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THERMAL CONDUCTIVITY OF POTASSIUM VAPOR

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ABSTRACT

The purpose of this investigation was to design, construct and operate a high temperature cell for measuring the thermal conductivity of potassium vapor within the temperature range of 900-1400°F.

A thorough review of all the techniques used to measure thermal conductivity of gases and vapors was made with particular attention to those methods suitable for high temperatures and corrosive vapors. A parallel plate cell with guard heated top plate was selected. Heat generated in the 2.01 inch diameter top plate by the top plate heater was transferred across a 0.0182 inch vapor space to the bottom plate. Molybdenum was selected for the cell material because of its corrosion resistance to potassium, low emissivity and high thermal conductivity.

The thermal conductivity of nitrogen was measured with the cell to serve as a check on the cell and analysis procedure. The thermal conductivity of nitrogen thus measured for a temperature range of 900 to 1200°F. was in excellent agreement (within 1 percent) with existing data.

Thermal conductivity data for superheated potassium vapor were taken at temperatures of 1000, 1100 and 1200°F. and a range of pressures of 0.01 to 0.075 atmospheres. The pressure of the potassium vapor in the cell was kept below the saturation pressure by maintaining liquid potassium in a boiler connected to the thermal conductivity cell at a temperature 100 to 400°F. below the cell temperature. As predicted by theory the data show that pressure has a significant effect on the thermal conductivity. Combining theory with experimental results, the increase in thermal conductivity over that for an equivalent non-reacting system at 1100°F. was found to be 7 and 42 percent, for pressures of 0.01 and 0.075 atmospheres, respectively. The increase is caused by the heat of reaction associated with shifts in the equilibrium composition with changes in temperature and pressure. Potassium exists in the vapor as a monomer, dimer and tetramer. The thermal conductivity of potassium for an equivalent non-reacting system at 1100°F. was calculated to be 0.0074 Btu/hr.-ft.-°F. as compared to measured values of 0.0079, 0.0088, and 0.0105 Btu/hr.-ft-°F. at pressures of 0.01, 0.03, and 0.075 atmospheres, respectively. Kinetic theory was used as a basis for placing correlating curves through the data. The mean values of the thermal conductivity of potassium are estimated to be accurate to within ± 10 percent. These results agree closely with a limited amount of data taken with a different type cell reported in the literature.

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NOMENCLATURE

A	Heat transfer area, sq. ft.
a	Cell constant in Eq. 44.
a	Distance from center of hot wire cell in Eq. 42, ft.
B.	Correction for Wheatstone bridge unbalance in Eq. 44, millivolts.
c_p	Heat capacity at constant pressure, Btu/lb.-°F.
c_r	Heat capacity for rotation, Btu/lb.
c_t	Heat capacity for translation, Btu/lb.
c_v	Heat capacity at constant volume, Btu/lb.-°F.
C_v	Heat capacity at constant volume, Btu/lb.mole-°F.
d	Distance between top and bottom plates in Eq. 76, ft.
D	Diameter, ft.
D	Diffusion coefficient, sq. cm./sec. or sq.ft./hr.
D	Thickness of top plate in Eq. 76, ft.
f	Eucken factor.
F_a	Radiation configuration factor.
F_e	Factor to account for the departure of the two surfaces from complete blackness.
g	Temperature jump distance, ft.
h	Convective heat transfer coefficient, Btu/hr.-sq.ft.-°F.
i	Current, amperes.
k	Boltzman's constant.

k	Equilibrium constant, atm.$^{-1}$ or atm.$^{-3}$.
k	Thermal conductivity, Btu/hr.-ft.-°F.
K_1	Potassium monomer
K_2	Potassium dimer
K_4	Potassium tetramer
k_c	Actual thermal conductivity, Btu/hr.-ft.-°F.
k_{corr}	Thermal conductivity corrected to constant boiler temperature, Btu/hr.-ft.-°F.
k_f	Frozen thermal conductivity, Btu/hr.-ft.-°F.
k_r	Contribution to thermal conductivity due to chemical reaction, Btu/hr.-ft.-°F.
k_{rad}	Contribution of radiation to total thermal conductivity, k_t, Btu/hr.-ft.-°F.
k_{ref}	Thermal conductivity of reference gas, Btu/hr.-ft.-°F.
k_t	Total thermal conductivity including radiation, Btu/hr.-ft.-°F.
ℓ	Length, ft.
ℓ	Mean free path of molecules, cm.
M	Molecular weight.
n	Number of molecules in chemical balance.
Nu	Nusselt number.
P	Pressure, atmospheres.
Pr	Prandtl number.
Q	Heat duty, Btu/hr.

Q_c	Heat duty for conduction, Btu/hr.
Q_{rad}	Heat duty for radiation, Btu/hr.
Q_t	Total heat duty, Btu/hr.
r	Molecular separation distance in Eq. 12, A°.
r_1	Radius of hot wire, ft.
r_2	Radius of cell container, ft.
r_g	Inside radius of guard plate cover in Eq. 76, ft.
r_u	Radius of top plate in Eq. 76, ft.
R	Gas constant, appropriate units.
T	Absolute temperature, °R.
t_1	Inlet temperature of vapor to heat exchanger, °F.
t_2	Outlet temperature of vapor from heat exchanger, °F.
T_1	Absolute temperature of the hotter surface, °R.
T_2	Absolute temperature at the colder surface, °R.
T_b	Absolute temperature at normal boiling point, °K.
T_m	Absolute temperature of the molecules after collision
T_o	Absolute temperature of the molecules before collision in Eq. 21, °R.
t_r	Recovery temperature which flat plate assumes in high velocity flow when it exchanges heat with fluid, °F.
T_s	Absolute temperature of the surface in Eq. 21, °R.

t_s	Static temperature of vapor in Eq. 48, °F.
t_t	Total temperature in the vapor at a sufficient distance from plate in Eq. 48, °F.
t_w	Tube wall temperature of heat exchanger, °F.
v	Mean molecular speed, cm./sec. or ft./sec.
V_b	Molecular volume of liquid at normal boiling point, cu.cm./g. mole
W	Flow rate, lbs./hr.
x	Mole fraction.
X_s	Plate spacing, ft.
X_t	Output from Wheatstone bridge, millivolts.
α	Accomodation coefficient in Eq. 22.
α	Thermal diffusivity, $k/\rho c_p$.
γ	Ratio of heat capacity at constant pressure to heat capacity at constant volume.
γ_o	Ratio of heat capacity at constant pressure to heat capacity at constant volume for ideal gas.
ΔH	Heat of reaction, Btu/lb. mole.
ΔH_2°	Standard heat of reaction for monomer to dimer, Btu/lb. mole dimer.
ΔH_4°	Standard heat of reaction for monomer to tetramer, Btu/lb. mole tetramer.
Δt	Temperature difference, °F.

Δt_{ref}	Temperature difference for reference gas, °F.
ε	Lennard-Jones force constant.
ε	Radiation emissivity.
θ	Temperature rise of vapor from initial condition in Eq. 50, °F.
μ	Viscosity, poises or lb./ft.hr.
ρ	Density g./cu.cm. or lb./cu.ft.
σ	Lennard-Jones force constant, A°.
τ	Time from initial condition, hr.
ϕ	Potential energy of interaction between two molecules.
Ω_D	Lennard-Jones collision integral for diffusion.
Ω_V	Lennard-Jones collision integral for viscosity.
ω	Frequency for a periodic temperature variation in Eq. 58.

CHAPTER I

INTRODUCTION

The use of alkali metals in nuclear power generation systems has been of considerable interest in recent years both in conventional nuclear power plants and in magnetohydrodynamics (MHD) power generation (86) for space craft. During this time, several experimental and design studies of Rankine cycle space power generation systems have been initiated with potassium as the working fluid. These studies include the SPUR-SNAP (79) program and the General Electric (12,36) boiling and condensing investigations. In all such investigations accurate transport property data are necessary for complete experimental and theoretical analysis. The thermal conductivity of the vapor is such a property.

Heat transfer data for boiling, condensation and forced convection of alkali metals have been taken by an increasing number of investigators since 1955 when Lyon (71) completed an extensive study of boiling of liquid metals which included sodium and a mixture of sodium and potassium. The General Electric Company (36) measured boiling heat transfer coefficients for potassium in forced convection in 1964 and Padilla (78) measured film boiling heat transfer coefficients for potassium in 1966.

Theoretical film boiling heat transfer correlations have been formulated by Bromley (11), Chang (20), and Berenson (6). In order to evaluate the validity and soundness of these theoretical models in comparison with experimental data, it is necessary to know the physical properties of the vapor and liquid. In each correlation, the thermal conductivity of the vapor is an important variable. The thermal conductivity of the vapor is important also in forced convection heat transfer and in two phase forced convection heat transfer where an alkali metal vapor is the working fluid.

Experimental measurements of thermal conductivity, viscosity and heat capacity are important thermodynamic properties because of the important relationships between the three variables. An independent evaluation of the experimental data would be possible based on thermodynamic considerations.

The objective of this work was to measure the thermal conductivity of potassium vapor in the range of 900 to 1400°F. at pressures below the saturation pressure using a parallel plate thermal conductivity cell.

CHAPTER II

LITERATURE REVIEW

A. Introduction

Heat conduction in gases is a diffusion process in which gases moving from a warmer position to a colder position and vice-versa exchange kinetic energy as a result of molecular collisions. Although the gas molecules may be identical, they will have different average velocities because of temperature differences.

The basic law of heat conduction is

$$Q = k \frac{A}{X_s} \Delta t \tag{1}$$

The law originated with Biot (7) but is generally called Fourier's equation and it was used as a fundamental equation in Fourier's analytic theory of heat (35). In differential form, for one dimension heat conduction, Fourier's equation is

$$Q = -k\ A \frac{dt}{dx} \tag{2}$$

The thermal conductivity of gases can be determined experimentally from Equation 1 by measuring the heat flux and the temperature gradient. It can be determined also from simple kinetic theory in which thermal conductivity is related to the viscosity and to the constant volume heat capacity of the vapor. Modern kinetic theory has been used to extend the theoretical efforts to include the calculation of thermal conductivity (or viscosity) based on a mathematical model for the intermolecular forces.

Experimental measurements of the thermal conductivity of gases and vapors which associate or dissociate with changes in temperature are often considerably higher than the values of an equivalent non-reacting mixture of the species. This apparent increase in thermal conductivity is due to the heat of reaction associated with changes in the equilibrium composition with temperature as the molecules move through the temperature gradient. Potassium in its vapor state exists as a monomer, dimer and tetramer in equilibrium and would be expected to have a higher effective thermal conductivity than for a non-reacting condition.

