414.0 | 2.549213 | 285.63 | 464.0 | 2.722768 | 290.51 |
| 415.0 | 2.552713 | 285.72 | 465.0 | 2.726209 | 290.61 |
| 416.0 | 2.556212 | 285.82 | 466.0 | 2.729649 | 290.71 |
| 417.0 | 2.559709 | 285.91 | 467.0 | 2.733088 | 290.81 |
| 418.0 | 2.563206 | 286.01 | 468.0 | 2.736525 | 290.91 |
| 419.0 | 2.566701 | 286.10 | 469.0 | 2.739962 | 291.01 |
| 420.0 | 2.570195 | 286.20 | 470.0 | 2.743397 | 291.11 |
| 421.0 | 2.573688 | 286.30 | 471.0 | 2.746831 | 291.21 |
| 422.0 | 2.577179 | 286.39 | 472.0 | 2.750264 | 291.31 |
| 423.0 | 2.580670 | 286.49 | 473.0 | 2.753695 | 291.41 |
| 424.0 | 2.584159 | 286.59 | 474.0 | 2.757125 | 291.51 |
| 425.0 | 2.587647 | 286.68 | 475.0 | 2.760555 | 291.61 |
| 426.0 | 2.591135 | 286.78 | 476.0 | 2.763983 | 291.72 |
| 427.0 | 2.594620 | 286.88 | 477.0 | 2.767409 | 291.82 |
| 428.0 | 2.598105 | 286.97 | 478.0 | 2.770835 | 291.92 |
| 429.0 | 2.601588 | 287.07 | 479.0 | 2.774260 | 292.02 |
| 430.0 | 2.605071 | 287.17 | 480.0 | 2.777683 | 292.12 |
| 431.0 | 2.608552 | 287.26 | 481.0 | 2.781105 | 292.22 |
| 432.0 | 2.612032 | 287.36 | 482.0 | 2.784526 | 292.32 |
| 433.0 | 2.615511 | 287.46 | 483.0 | 2.787945 | 292.42 |
| 434.0 | 2.618988 | 287.55 | 484.0 | 2.791364 | 292.53 |
| 435.0 | 2.622465 | 287.65 | 485.0 | 2.794781 | 292.63 |
| 436.0 | 2.625940 | 287.75 | 486.0 | 2.798197 | 292.73 |
| 437.0 | 2.629414 | 287.85 | 487.0 | 2.801612 | 292.83 |
| 438.0 | 2.632887 | 287.94 | 488.0 | 2.805026 | 292.93 |
| 439.0 | 2.636359 | 288.04 | 489.0 | 2.808439 | 293.04 |
| 440.0 | 2.639829 | 288.14 | 490.0 | 2.811850 | 293.14 |
| 441.0 | 2.643299 | 288.24 | 491.0 | 2.815260 | 293.24 |
| 442.0 | 2.646767 | 288.33 | 492.0 | 2.818669 | 293.34 |
| 443.0 | 2.650234 | 288.43 | 493.0 | 2.822077 | 293.44 |
| 444.0 | 2.653700 | 288.53 | 494.0 | 2.825484 | 293.55 |
| 445.0 | 2.657164 | 288.63 | 495.0 | 2.828889 | 293.65 |
| 446.0 | 2.660628 | 288.73 | 496.0 | 2.832293 | 293.75 |
| 447.0 | 2.664090 | 288.83 | 497.0 | 2.835696 | 293.86 |
| 448.0 | 2.667551 | 288.92 | 498.0 | 2.839098 | 293.96 |
| 449.0 | 2.671011 | 289.02 | 499.0 | 2.842499 | 294.06 |