B. Theory of Thermal Conductivity

Simple Kinetic Theory The theory of conduction of heat by molecular self diffusion was developed by Maxwell (73) and Boltzman (9). For monatomic molecules which possess only the kinetic (translation) energy corresponding to their velocity, the thermal conductivity was estimated to be

$$k = 1/3\ \rho v \ell c_v \tag{3}$$

Since the simple kinetic theory of gases predicts that the viscosity of the gas for a constant velocity is

$$\mu = 1/3\ \rho v \ell \tag{4}$$

The predicted thermal conductivity of a gas from simple kinetic theory is

$$k = \mu c_v \tag{5}$$

Equation 5 predicts values of thermal conductivity which are generally low.

Chapman (21) made calculations in 1912 which showed that for monatomic, spherical molecules with any central forces between them, Equation 5 was low by a factor of 2.5. This value was predicted independently by Enskog (30) in 1917 for a repulsive potential energy between molecules of the form

$$E(r) = \alpha \varepsilon (\sigma/r)^n \tag{6}$$

where α and n are constants, n being the steepness of the repulsive wall. Variations in n from five to infinity change the factor by less than 1 percent. Therefore, if the kinetic theory is correct, thermal conductivities for monatomic gases should be closely related by

$$k = 2.5 \mu c_v \tag{7}$$

Equation 7 is most often written as

$$k = f \mu c_v \tag{8}$$

and the numerical factor f called the Eucken factor. A review of thermal conductivity data by Liley (69) showed that k varies from

2.40 to 2.60 for monatomic gases over a range of temperatures from 200 to 2700°R.

Eucken Factor Eucken (31) originally proposed a magnifying factor for Equation 5 to account for the fact that an average molecular velocity as used in simple kinetic theory will predict low values of thermal conductivity. Molecules with greater energy transport their energy faster than molecules with less energy because the energy level is proportional to $c_v T$ and T is proportional to the velocity squared (61).

Eucken (31) further proposed that the thermal conductivity of diatomic gases could be estimated by accounting for rotation as well as translation. He split the specific heat into two components, c_r and c_t for translation which led to

$$k = \left(\frac{2.5\ c_t}{c_v} + \frac{c_r}{c_v} \right) \mu\ c_v \tag{9}$$

for diatomic molecules with negligible energy of oscillation. Since there is no correlation between the velocity of the molecule and internal rotation, the contribution of rotation can be expressed in the form of Equation 9 rather than Equation 7 which is appropriate for the translational contribution. Equation 9 has been simplified to (see Reference 82)

$$k = \frac{9\gamma - 5}{4}\ c_v \tag{10}$$

or

$$k = \frac{9-5/\gamma}{4} c_p \tag{11}$$

The value of the Eucken factor for diatomic gases is less than 2.5. Liley (69) reported values of 1.8 to 2.3 for temperatures from 130°R to 2100°R.

Several authors (40,48,54) have presented variations of the Eucken factor given in Equation 9 for polyatomic gases and vapors. The values of the thermal conductivity of diatomic molecules predicted by their equations are generally more accurate at temperatures above 100°F. For linear non-polar molecules such as nitrogen and oxygen the predicted values are within 6 percent of experimental results. This presupposes that accurate values of the viscosity and heat capacity are available. If both viscosity and heat capacity values are predicted from theory, the thermal conductivity estimates could be in error by amounts greater than 6 percent.

Modern Kinetic Theory Modern kinetic theory, or as often called, the Chapman-Enskog theory, is based upon the number, time, velocity distribution of molecules in space and their interaction with each other. It is rigorous only for dilute monatomic gases. The theory does provide however tremendous insight in predicting transport properties of gases that can be considered dense.

In the theory one of the more common models for describing the intermolecular interaction of non-polar molecules is the Lennard-Jones (6-12) potential. In this model the intermolecular potential energy function is given by

$$\phi(r) = 4\varepsilon \left[(\sigma/r)^{12} - (\sigma/r)^{6} \right] \tag{12}$$

where the parameters σ and ε have dimensions of length and energy respectively, ε being the depth of the potential well and σ being the collision diameter for low energy collisions. The parameters σ and ε are constants characteristic of the chemical species of the colliding molecules.

From modern kinetic theory the thermal conductivity of a pure monatomic gas is given in first approximation by (56)

$$k = 1.9891 \times 10^{-4} \frac{(T/M)^{1/2}}{\sigma^2 \Omega_v} \tag{13}$$

where in Equation 13

k = thermal conductivity in cal/cm sec°k

M = molecular weight

T = temperature in °K

σ = collision diameter in A°

Ω_v = collision integral

when compared to the modern kinetic theory of viscosity of pure monatomic gases. Equation 13 leads to

$$k = \frac{15}{4} \frac{R}{M} \mu \tag{14}$$

where

μ = viscosity in poises.

Since C_v is 3/2Rfor monatomic gases, Equation 14 simplifies to

$$k = 2.50\ \mu c_v \tag{7}$$

which was developed in the simple kinetic theory.

Although the Chapman-Enskog kinetic theory strickly speaking, does not apply to polyatomic gas molecules because of the internal degrees of freedom, it may be applied quite successfully to such molecules when they are reasonably spherical. This is true because the viscosity and the diffusion of simple polyatomic molecules are not appreciably affected by the presence of internal degrees of freedom. Therefore, the thermal conductivity of diatomic gas molecules can be approximately from Equation 13 if multiplied by the Eucken factor. Thus for diatomic gas molecules

$$k = 1.9891 \times 10^{-4}\left[\frac{4}{15}\frac{C_v}{R} + \frac{3}{5}\right]\frac{(T/M)^{1/2}}{\sigma^2\Omega_v} \tag{15}$$

The Eucken factor in Equation 15 varies between 1.2 and 1.5 for a considerable range of gases (56).

Estimation of the thermal conductivity of monatomic and diatomic gases from Equations 13 and 15, respectively require values for the collision diameter σ and the molecular collision integral Ω_v. Values of Ω_v depend upon the intermolecular potential energy function. Values of Ω_v are tabulated as a function of kT/ε for the Lennard-Jones potential function where k in this instance is Boltzman's constant. Therefore, the fundamental parameters necessary to estimate thermal conductivity are the collision diameter σ and the depth of the potential well ε.

Hirschfelder, Curtiss, and Bird (56) give methods of determining the Lennard-Jones parameters from experimental viscosity data or experimental vapor pressure data. They recommend that the parameters obtained from viscosity data should be used for making transport property calculations and that parameters obtained from experimental second virial coefficients be used for calculation of thermodynamic properties. A third method for estimating the parameters was developed empirically by Wilke and Lee (104) in which the force constants are estimated by the expressions

$$\sigma = 1.18\, V_b^{1/3} \tag{16}$$

and

$$\frac{\varepsilon}{k} = 1.21\, T_b \tag{17}$$

where T_b and V_b are the normal boiling point and the molecular volume at the normal boiling point, respectively.

Modern kinetic theory also permits the estimation of the diffusion coefficient of a binary mixture using the constants σ and ε for the Lennard-Jones potential. Hirschfelder, Curtiss and Bird (56) give for the diffusion coefficient of a binary mixture in first approximation

$$D_{12} = \frac{0.001858\ T^{3/2}\left[\left(M_1+M_2\right)/M_1M_2\right]^{1/2}}{P\ \sigma_{12}^{2}\ \Omega_D} \tag{18}$$

where, D_{12} = binary diffusion coefficient cm^2/sec

σ_{12} = arithmetic mean of σ_1 and σ_2

Ω_D = collision integral comparable to Ω_v

The procedure requires a knowledge of the force constants for both components. The collision integral Ω_D is tabulated for the Lennard-Jones potential as a function of kT/ε_{12}. In the case of diffusion

$$\sigma_{12} = 1/2\ (\sigma_1 + \sigma_2) \tag{19}$$

and

$$\varepsilon_{12} = \sqrt{\varepsilon_1\ \varepsilon_2} \tag{20}$$

Accomodation Coefficient When gas or vapor molecules collide with a solid surface they do not always come to the surface temperature before they rebound. The degree to which molecules approach the surface temperature upon collision is given by the thermal accomodation coefficient defined as

$$\alpha = \frac{T_m - T_o}{T_s - T_o} \tag{21}$$

Where T_o and T_m are the temperatures of the molecules before and after collision, respectively and T_s is the surface temperature. The magnitude of the accomodation coefficient is a function of the molecule, surface material, and temperature. A complete review of the subject is given by Vines (99).

Although kinetic theory asserts that the thermal conductivity of a perfect gas is independent of pressure, all conventional thermal conductivity cells exhibit a decrease in thermal conductivity with decreases in pressure at very low pressures. This phenomenia results from the temperature discontinuity which exists at the surface of the cell. When the pressure is such that the mean free path of the molecules is of the same order of magnitude as the distance between which temperatures are being measured, the effect becomes very pronounced. The effect of thermal accomodation upon thermal conductivity is most noticeable at pressures below 0.01 atmospheres. At pressures above 0.01 atmospheres the effect is rather small and becomes even more so as the pressure is increased.

Accomodation coefficients are generally obtained from the slope of a plot of the reciprocal of the thermal conductivity versus the reciprocal of the pressure for low pressure thermal conductivity data.

Kennard (63) gives the following expression for the temperature jump distance:

$$g = \left(\frac{2-\alpha}{\alpha}\right)\left[\frac{(2\pi MRT)^{1/2}k}{(\gamma_o+1)C_vP}\right] \tag{22}$$

C. Thermal Conductivity of Gas Mixtures in Chemical Equilibrium

Many gases such as nitrogen dioxide and hydrogen fluoride undergo association-dissociation reactions over a range of temperatures. Alkali metal vapor also exhibit this phenomenia. Such reactions are

$$2NO_2 \rightleftarrows N_2O_4 \tag{23}$$

$$2K \rightleftarrows K_2 \tag{24}$$

$$4K \rightleftarrows K_4 \tag{25}$$

Since the equilibrium gas compositions for Equations 23 to 25 vary with temperature, concentration gradients will always exist whenever a temperature gradient is imposed between two surfaces. Diffusion of the molecules from an equilibrium condition to a different temperature region results in a further shift in the concentration to satisfy the equilibrium conditions at the new temperature. Changes in composition will result in a release or absorption of energy. In a gas such as potassium vapor which absorbs heat by dissociating as the gas temperature is increased, heat is transferred to the reacting molecules as the molecules dissociate in the high temperature region. The molecules then diffuse toward the low temperature region since there is a lower concentration of dissociated molecules at the lower temperature. In the low temperature region the gas molecules reassociate releasing the heat absorbed from the high temperature dissociation. This phenomenon was first recognized by Nernst (77) who attributed the exceptionally high thermal conductivity of nitrogen dioxide to this effect.

In mixtures of gases in chemical equilibrium the effective thermal conductivity (conductivity determined by physical measurement) may be considerably higher than for the "frozen" thermal conductivity of non-reacting mixtures. The "frozen" thermal conductivity is the conductivity one would expect to exist if no chemical reactions took place. The "frozen" thermal conductivity may be predicted from theory to the extent that theory applies to each specie and to the mixture. The effective thermal conductivity is given by

$$k_c = k_f + k_r \tag{26}$$

For the NO_2 - N_2O_4 equilibrium at 125°F., the effective thermal conductivity (24) has been found to be 10 times greater than the "frozen" thermal conductivity, that is,

$$\frac{k_c}{k_f} = 10 \tag{27}$$

Several investigators have considered the effective thermal conductivity of gases undergoing simple dissociations. Dirac (28) and Hirschfelder (56) both developed the theory for systems of reacting gases with finite chemical reaction rates. Hirschfelder concluded that the assumption of local chemical equilibrium is good when the activation-energy for reaction in one direction is small. In a later work, Hirschfelder (57) developed also the theory for heat transfer in chemically reacting gases in which local equilibrium is assumed, i.e., very high chemical reaction rates. For such conditions the theory is based upon the total heat flux vector which includes the effect of the bulk transport of energy due to the diffusion of molecules.

Meixner (74), Hasse (52), and Prigogine (101) and his associates considered problems of heat transfer in a chemically reacting mixture from the standpoint of thermodynamics of irreversible processes. Their method leads to the same relationship as is obtained from assuming the local composition is in equilibrium with the local temperature.

For single reactions of the dissociation type $A \rightleftarrows nB$, all the methods result in expressions which are equivalent to

$$k_r = D_{AB} \frac{P}{RT} \frac{\Delta H^2}{RT^2} \frac{x_A x_B}{(nx_A+x_B)^2} \tag{28}$$

Butler and Brokaw (14) extended the work of Hirschfelder to include gas mixtures involving any number of reactants, inert diluents and chemical equilibria. For three reacting components such as exist in the potassium vapor, the results of Butler and Brokaw reduce to

$$k_r = -\frac{1}{RT^2}\,\frac{\begin{vmatrix} 0 & \Delta H_2 & \Delta H_4 \\ \Delta H_2 & A_{11} & A_{12} \\ \Delta H_4 & A_{21} & A_{22} \end{vmatrix}}{\begin{vmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{vmatrix}} \tag{29}$$

where for the reactions

$$K_2 \rightleftarrows 2K_1 \tag{30}$$

and

$$K_4 \rightleftarrows K_1 \tag{31}$$

$$A_{11} = 16\,\frac{RT}{D_{14}P}\,\frac{x_4}{x_1} + \frac{RT}{D_{24}P}\,\frac{x_4}{x_2} + \frac{RT}{D_{12}P}\,\frac{\left(x_1+2x_2\right)^2}{x_1\,x_2} \tag{32}$$

$$A_{22} = 2\,\frac{RT}{D_{12}P}\,\frac{x_2}{x_1} + \frac{RT}{D_{24}P}\,\frac{x_2}{x_4} + \frac{RT}{D_{14}}\,\frac{\left(x_1+4x_4\right)^2}{x_1\,x_4} \tag{33}$$

and

$$A_{12} = A_{21} = 8\,\frac{RT}{D_{12}P}\,\frac{x_2}{x_1} + \frac{8RT}{D_{14}P}\,\frac{x_4}{x_1} + 4\,\frac{RT}{D_{12}P} + 2\,\frac{RT}{D_{14}P} - \frac{RT}{D_{24}P} \tag{34}$$

D. Experimental Methods

Experimental techniques for the measurement of the thermal conductivity of gases can be divided into two general categories: steady state and transient methods. Steady state thermal conductivity apparatus include such devices as parallel plates, (75) concentric cylinders (84), concentric spheres (66), hot wires (17), hot ribbon filaments (62), and porous beds (58). Thermal diffusivity (98) and Prandtl number methods (29) are used also. Dynamic probe (2) and shock wave (25) methods are common transient techniques. All the devices have certain advantages and disadvantages with regard to the measurement of the thermal conductivity of alkali metal vapors.

1. Steady State Methods Steady state methods were used first in 1840 when Andrews (4) developed a simple hot wire cell. Through the years steady state methods have developed extensively and are preferred for reliability. Data from steady state methods are used generally as standards and transient methods evaluated by comparison.

Parallel Plates The parallel plate method is the simplest method conceptually. It was first used by Christiansen (22) in 1881. The rate of heat transfer and the temperature difference between a heated plate and a parallel plate spaced at a small distance away is measured. Hercus and Laby (54) improved the technique somewhat by the use of guard rings and Michels, Sengers and Van Der Guilk (75) improved the procedure significantly by the use of an insulated guard heater. The thermal conductivity cell of Michels, Sengers and Van Der Guilk was designed to minimize convection heat transfer between the two horizontal parallel plates. A schematic representation of their cell is given in Figure 1. By placing thermocouples at several points in the guard plate and top plate and by connecting the thermocouples together to detect very small differences in the average guard and top plate temperatures, they were able to balance the heat inputs to the guard and top plate heaters to prevent heat loss from the top plate except in the direction desired. They were able to obtain extremely accurate results for very small heat fluxes and temperature differences between the cell plates. Such conditions are necessary when convective heat transfer is significant, i.e., near the critical.

The thermal conductivity is found from

$$k = \frac{Q_c X_s}{A\,\Delta t} \qquad (35)$$

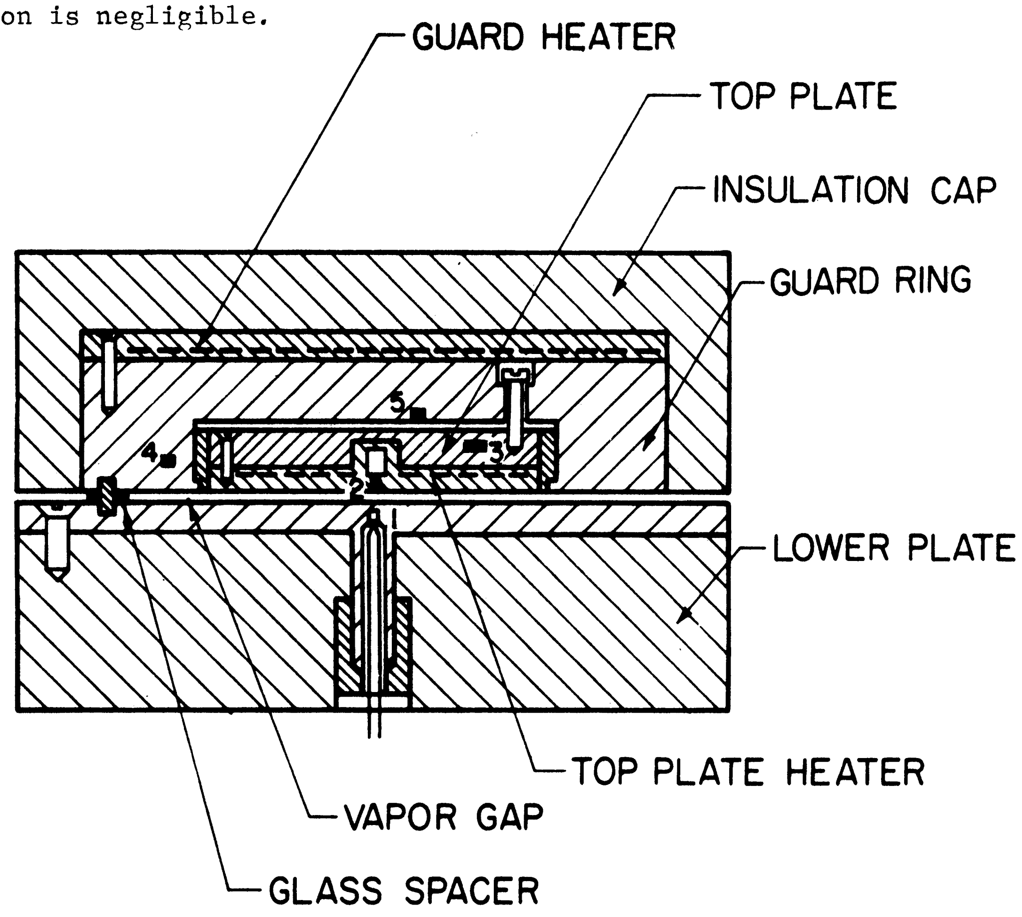
At elevated temperatures the contribution of radiation to the overall heat transfer process can become significant even for small plate spacings. For such conditions the heat transferred by conduction Q_c is obtained by subtracting the radiant transfer $Q_{rad.}$ from the total heat transferred Q_t.

$$Q_c = Q_t - Q_{rad.} \qquad (36)$$

where

$$Q_{rad.} = \sigma A \, F_e F_a \, (T_1^{\,4} - T_2^{\,4}) \tag{37}$$

Radiation effects can be measured at elevated temperatures in the absence of conduction by operating at low pressures, i.e., 1 micron of mercury absolute. At such pressures the contribution of conduction is negligible.



NOTE: NUMBERS DENOTE LOCATION OF THERMOCOUPLES

Figure 1. Schematic Representation of the Thermal Conductivity Cell of Michels, Sengers and Van Der Guilk (75)

The contribution of convective heat transfer can be made insignificant by the proper design and operation of a thermal conductivity cell. If the Grashof number is below 10, (60) convection within the cell becomes very small with respect to conduction ~~and~~ radiation. In a parallel plate apparatus, the small vertical distance between horizontal parallel plates presents the most favorable orientation for minimizing convection. Grashof numbers of 10^{-4} are not uncommon in such cells.