8167-25-B PLATINUM RESISTANCE THERMOMETER 1835855 T.C. 1 M.A.
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| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| 500.0 | 2.845898 | 294.16 | 550.0 | 3.014345 | 299.45 |
| 501.0 | 2.849297 | 294.27 | 551.0 | 3.017683 | 299.56 |
| 502.0 | 2.852694 | 294.37 | 552.0 | 3.021020 | 299.66 |
| 503.0 | 2.856089 | 294.47 | 553.0 | 3.024356 | 299.77 |
| 504.0 | 2.859484 | 294.58 | 554.0 | 3.027691 | 299.88 |
| 505.0 | 2.862878 | 294.68 | 555.0 | 3.031024 | 299.99 |
| 506.0 | 2.866270 | 294.79 | 556.0 | 3.034356 | 300.10 |
| 507.0 | 2.869661 | 294.89 | 557.0 | 3.037687 | 300.21 |
| 508.0 | 2.873051 | 294.99 | 558.0 | 3.041017 | 300.32 |
| 509.0 | 2.876440 | 295.10 | 559.0 | 3.044346 | 300.43 |
| 510.0 | 2.879827 | 295.20 | 560.0 | 3.047673 | 300.54 |
| 511.0 | 2.883214 | 295.31 | 561.0 | 3.050999 | 300.65 |
| 512.0 | 2.886599 | 295.41 | 562.0 | 3.054324 | 300.76 |
| 513.0 | 2.889983 | 295.51 | 563.0 | 3.057648 | 300.86 |
| 514.0 | 2.893365 | 295.62 | 564.0 | 3.060971 | 300.97 |
| 515.0 | 2.896747 | 295.72 | 565.0 | 3.064292 | 301.08 |
| 516.0 | 2.900127 | 295.83 | 566.0 | 3.067612 | 301.19 |
| 517.0 | 2.903506 | 295.93 | 567.0 | 3.070931 | 301.30 |
| 518.0 | 2.906884 | 296.04 | 568.0 | 3.074249 | 301.41 |
| 519.0 | 2.910261 | 296.14 | 569.0 | 3.077565 | 301.52 |
| 520.0 | 2.913637 | 296.25 | 570.0 | 3.080880 | 301.64 |
| 521.0 | 2.917011 | 296.35 | 571.0 | 3.084194 | 301.75 |
| 522.0 | 2.920384 | 296.46 | 572.0 | 3.087507 | 301.86 |
| 523.0 | 2.923756 | 296.56 | 573.0 | 3.090819 | 301.97 |
| 524.0 | 2.927127 | 296.67 | 574.0 | 3.094129 | 302.08 |
| 525.0 | 2.930496 | 296.77 | 575.0 | 3.097438 | 302.19 |
| 526.0 | 2.933865 | 296.88 | 576.0 | 3.100746 | 302.30 |
| 527.0 | 2.937232 | 296.99 | 577.0 | 3.104053 | 302.41 |
| 528.0 | 2.940598 | 297.09 | 578.0 | 3.107359 | 302.52 |
| 529.0 | 2.943963 | 297.20 | 579.0 | 3.110663 | 302.63 |
| 530.0 | 2.947326 | 297.30 | 580.0 | 3.113966 | 302.75 |
| 531.0 | 2.950689 | 297.41 | 581.0 | 3.117268 | 302.86 |
| 532.0 | 2.954050 | 297.52 | 582.0 | 3.120569 | 302.97 |
| 533.0 | 2.957410 | 297.62 | 583.0 | 3.123868 | 303.08 |
| 534.0 | 2.960769 | 297.73 | 584.0 | 3.127166 | 303.19 |
| 535.0 | 2.964126 | 297.84 | 585.0 | 3.130463 | 303.30 |
| 536.0 | 2.967482 | 297.94 | 586.0 | 3.133759 | 303.42 |
| 537.0 | 2.970838 | 298.05 | 587.0 | 3.137054 | 303.53 |
| 538.0 | 2.974191 | 298.16 | 588.0 | 3.140347 | 303.64 |
| 539.0 | 2.977544 | 298.26 | 589.0 | 3.143639 | 303.75 |
| 540.0 | 2.980896 | 298.37 | 590.0 | 3.146930 | 303.87 |
| 541.0 | 2.984246 | 298.48 | 591.0 | 3.150220 | 303.98 |
| 542.0 | 2.987595 | 298.59 | 592.0 | 3.153508 | 304.09 |
| 543.0 | 2.990943 | 298.69 | 593.0 | 3.156795 | 304.21 |
| 544.0 | 2.994290 | 298.80 | 594.0 | 3.160082 | 304.32 |
| 545.0 | 2.997635 | 298.91 | 595.0 | 3.163366 | 304.43 |
| 546.0 | 3.000980 | 299.02 | 596.0 | 3.166650 | 304.55 |
| 547.0 | 3.004323 | 299.12 | 597.0 | 3.169932 | 304.66 |
| 548.0 | 3.007665 | 299.23 | 598.0 | 3.173213 | 304.77 |
| 549.0 | 3.011005 | 299.34 | 599.0 | 3.176493 | 304.89 |