The parallel plate method includes also the variable gap method (70). As the name implies, the space between plates is variable. This can be done easily with a parallel plate cell and is a definite advantage when the effect of radiation on the total heat transfer is being sought independently of very low pressure runs. By measuring the combined effects of radiation and conduction for a series of plate spacings the actual thermal conductivity of the gas is determined from the changes in the overall heat transfer coefficient with plate spacings. For constant T and Δt the thermal conductivity can be computed from such runs using Equation 38.

$$\frac{\Delta t\ X_s}{k\ A} = \frac{1}{Q_t} - \frac{1}{Q_{rad.}} \tag{38}$$

Measurements of the contribution of radiation for other steady state and transient devices are not as simple.

Concentric cylinders To obviate the difficulty of undesired and undetermined heat losses in a parallel plate apparatus, early investigators, notably Stefan (92), devised and experimented with concentric cylinder thermal conductivity cells. The concept is similar in nature to the parallel plate method in that a cylinder is placed inside a hollow cylinder forming a small uniform gap between the two cylinders across which heat is transferred by conduction. Heat input to the center cylinder is transmitted radially to the outer cylinder except for heat losses at the ends. The end area is usually a small fraction of the total surface area of the inner cylinder and thus the heat losses are minimized by the geometry of the cell.

Keyes and Sandell (64) made significant improvements in the concentric cylinder method by placing a bottom on the outer or receiver cylinder at a distance from the inner or emitter cylinder equal to the radial spacing between cylinders. They placed a guard heater above the cell to prevent heat loss from the emitter by conduction at the top surface and by transfer along the electrical leads. The cell was constructed of silver with an axial heater throughout the length of the inner cylinder. Thermocouples were placed in the cylinder walls of both the inner and outer cylinders. The inner cylinder was approximately 7/8 inches in diameter with a length of 4 1/2 inches. The radial gap was 0.025 inches. Radiation effects were minimized because the low emissivity of silver and convection was minimized by maintaining small temperature differences.

Rothman (84) made measurements on several gases up to temperatures of 1400°F. using a cell similar in design to the cell of Keyes and Sandell (64).

Vines (100) also made high temperature thermal conductive measurements of gases going to temperatures of 1650°F. The inner cylinder of his vertical concentric cylinder cell, shown in Figure 2, consisted of three sections placed on a hollow rod containing the thermocouple and heater wires. The two shorter sections on each end of the middle emitter cylinder were separated from the middle section by a 0.039 inch gap. Guard heaters located in the end sections were used to reduce heat loss from the ends. Nearly all the heat transferred from the emitter was in the radial direction across a 0.0786 inch gap to the outer cylinder. Conductivities were found from the total heat transferred from the emitter at steady state. The heat transferred by radiation and end conduction was determined from data taken with the apparatus highly evacuated and at the same temperature levels as the normal runs. Applying such corrections, the heat transferred by conduction becomes

$$Q_c = Q_t - Q_{rad}. \tag{36}$$

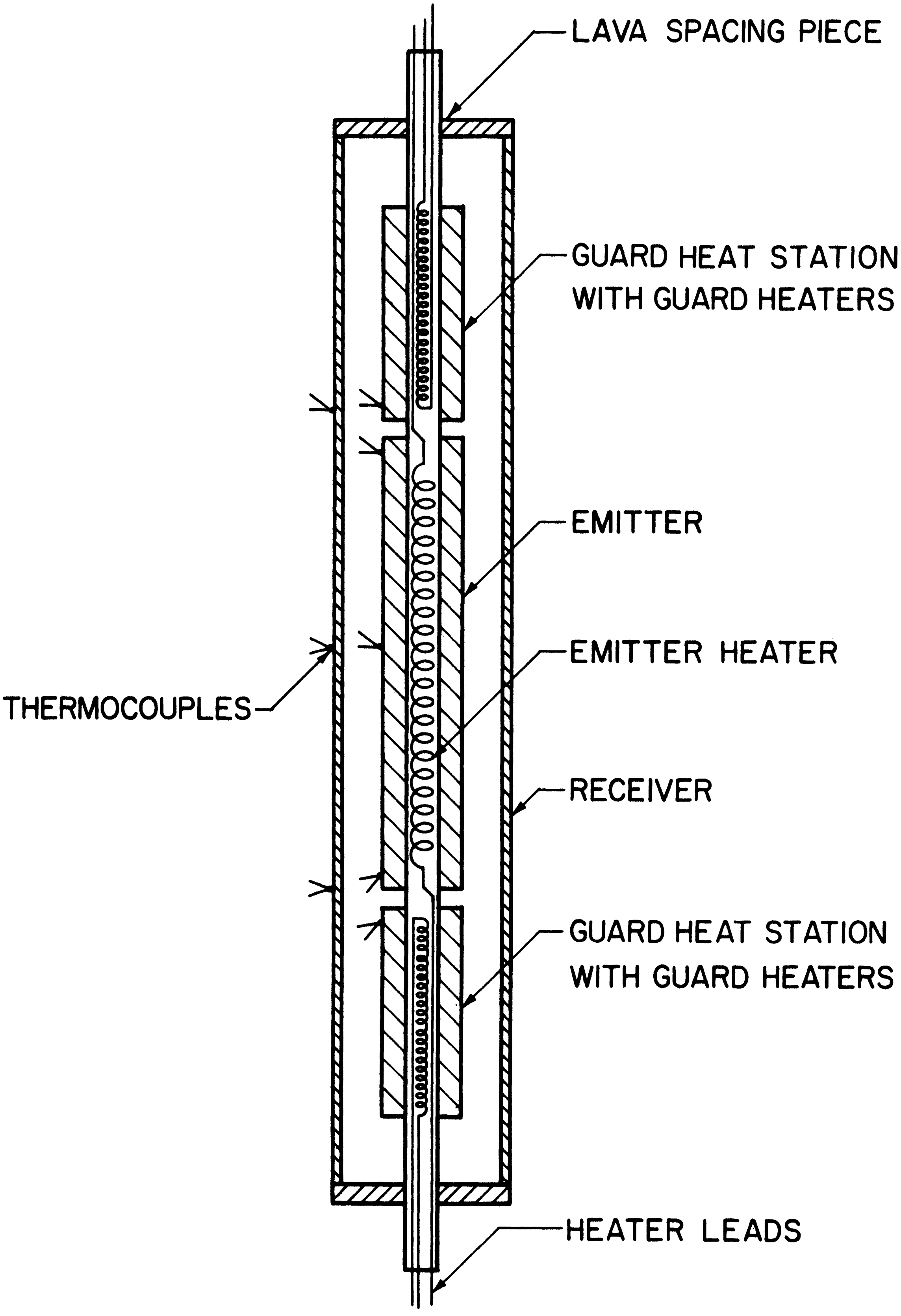


Figure 2. Schematic Representation of Thermal Conductivity Cell of Vines (100)

where

$$Q_{rad.} = f\ (T,\ \Delta t) \tag{39}$$

The thermal conductivity is found then from

$$k = \frac{Q_c \ln \frac{r_2}{r_1}}{2\pi \ell \Delta t} \tag{40}$$

Although most concentric cylinders cells are vertical, Lee (67) built a horizontal cell with a very small radial gap to minimize convection and radiation effects. Gilmore (38), Kramer and Comings (65) and Gilmore and Comings (39) built similar cells. Gilmore and Comings (39) made measurements on gas mixtures using a cell consisting of three horizontal concentric cylinders - the outer two were of copper with a 0.006 inch clearance between them and the inner cylinder was of a synthetic glass bonded mica. A fine platinum wire wound around the mica cylinder became the emitter heater and resistance thermometer. Guard heaters were not used in the ends but the ends were insulated. To account for end losses Gilmore and Comings obtained the necessary cell constants (bias corrections) by measuring the quantity $\Delta t/Q_t$ for gases of known thermal conductivity over the temperature range of interest.

<u>Concentric Spheres</u> Concentric sphere thermal conductivity cells were first introduced in 1875 by Kundt and Warburg (66). Other investigators employed the technique over the next 35 years but with limited success. Although the concept is excellent with

regards to heat loss from the emitter, severe difficulties are encountered in obtaining good boundary conditions of spherical symmetry.

Hot Wire Hot wire thermal conductivity cells consist basically of an electrically heated fine wire, usually platinum, stretched axially within a cylindrical container containing the gas or vapor of interest. The wire serves both as an electrical heater and a resistance thermometer. Andrews (4) in 1840 made the first measurements on such cells. Kundt and Warburg (66) predicted the existance of a temperature discontinuity in such cells at low pressure in 1879. Significant improvements in hot wire cells were made by Schleirmacher (85) by using a pair of potential lead wires across the center portion of the hot wire. This reduced the error caused by axial conduction along the wire. Subsequent investigators (17, 41, 83), eliminated the end effects by using two cells identical except for the wire length. Such apparatus are termed compensated hot wire systems. By subtracting the two results for the same temperature conditions the end effects were presumably eliminated and the heat transferred for the effective wire length determined.

Gregory and Archer (44,45,46) conducted a series of experiments to determine the effects of convection in horizontal and vertical hot wire cells. Experimenting with two compensated hot wire systems in which the receiver cylinders were of different radii, they found it was possible to eliminate the effects of convection by observing the pressures in both systems at which such losses vanished, the temperature conditions in the two systems being identical. Later Gregory (47) modified the hot wire procedure to permit better analysis of the data. He maintained the electrically heated emitter wire at a constant temperature while the pressure of the gas was lowered for successive runs. By plotting $\frac{2\pi \ell \Delta t}{Q_c \ln(r_2/r_1)}$ versus 1/P a straight line was observed. The intercept is the thermal conductivity at high pressures as can be seen from Equation 40 and the slope of the line A is a measure of a quantity which is related to the temperature jump at the wire. The slope A is given by (99)

$$A = \frac{gP}{k\ r_1 \ln\left(\frac{r_2}{r_1}\right)} \qquad (41)$$

The accomodation coefficient can be found from Equations 22 and 41. Much of the earliest experimental work on accomodation coefficients and temperature jumps was performed by Gregory (47) and Archer (5).

Although few high temperature conductivity data have been taken with hot wire cells, Stops (94) obtained data up to 1900°F. for air and carbon dioxide using a simple platinum hot wire in a fused quartz cell. Radiation effects amounted to 21 percent and end losses amounted to 8 percent at 1900°F.

Callear and Robb (15,16) developed a new approach in hot wire techniques to obviate the difficulty of separating the effects of the temperature jump and the reduction of thermal conductivity with pressure at low pressures. They built a cell containing two identical wires. One wire was used to supply heat to the gas and the other wire, situated some distance from the first wire, was used to measure the temperature produced by the heated wire. In this way they were able to eliminate the interference from the temperature discontinuity arising at the solid gas interface of the heated wire. For a heated wire located coaxially in a hollow cylinder of radius a and a second wire located at a distance r from the heated wire

$$k = \frac{Q \ln\left(\frac{r}{a}\right)}{2\pi \ell \Delta t} \tag{42}$$

Coffin and O'Neal (24) developed a new approach to hot wire thermal conductivity methods using four simple 0.005 inch diameter platinum filaments each with a pair of potential lead wires. The filaments were incorporated into two stainless-steel block containers which possessed a high degree of symmetry in the construction. Each container held a pair of filaments. The two pairs of cells (one reference pair; one test pair) were connected in a Wheatstone bridge circuit as shown in Figure 3.

In the bridge circuit the potential difference indicated is proportional to the temperature difference between the reference and test filament wires. Since the temperature difference between the filament and block can be given as

$$\Delta t_{ref} = \frac{a}{k_{ref}} \tag{43}$$

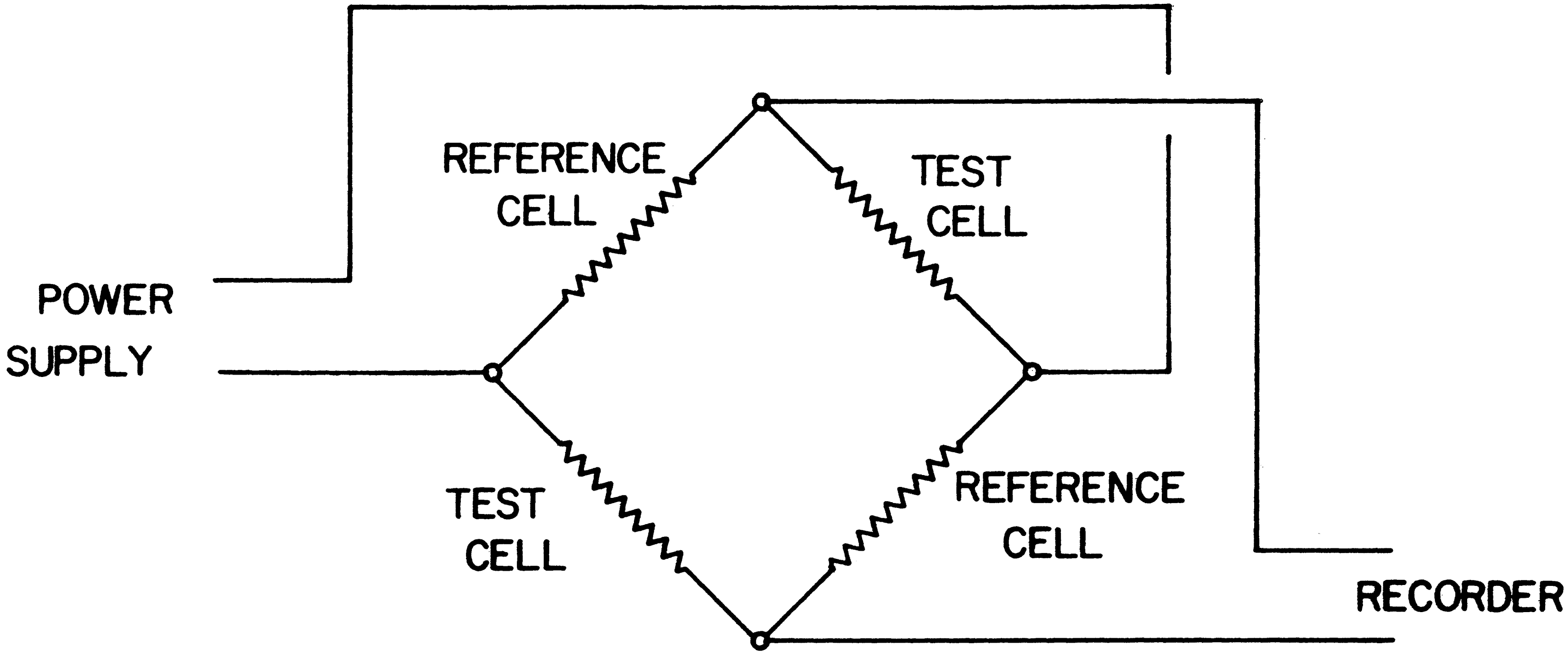


Figure 3. Wheatstone Bridge Circuit for a Symmetrical Two Pair Hot Wire Thermal Conductivity Cell of Coffin and O'Neal (24)

where a is a constant involving the geometry of the cells and the power dissipated by a wire, the potential output of the bridge circuit is

$$X_t = a \left(\frac{1}{k_{ref}} - \frac{1}{k_c} \right) + B \tag{44}$$

where B is a correction for any inherent unbalance of the bridge. By operating with gases of known thermal conductivity, Coffin and O'Neal found the values of the two constants. Then operating with nitrogen as a standard reference gas they were able to evaluate the thermal conductivity of other gases from Equation 44.

Hot Ribbon Filaments The hot ribbon filaments method is a variation of the hot wire in which a thick wire or ribbon is used in lieu of a fine wire. Kannuluik and Martin (62) used a 0.0587 inch diameter platinum wire and solved the heat conduction equation for their case to yield the thermal conductivity. More recently Gottlieb and Zollweg (43) experimented with a hot ribbon filament at filament temperatures up to 2400°F. The filament was a 0.079 inch wide tungsten strip and the collector was a pair of nickel plates located 0.005 inches away. End effects were eliminated by using two cells with the filaments in one twice as long as the other. Radiation efforts were studied extensively to determine radiation losses for different filament temperatures. The emissivity at constant emitter temperature was found to change less than 0.3 percent for alkali metal vapors at different pressures.

Heat Transfer Theory (53) and experimental efforts (37) have shown that for low Graetz numbers, the Nusselt number becomes independent of the Reynolds number and becomes asymotically equal to

$$Nu = \frac{hD}{k} = 3.658 \qquad (45)$$

Low Graetz numbers are easily obtained for laminar flow in a long tube having a small diameter and a constant wall temperature. If the convective heat transfer coefficient is determined experimentally, the thermal conductivity is found from Equation 45.

Although accurate heat flux measurements are difficult to make at high temperatures, Achener (1) and Fisher (34) proposed to make such measurements for cesium and rubidium up to temperatures of 1800°F. using a capillary tubing with a 1/16 inch inside diameter and 1.5 foot length as a heat exchanger. The capillary tube was to be placed above a pool of boiling liquid metal whose temperature would be controlled by an overpressure of argon. In this way a nearly uniform wall temperature could be maintained. For conditions where the liquid metal condensing resistance and wall metal resistance are small, the thermal conductivity can be found from

$$k = \frac{Wc_P}{3.658\ \pi \ell} \ \ln\left(\frac{t_w - t_1}{t_w - t_2}\right) \qquad (46)$$

Porous Beds The effective thermal conductivity of porous beds can be used to determine the thermal conductivity of the gas contained intersitially. Israel, et al. (58) found the thermal conductivity of hydrogen at 2000°F. to 4700°F. by measuring the effective conductivity of porous tungsten specimens filled with pressurized hydrogen. Effective conductivities were determined from temperature measurements on the upper flat surface of the right circular cylindrical porous specimen heated by high frequency induction currents. The values of effective conductivities were calculated by equating the axial, centerline heat flux at the surface of the specimen, determined from the solution of the heat conduction boundary valve problem, to the radiation and thermal convection heat losses at the same point.

Prandtl Number Method Any method for measuring a property value such as thermal conductivity must be based on a fundamental relationship which contains besides the desired property only quantities which can be accurately determined. The Prandtl number expressed as

$$Pr = \frac{c_p \mu}{k} \tag{47}$$

could be used to find the thermal conductivity of a gas providing the Prandtl number could be determined independently based on measurable quantities other than those appearing in Equation 47. Pohlhausen (81) derived a unique solution for high-velocity, steady, two-dimensional flow in which heat is transferred by convection only. He related the Prandtl number to a recovery factor defined as

$$r = \frac{t_r - t_s}{t_t - t_s} \quad (48)$$

For Prandtl numbers between 0.5 and 5, the relationship between the Prandtl number and the recovery factor is expressed accurately as

$$r = Pr^{1/2} \quad (49)$$

Eckert and Irvine (29) designed a high-velocity flow device to accurately evaluate the recovery factor by measuring temperatures and pressures. Their results for air between 60°F. and 360°F. calculated from Equations 47-49 agreed within 4 percent with National Bureau of Standards data.

2. Transient Methods In the past, steady state methods have been preferred because of general reliability. However, with improved instrumentation and experience the dynamic and transient methods are becoming more and more useful. Thermal conductivity measurements by any method seldom give any indications of poor values. The data will normally be self-consistent and only by comparing different methods can self-consistent errors be detected.

Dynamic Probe Method The dynamic probe method (90,97,105) is an absolute, transient (dynamic) method. Heat is generated for short time periods in a long, thin probe positioned centrally in a cylindrical reservoir and the time-temperature history of the sample fluid recorded during the heating period at some radial distance away from the probe. The thermal conductivity of the fluid may be calculated from the time-temperature record and the power input to the probe by a method developed by Carslaw and Jaeger (19).

The temperature rise θ at a point r in an infinite mass of fluid heated by a very long and very small diameter heat source is

$$\theta(\tau, r) = \frac{Q}{2\pi k}\ I\ (x) \tag{50}$$

where

$$x = \frac{r}{2(\alpha\tau)^{1/2}} \tag{51}$$

and

$$I(x) = 0.5772 - \ln x + \frac{x^2}{2} - \frac{x^4}{8} \ . \ . \ . \tag{52}$$

For small values of x, i.e., large τ and small r, the higher order terms in x may be neglected and

$$\theta = \frac{Q}{2\pi k}\left[0.5772 - \ln \frac{r}{2(\alpha\tau)^{1/2}}\right] \tag{53}$$

From Equation 53, the temperature rise between times τ_1 and τ_2 is given by

$$\Delta\theta = \theta_2 - \theta_1 = \frac{Q}{4\pi k} \ln \frac{\tau_2}{\tau_1} \tag{54}$$

for negligible changes in the thermal diffusivity or in terms of the thermal conductivity

$$k = \frac{Q}{4\pi\Delta\theta} \ln \frac{\tau_2}{\tau_1} \tag{55}$$

Experimentally the thermal conductivity is found by measuring the slope $\frac{Q}{4\pi k}$ of the straight line obtained from a plot of θ versus $\ln \tau$. Data taken during the first few seconds are usually disregarded since the higher order terms in Equation 52 may be significant. This is usually apparent in the time-temperature history.