8167-25-H PLATINUM RESISTANCE THERMOMETER 1835855 T.C. 1 M.A.
(IPTS - 68) OCTOBER 1975

| TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. | TEMP. DEG. C | RESISTANCE RATIO | INVERSE DIFF. |
|---|---|---|---|---|---|
| 600.0 | 3.179772 | 305.00 | 650.0 | 3.342137 | 310.85 |
| 601.0 | 3.183049 | 305.11 | | | |
| 602.0 | 3.186326 | 305.23 | | | |
| 603.0 | 3.189601 | 305.34 | | | |
| 604.0 | 3.192874 | 305.46 | | | |
| 605.0 | 3.196147 | 305.57 | | | |
| 606.0 | 3.199418 | 305.69 | | | |
| 607.0 | 3.202688 | 305.80 | | | |
| 608.0 | 3.205957 | 305.92 | | | |
| 609.0 | 3.209225 | 306.03 | | | |
| 610.0 | 3.212491 | 306.15 | | | |
| 611.0 | 3.215757 | 306.26 | | | |
| 612.0 | 3.219021 | 306.38 | | | |
| 613.0 | 3.222283 | 306.49 | | | |
| 614.0 | 3.225545 | 306.61 | | | |
| 615.0 | 3.228805 | 306.72 | | | |
| 616.0 | 3.232064 | 306.84 | | | |
| 617.0 | 3.235322 | 306.95 | | | |
| 618.0 | 3.238579 | 307.07 | | | |
| 619.0 | 3.241834 | 307.19 | | | |
| 620.0 | 3.245088 | 307.30 | | | |
| 621.0 | 3.248341 | 307.42 | | | |
| 622.0 | 3.251593 | 307.54 | | | |
| 623.0 | 3.254843 | 307.65 | | | |
| 624.0 | 3.258092 | 307.77 | | | |
| 625.0 | 3.261340 | 307.89 | | | |
| 626.0 | 3.264587 | 308.00 | | | |
| 627.0 | 3.267832 | 308.12 | | | |
| 628.0 | 3.271077 | 308.24 | | | |
| 629.0 | 3.274320 | 308.35 | | | |
| 630.0 | 3.277561 | 308.47 | | | |
| 631.0 | 3.280802 | 308.59 | | | |
| 632.0 | 3.284041 | 308.71 | | | |
| 633.0 | 3.287279 | 308.83 | | | |
| 634.0 | 3.290516 | 308.94 | | | |
| 635.0 | 3.293752 | 309.06 | | | |
| 636.0 | 3.296986 | 309.18 | | | |
| 637.0 | 3.300219 | 309.30 | | | |
| 638.0 | 3.303451 | 309.42 | | | |
| 639.0 | 3.306682 | 309.54 | | | |
| 640.0 | 3.309911 | 309.65 | | | |
| 641.0 | 3.313139 | 309.77 | | | |
| 642.0 | 3.316366 | 309.89 | | | |
| 643.0 | 3.319592 | 310.01 | | | |
| 644.0 | 3.322816 | 310.13 | | | |
| 645.0 | 3.326039 | 310.25 | | | |
| 646.0 | 3.329261 | 310.37 | | | |
| 647.0 | 3.332482 | 310.49 | | | |
| 648.0 | 3.335702 | 310.61 | | | |
| 649.0 | 3.338920 | 310.73 | | | |

## CALIBRATION PROCEDURES

The procedure used to calibrate the platinum resistance thermometer to be used in the system, is outlined below. The preheater bath is incorporated as a multi-temperature bath used to set the value of the data points. Suggested temperatures for the calibration points are room temperature, $380^{\circ}$ F, and $700^{\circ}$ F.