Allen (2) devised a technique which combined continuous measurements with constant power dissipation. The power dissipation was maintained constant by using an electrical circuit having a high impedance thermionic valve (a power pentode) with a mutual conductance equal to the reciprocal of the wire resistance. In such a circuit, changes in voltage correspond directly to changes in resistance such that the power output is constant. Changes in voltage (thus equivalent to changes in temperature) were recorded by a cathode ray oscillograph. Thermal capacity effects were reduced by using a 0.001 inch diameter platinum wire.

Shock Wave Method In recent years several investigators (18, 25,50,80,88) have deduced the thermal conductivity of gases at high temperatures from the measurement of heat transfer rates from the heated gases to an end well of a shock tube in a reflected shock wave. Shock speeds are determined with the aid of a raster oscilloscope display by noting temperature changes in a series of thin film temperature detectors placed along the shock tube. The heat transfer from the end wall is related to the temperature change occurring at the wall upon reflection of shock wave. The wall temperature is measured with some type of thin-film temperature gauge. Collins and Menard (25) used a gauge consisting of a platinum film sputtered onto a quartz substrate. The gauge was connected to a differential amplifier and the resulting voltage change was presented on an oscilloscope. Camac and Feinberg (18) built an end wall heat transfer element consisting of a thin opaque carbon layer on a transparent sapphire window. They then measured the temperature of the element with a calibrated infrared detector.

In the determination of the thermal conductivity, the region behind the reflected shock is idealized to consist of a hot semi-infinite gas adjacent to a semi-infinite solid and the continuity and energy equations written for such conditions. The equations lead to a second order differential equation for which one boundary condition can be measured with a temperature gauge and a second boundary condition approximated by assuming that the thermal conductivity is related to

$$k = a\ T^{b} \tag{56}$$

In the dimensionless form of the differential equation the constant a cancels out. The best values of b are found by an iterative procedure in which values of b are assumed and the solution of the differential equation for the end wall heat flux compared to the experimental values of the heat flux. The best value of b is found by minimizing the sum of the square of the deviations between the experimental data and the theoretical curve.

Since only the temperature dependence of the thermal conductivity is found in this method, i.e., the constant b, values of the constant a must be obtained from other data in order to give absolute values of thermal conductivity.

<u>Thermal Diffusivity Method</u> Analysis of transient heat transfer systems involve the temperature distribution with respect to time as well as distance. For example the unsteady state heat conduction equation in cylindrical coordinates is

$$\frac{\partial \theta}{\partial \tau} = \alpha \left[\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r} \frac{\partial \theta}{\partial r} \right] \tag{57}$$

In such systems the thermal diffusivity, $\alpha = \frac{k}{\rho c_p}$, is an important parameter which may be evaluated from the individual terms or may be determined experimentally as a group as originally suggested by Groeber (49). Experimental determinations of thermal diffusivity provide a good independent check on the consistency of the individual terms.

The theory of operation of a device to measure the thermal diffusivity of a fluid contained in a cylindrical system was developed by Van Zee and Babcock (98). They made thermal diffusivity measurements of molten glass. Later, Harrison, Boteler and Spurlock (51) made similar measurements on nitrogen.

In the system of Harrison, Boteler and Spurlock (51) the current through the cylindrical container was varied by changing the field current in a motor-driven direct current generator. Changes in the field current generator were controlled by a function generator such that the temperature fluctuation measured by a thermocouple located at a distance R from the center and near the container wall could be represented by

$$\theta\,(R,\tau) = A_R \cos\,(\omega\tau) \tag{58}$$

When the temperature fluctuations at R are given by Equation 58, the temperature fluctuations at the center of the cylinder are given by (51)

$$\theta(0,\tau) = A_R \left[\frac{\cos(\omega\tau)\left[\mathrm{ber}\sqrt{\frac{\omega}{\alpha}}\,R\right] + \sin(\omega\tau)\left[\mathrm{bei}\sqrt{\frac{\omega}{\alpha}}\,R\right]}{\sqrt{\mathrm{ber}^2\sqrt{\frac{\omega}{\alpha}}\,R + \mathrm{bei}^2\sqrt{\frac{\omega}{\alpha}}\,R}} \right] \tag{59}$$

Equation 59 can be written as

$$\theta(0,\tau) = \left[\frac{A_R}{\sqrt{\mathrm{ber}^2\sqrt{\frac{\omega}{\alpha}}\,R + \mathrm{bei}^2\sqrt{\frac{\omega}{\alpha}}\,R}} \right] \cos\left[\omega\tau - \tan^{-1}\frac{\mathrm{bei}\sqrt{\frac{\omega}{\alpha}}\,R}{\mathrm{ber}\sqrt{\frac{\omega}{\alpha}}\,R} \right] \tag{60}$$

From Equation 60, the ratio of the amplitude at the center A_o to the amplitude at R, A_R is

$$\frac{A_o}{A_R} = \frac{1}{\sqrt{\text{ber}^2 \sqrt{\frac{\omega}{\alpha}}\, R + \text{bei}^2 \sqrt{\frac{\omega}{\alpha}}\, R}} \qquad (61)$$

and the phase shift ϕ at the center is

$$\phi = \tan^{-1} \frac{\text{bei} \sqrt{\frac{\omega}{\alpha}}\, R}{\text{ber} \sqrt{\frac{\omega}{\alpha}}\, R} \qquad (62)$$

Experimentally the amplitude attenuation A_o/A_R and the phase shift ϕ are measured for known values of ω. Since the only unknown in Equations 61 and 62 is α, the thermal diffusivity is readily determined.

Harrison, Boteler and Spurlock (51) estimated the accuracy of their nitrogen data at about 5 percent and indicated that significant improvements are not likely.

It should be noted that in the dynamic probe and shock wave methods that the thermal diffusivity is effectively eliminated from the problem by suitable manipulations.

E. Experimental Cells for Alkali Metal Vapors

Several investigators have constructed and experimented with cells designed to measure the thermal conductivity of alkali metal vapors at elevated temperatures. There were unfortunately very limited results.

Gottlieb and Zollweg (43) obtained thermal conductivity data on cesium, potassium and rubidium vapors at vapor temperatures of 1400-1600°F. in a hot ribbon filament cell at low pressures. The maximum vapor pressure for potassium was 0.88 mm Hg. or 0.017 lbs./sq. in. They reported an accomodation coefficient of 0.57 for potassium as determined from a plot of 1/k versus 1/P. They further reported that the thermal conductivity of potassium was 0.0104 Btu/hr.-ft.-°F. at 1430°F. with no significant (less than 10 percent) temperature dependence between 1250°F. and 1610°F.

In 1963, Lemon et al. (68) built and checked out a 0.001 inch diameter bare wire dynamic probe thermal conductivity cell. Calibration checks with air and nitrogen were very satisfactory at ambient temperatures but thermal conductivity measurements on potassium vapor at various degrees of superheat from 750-1470°F. showed a marked dependence upon the power input to the probe. Several tests were made to locate the source of trouble. After the tests proved to be unsuccessful, the program was terminated.

Blum (8) reported upon a concentric cylinder cell similar to the cell of Vines (100). The thermal conductivities of sodium and potassium vapors were to be measured but no data have been presented as yet.

Fisher and Achener (34) made a comprehensive analytical investigation of a dynamic method of measuring the diffusivities of alkali metal vapors in 1964. In such a device, the thermal conductivity is obtained from $k = \alpha c_p \rho$ (63)

They concluded that it would be necessary to use sheathed thermocouples to detect temperatures if alkali metal vapors at high temperatures were used. This proved to be a serious disadvantage since sheathed thermocouples would have an adverse effect on the definition of the response curve which could not be improved without decreasing the sensitivity. On the basis of their findings they concluded that this transient method of measuring the diffusivity of alkali metal vapors at elevated temperatures had too many inherent problems to warrant construction. In 1966 Achener (1) designed and proposed to build a long tube small diameter heat exchanger from which he would deduce thermal conductivities from convective heat transfer coefficients at low Graetz numbers.

In 1964, Tepper, Zelenak, Roehlich and May (95) reported on plans to measure the thermal conductivity of cesium and rubidium vapor by a transient hot wire technique. Recently Staub (91) indicated that measurements had been made by Tepper on cesium, rubidium and potassium vapors but the report could not be obtained.

Timrot and Totskii (96), two Russian scientists, developed a dilatometric method for the determination of the thermal conductivity of corrosive gases at high temperatures. The temperature drop across the layer of the gas to be investigated is determined from the thermal expansion of the walls enclosing the gas layer. End effects are eliminated with guard heaters. Measurements of the thermal conductivity of helium with their device showed good agreement with published experimental data.

Stefanov, Timrot, Totskii, and Chu Wen-hao (93) made measurements of the thermal conductivity of potassium and sodium by the dilatometric method. The potassium measurements were in the range of 1050°F. to 1780°F. and from 0.3 lbs./sq.in. to 13.4 lbs./sq.in. pressure. They indicated an average maximum error in the data of 20 percent. Figure 4 was prepared from a table in Reference 93.

In view of the work attempted and under progress and after examining all the possible methods of measuring the thermal conductivity of vapors, the guarded top plate parallel plate thermal conductivity cell seemed to offer considerable promise. The construction of such a cell is reasonably simple even when refractory metals are used. Since no bare electrical wires are required in contact with potassium vapor, the containment of potassium and the operation of the cell are greatly improved. The accuracy possible with a guarded top plate parallel plate thermal conductivity cell should be comparable with concentric cylinder cells.