1) Insert the calibrated thermometer, used as a standard, into the middle hole in the shield above the preheater bath.
2) Insert the thermometers to be calibrated in the surrounding holes to the same depth, and angle them in so that they are in contact with the calibrated thermometer.
3) Connect the leads of the calibrated thermometer to one Fluke meter and the leads of the thermometer to be calibrated to the other Fluke meter.
4) Set the bath temperature and read values for both thermometers once they stabilize. (During the calibration of the thermometers a cycling effect was noticed in the temperatures. The median value was used for the calibration purposes.)
5) Repeat step four for each thermometer at each temperature.

Table A1

Results of Calibration

Thermometer, Sample Oil Inlet

| | | | | | |
|---|---|---|---|---|---|
| Temperature | 62.3687 | 208.912 | 385.572 | 561.622 | 711.607 |
| Resistance | 106.702 | 137.953 | 174.602 | 210.210 | 239.240 |

ALPHA = .0038448

DELTA = 1.541015

RESISTANCE AT 32° F = 100.121838

Thermometer, Sample Oil Outlet

| | | | | | |
|---|---|---|---|---|---|
| Temperature | 62.3153 | 208.703 | 385.488 | 561.632 | 711.936 |
| Resistance | 106.559 | 137.674 | 174.287 | 210.675 | 239.015 |

ALPHA = .0038366

DELTA = 1.475683

RESISTANCE AT 32° F = 100.014847

Thermometer, Freon Outlet

| | | | | | |
|---|---|---|---|---|---|
| Temperature | 62.3865 | 208.556 | 385.817 | 561.690 | 711.7068 |
| Resistance | 106.673 | 137.755 | 174.612 | 209.945 | 239.220 |

ALPHA = .0038455

DELTA = 1.537737

RESISTANCE AT 32° F = 100.090153

## CALCULATION PROCEDURES

The values of alpha, delta, and resistance at zero degrees centigrade are calculated using the equations in the Leeds and Northrup Report of Calibration. A computer program using successive substitution proved to be adequate in solving the equations.

Once alpha, delta, and resistance at zero degrees centigrade was determined, the values were then used to determine the resistances at temperatures between 32 and 700° F at increments of 1° F.

## APPENDIX B

### Pressure Measurement Calibration

The certification report of the Heise gauge is included in this appendix as well as the calibration of the pressure transducers based on the Heise gauge readings.

A least-squares fit of the data was incorporated. The use of a linear equation for the transducers is assured because of the calibration certification received for both transducers. They show the pressure and the output to be directly proportional.

DRESSER INDUSTRIES

INDUSTRIAL VALVE & INSTRUMENT DIVISION ☐ NEWTOWN, CONNECTICUT 06470
HEISE PLANT ☐ TEL. 203/426-4406 ☐ TWX: 710-467-0617



# CERTIFICATION REPORT
## of
## HEISE GAUGE No. 69132

This gauge has been calibrated with a piston gauge which has been compared with master piston gauges whose effective areas were determined with an estimated accuracy of 3 parts in 100,000 by the National Bureau of Standards Identification No. P6744 and No. P6745. The weights for those dead weight piston gauges have also been certified by the Bureau of Standards to have an average accuracy of within one part in 35,000.

| READING NUMBER | DEAD WEIGHT OR Hg COL. READING | GAUGE READING (Deviation from Dead Wt. or Hg Col.) |
|---|---|---|
| 1 | 100 psig | — |
| 2 | 200 | — |
| 3 | 300 | — |
| 4 | 400 | — |
| 5 | 500 | — |
| 6 | 600 | — |
| 7 | 700 | — |
| 8 | 800 | — |
| 9 | 900 | — |
| 10 | 1000 | — |
| 11 | 1100 | — |
| 12 | 1200 | — |
| 13 | 1300 | — |
| 14 | 1400 | — |
| 15 | 1500 | — |
| 16 | 1600 | — |
| 17 | 1700 | — |
| 18 | 1800 | — |
| 19 | 1900 | — |
| 20 | 2000 psig | — |