F. Physical Properties of Potassium

Many investigators have measured various thermodynamic and transport properties of the alkali metals and of potassium in particular during the past decade. A summary of these efforts for potassium

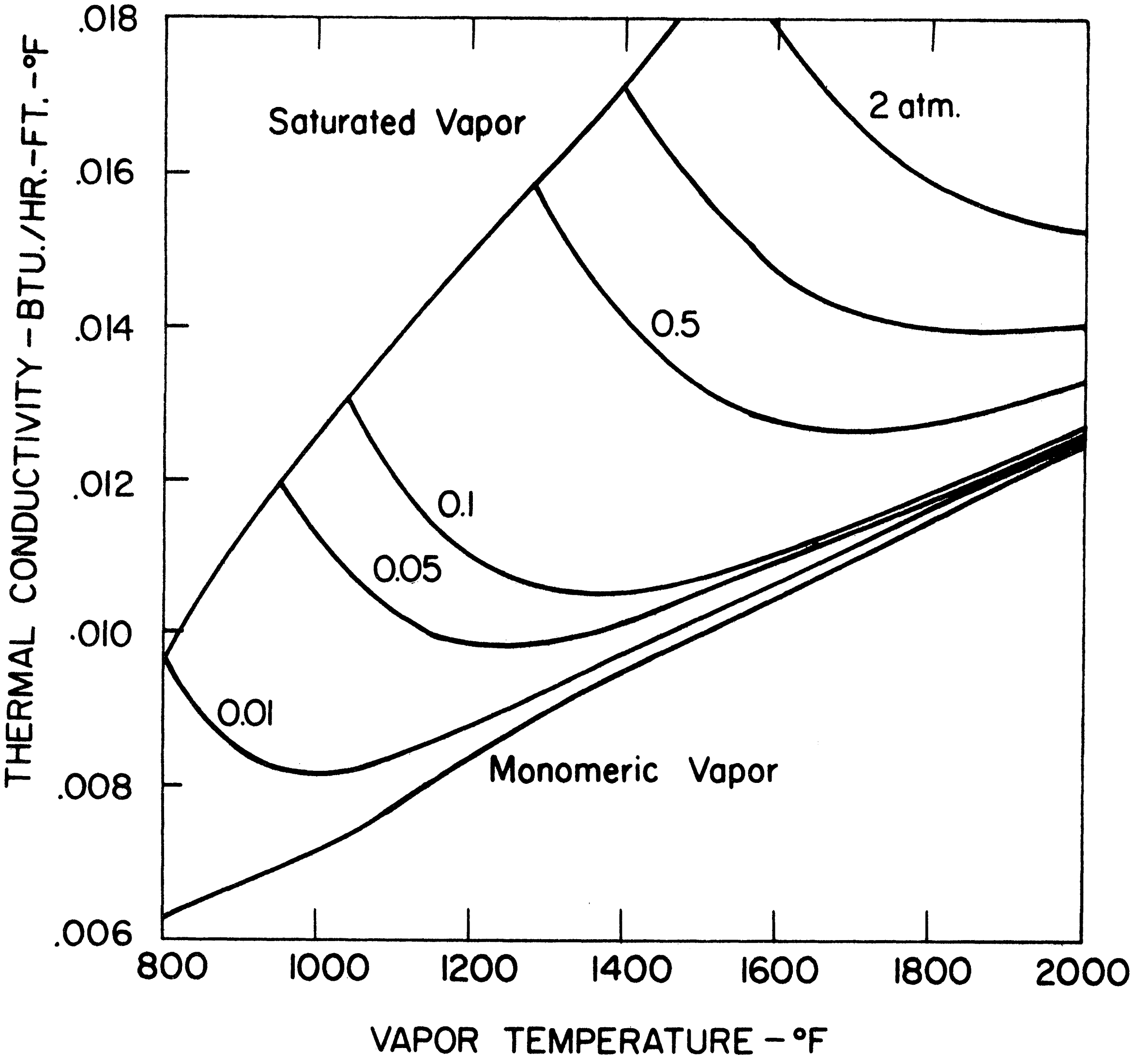


Figure 4. Experimental Thermal Conductivity Results for Potassium Vapor Measured with a Dilatometric Thermal Conductivity Cell (93)

through 1965 is given by Coe (23). The two properties of most importance in this investigation are the vapor pressure and the viscosity of the vapor.

A review of all the available vapor pressure data for potassium indicates that the most reliable data are those of Ewing et al. (32, 33) of the U.S. Naval Research Laboratory. Their vapor pressure data cover the range of 1200°F. to 2400°F. and is given by the equation

$$\log_{10} P = 6.12758 - \frac{8128.77}{T} - 0.53299 \log_{10} T \qquad (64)$$

where the pressure is in atmospheres and the temperature in °R. The average deviation of their experimental data from the correlating equation is $\pm$ 0.31 percent.

In the analysis of their data Ewing and co-workers found the first four virial coefficients for potassium and as a result developed a virial equation of state for potassium. The second virial coefficient which can be used to estimate the force constants for the Lennard-Jones potential is given as

$$\log_{10} \left| B \right| = - 3.8787 + \frac{4890.7}{T} + \log_{10} T \qquad (65)$$

where $B < 0$

Ewing and co-workers also verified the existence of the tetramer of potassium in the analysis of the vapor pressure data. The existence of the dimer had previously been verified spectroscopically. (55) They further found the equilibrium constants for the reactions

$$nK_1 \rightleftarrows K_n \tag{66}$$

These constants are given by

$$\log_{10} k_2 = -\ 3.8611 + \frac{5312.5}{T} \tag{67}$$

and

$$\log_{10} k_4 = -\ 10.1453 + \frac{13,745}{T} \tag{68}$$

The enthalpies for the two reactions were obtained from Van't Hoff's isochore equation and are given by

$$2K \rightleftarrows K_2,\ \Delta H_2^\circ = -\ 24,296 \text{ Btu/lb-mole} \tag{69}$$

$$4K \rightleftarrows K_4,\ \Delta H_4^\circ = -\ 62,860 \text{ Btu/lb-mole} \tag{70}$$

Since the equilibrium mole fractions of the monomer, dimer and tetramer are related by

$$k_n = \frac{x_n}{(x_1)^n p^{n-1}} \tag{71}$$

Equations 67, 68, and 71 can be used to find the equilibrium concentration of monomer, dimer and tetramer as a function of temperature and pressure.

The only known viscosity data for potassium vapor are those of Stefanov *et al.* (93) who made measurements with a falling - weight apparatus. A Geiger counter was used to monitor the position of a weighted piston carrying a Co-60 specimen. They estimated their data were accurate to 3 percent. The data are given in Figure 5 which was prepared from a table in Reference 93. These data are useful in the estimation of the force constants for the Lennard-Jones potential.

G. Theoretical Predictions of Thermal Conductivity of Potassium Vapor

Weatherford (102) *et al.* made predictions for the frozen thermal conductivity for the saturated vapor of potassium and the other alkali metals for the temperature range of 840°F. to 2240°F. Their results for potassium are shown in Figure 6. The results were calculated assuming that the Prandtl number $\frac{c_p \mu}{k}$ of the vapor was constant and equal to 0.73. The values of the frozen specific heat and the viscosity were taken from theoretical calculations of Shapiro and Meisl (87) and Weatherford (103), respectively.

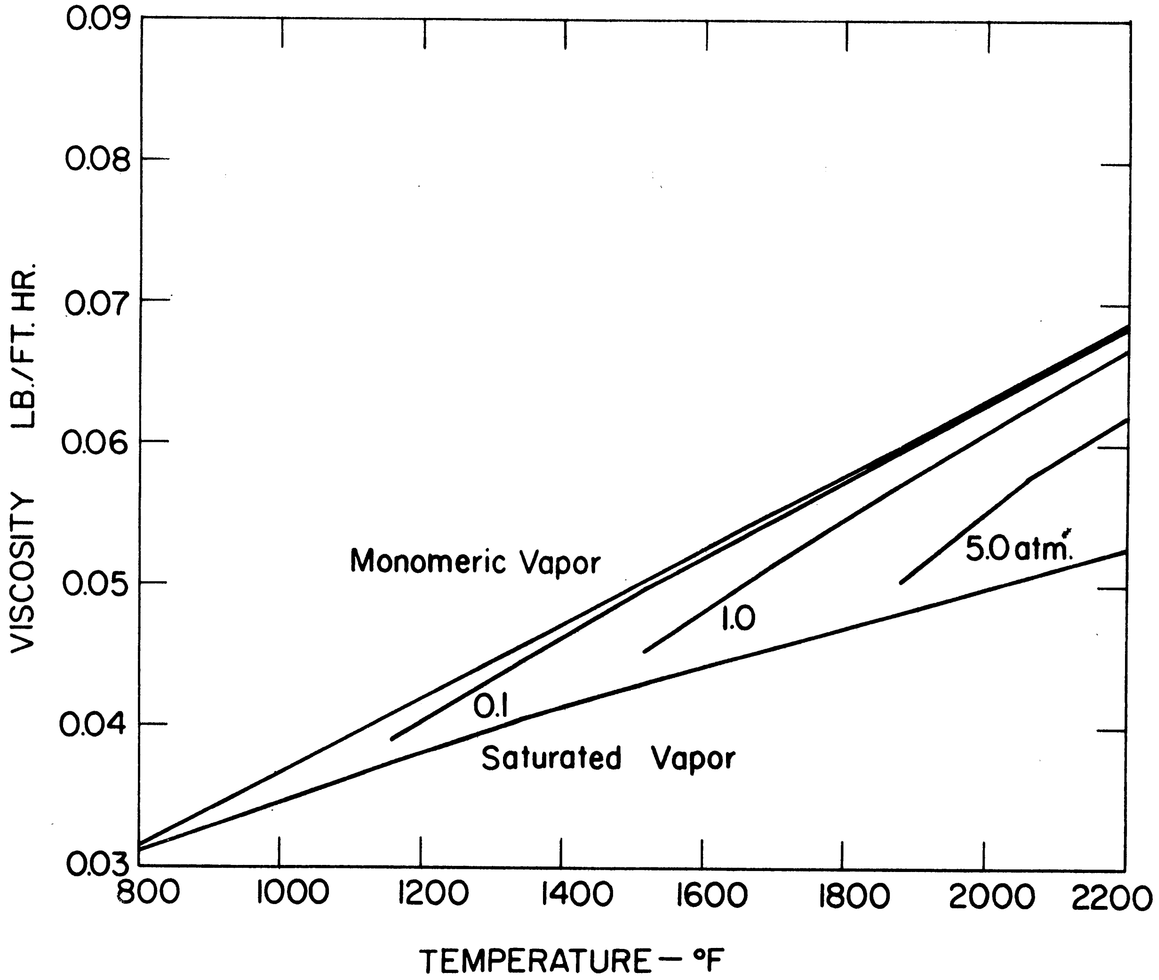


Figure 5. Experimental Viscosity Results for Potassium Vapor Measured with a Falling Piston Apparatus (93)