**Room Temperature at Test** 70° F

**Maximum Hysteresis** 2.0 psig

**Remarks:** Corrections are indicated where error is 2.0 psig or more.

**Date Tested** May 27, 1976

**Signed** A. K. Amer

## CALIBRATION PROCEDURE

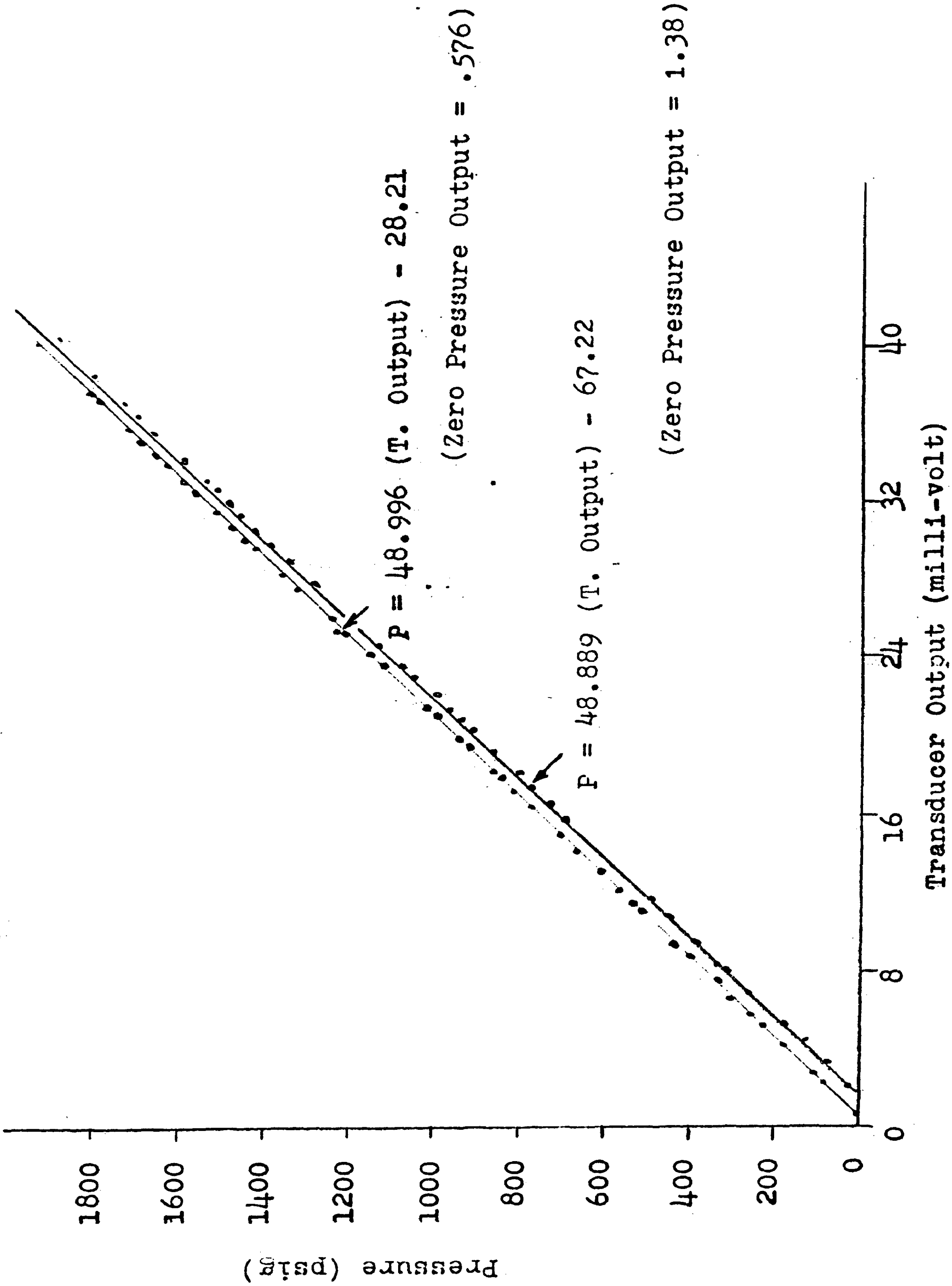
1) Adjust the back pressure regulator to a pressure of 2000 psig.
2) Start the main pump, keeping track of the pressure on the Heise gauge. When the pressure reaches 50 psig stop the main pump.
3) Pressurize the system using the bladder accumulator.
4) Adjust the pressure with the nitrogen regulator for the bladder accumulator to obtain the desired pressure for a data point.
5) Record the input and output to the transducer and the Heise gauge reading. (The input should be as close to 10.0 volts D.C. as possible.)
6) Repeat steps 4 and 5.

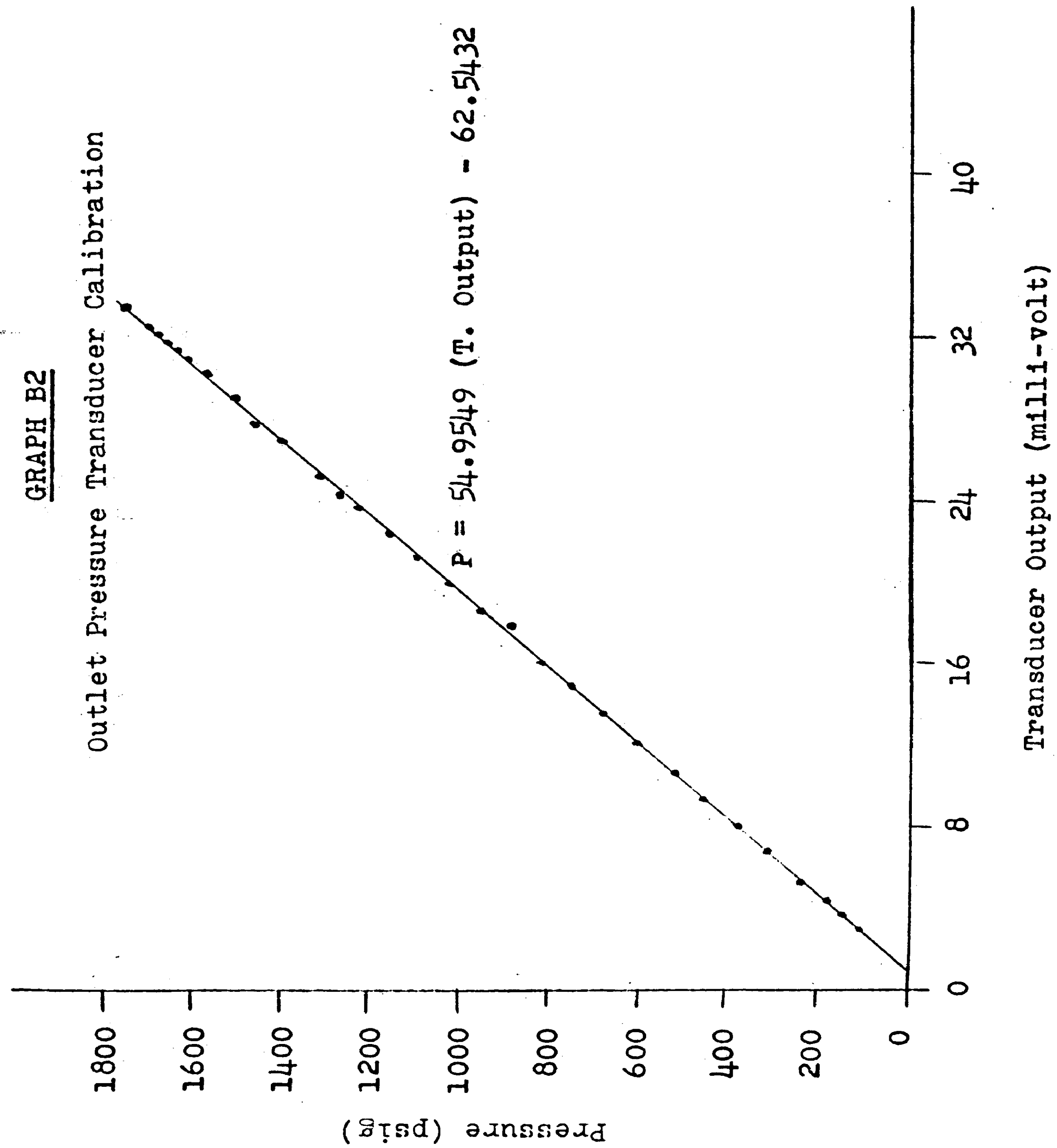
## CALIBRATION RESULTS

The results of the calibration are displayed in graphs B1 and B2. A point of interest is the dependence of the inlet transducer's reading on the water flow rate. A change in flow rate changes the zero pressure output from the transducer. This is shown in graph B1. The slope of the equation remains almost constant and the intercept should be adjusted to fit the zero value reading for the day.

GRAPH B1

Inlet Pressure Transducer Calibration






GRAPH B2

Outlet Pressure Transducer Calibration

## APPENDIX C

### Suppliers of Major Equipment

| | |
|---|---|
| Back-Pressure Regualtor (Grove) | Brock Easley Inc.<br>3700 Havana St., Suite 212<br>Denver, Colorado 80239 |
| Balance (Mettler) | VWR Scientific<br>3700 Havana<br>Denver, Colorado 80207 |
| Bladder Accumulator (Greer) | Warren Engineering<br>2301 S. Inca<br>Denver, Colorado 80223 |
| Calorimeter | Cryenco<br>Div. of Cryogenic Technology<br>4955 Bannock<br>Denver, Colorado |
| Condenser (American Standard) | Air Mac Manufacturing Co.<br>1158 South Jason Street<br>Denver, Colorado 80223 |
| Final Heater | Control Products Corporation<br>4431 W. Division Street<br>Chicago, Illinois 60651 |
| Final Heater Controller (Honeywell) | Honeywell Inc.<br>7825 East Prentice<br>Englewood, Colorado 80110 |
| Fittings (Swagelock) | Denver Valve and Fitting<br>P. O. Box 15636<br>970 Simms<br>Denver, Colorado 80215 |
| (Autoclave Engineers) | D. D. Frederick Company<br>115 W. 3rd Street<br>Tulsa, Oklahoma |
| Fluke Meter | Burnhill Three<br>1980 S. Quebec, Unit 4<br>Denver, Colorado 80231 |

| | |
|---|---|
| Freon Pump | Sargent Welch Scientific Co.<br>4040 Dahlia Street<br>Denver, Colorado 80207 |
| Glassware | R. H. Allen Company<br>Box 27<br>Boulder, Colorado 80302 |
| Heise Gauge | Heise Bourdon Tube Co., Inc.<br>Newtown, Ct. 06470 |
| Main Pump | Fluid Systems Inc.<br>1777 S. Bellaire<br>Denver, Colorado 80222 |
| Platinum Resistance Thermometer (Calibrated) | Leeds and Northrup<br>2715 S. Locust Street<br>Denver, Colorado 80222 |
| (Uncalibrated) | Omega Engineering<br>Box 4047 Springdale Station<br>Stamford, Ct. 06907 |
| Power Supply | Hewlett Packard<br>7965 East Prentice<br>Englewood, Colorado 80110 |
| Preheater | Techne Inc.<br>3700 Brunswick Pike<br>Princeton, N.J. 08540 |
| Pressure Transducers | Precise Sensors Inc.<br>235 W. Chestnut Ave.<br>Monrovia., Ca. 91016 |
| Refrigeration Unit | Cecil Boling Co.<br>1050 Yuma Street<br>Denver, Colorado 80204 |
| Surge Tank | Ross Equipment Co.<br>2149 S. Clermont<br>Denver, Colorado 80222 |
| Timer | Sargent Welch Scientific Co.<br>4040 Dahlia Street<br>Denver, Colorado 80207 |

| | |
|---|---|
| Vacuum System | Remanufactured Vacuum Products<br>7250 W. 38th Ave.<br>Wheatridge, Colorado 80033 |
| Variacs | VWR Scientific<br>3700 Havana<br>Denver, Colorado 80207 |

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