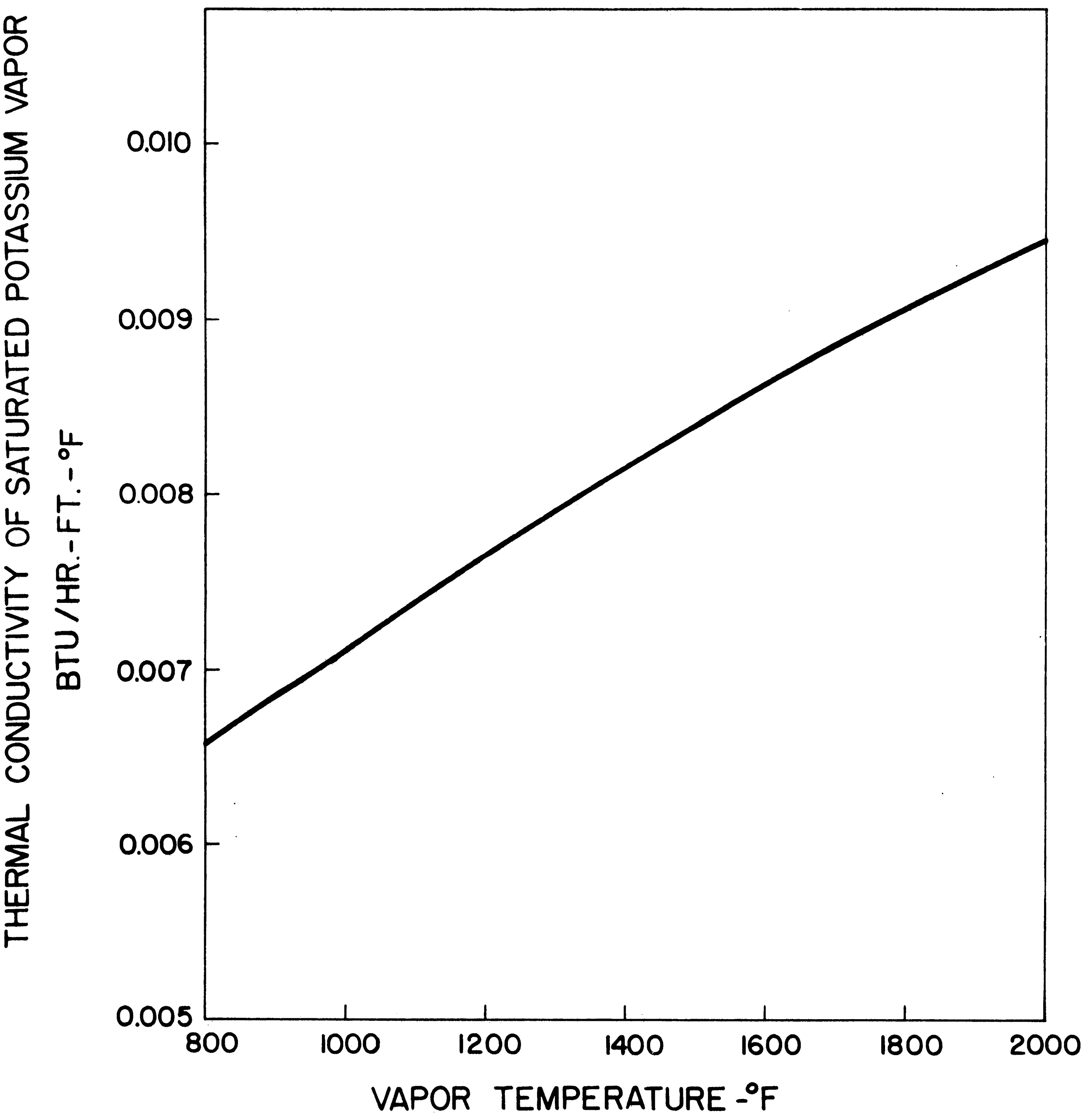


Figure 6. Theoretical Thermal Conductivity of Saturated Potassium Vapor (102)

CHAPTER III

DESCRIPTION OF EQUIPMENT

The parallel plate apparatus developed to measure the thermal conductivity of potassium vapor at elevated temperatures in this investigation is quite similar in design to the thermal conductivity cell used by Michels, Sengers and Van Der Guilk (75) for the measurement of the thermal conductivity of carbon dioxide vapor close to its critical temperature and pressure. Several differences in design were necessitated by the corrosion (3, 26,59,76), containment and loading problems (27) which exist when working with alkali metal liquids and vapors. Some of the principal differences involved the choice of materials of construction, type heaters, temperature measuring methods and guard plate insulation. Figure 7 gives a view of the disassembled cell and Figures 8 and 9 give a schematic representation of the cell construction. The cell consists of three principal sections; the top plate assembly, the guard cover assembly and the bottom plate.

Molybdenum was selected for the thermal conductivity cell material because of its desirable characteristics. Ideally, the cell material should have a high thermal conductivity to insure uniformity of temperature, a low emissivity to reduce the effects of radiation and a surface stability with regard to corrosion and changes in emissivity. Of all the materials that can be considered

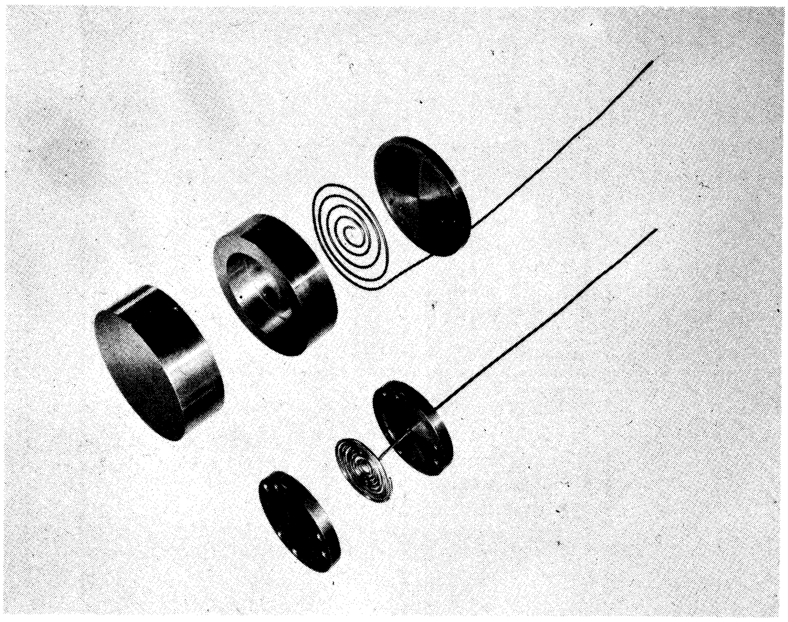


Figure 7. Disassembled View of the Thermal Conductivity Cell

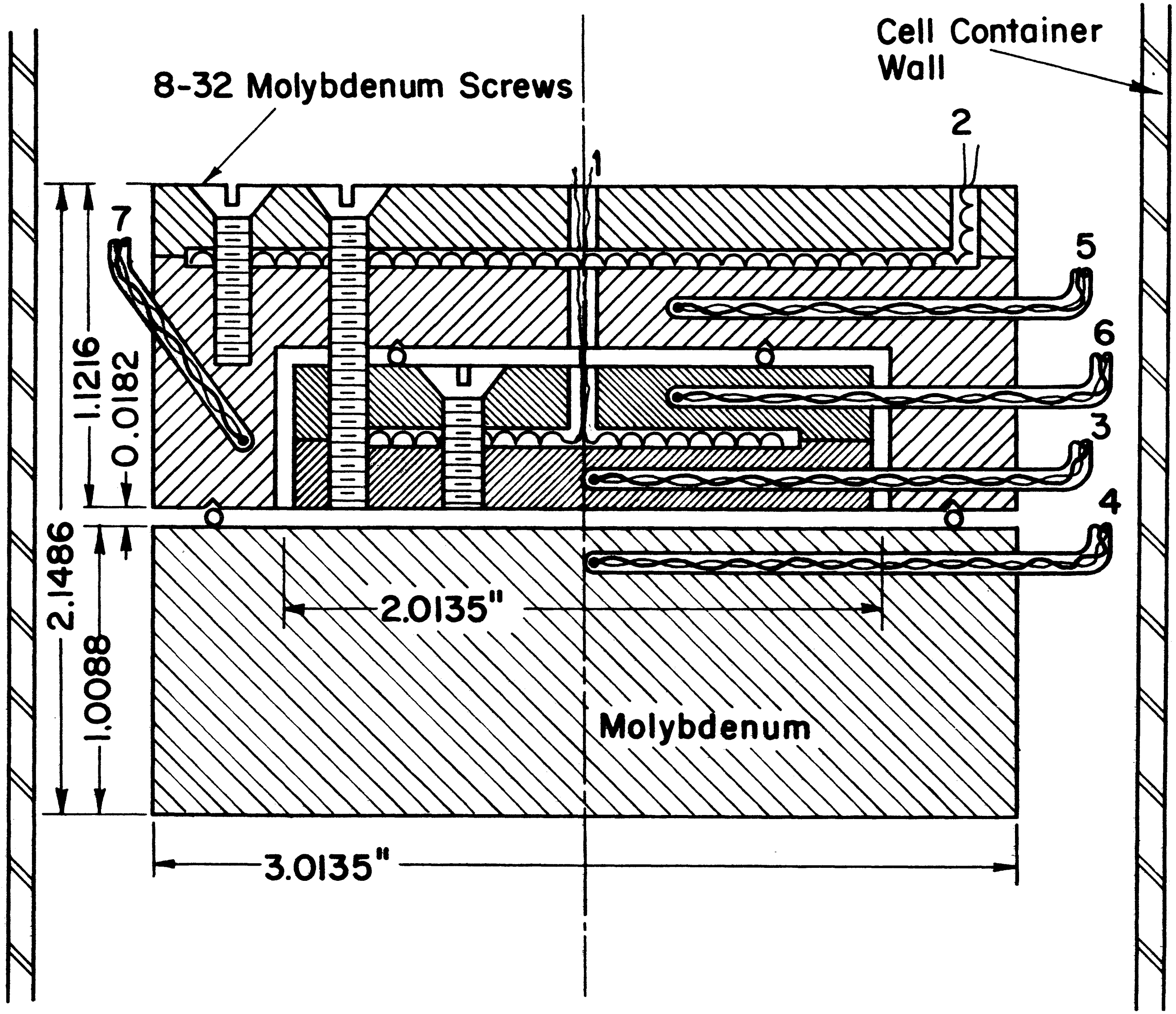


Figure 8. Schematic Representation of the Thermal Conductivity Cell Showing Heaters and Thermocouples

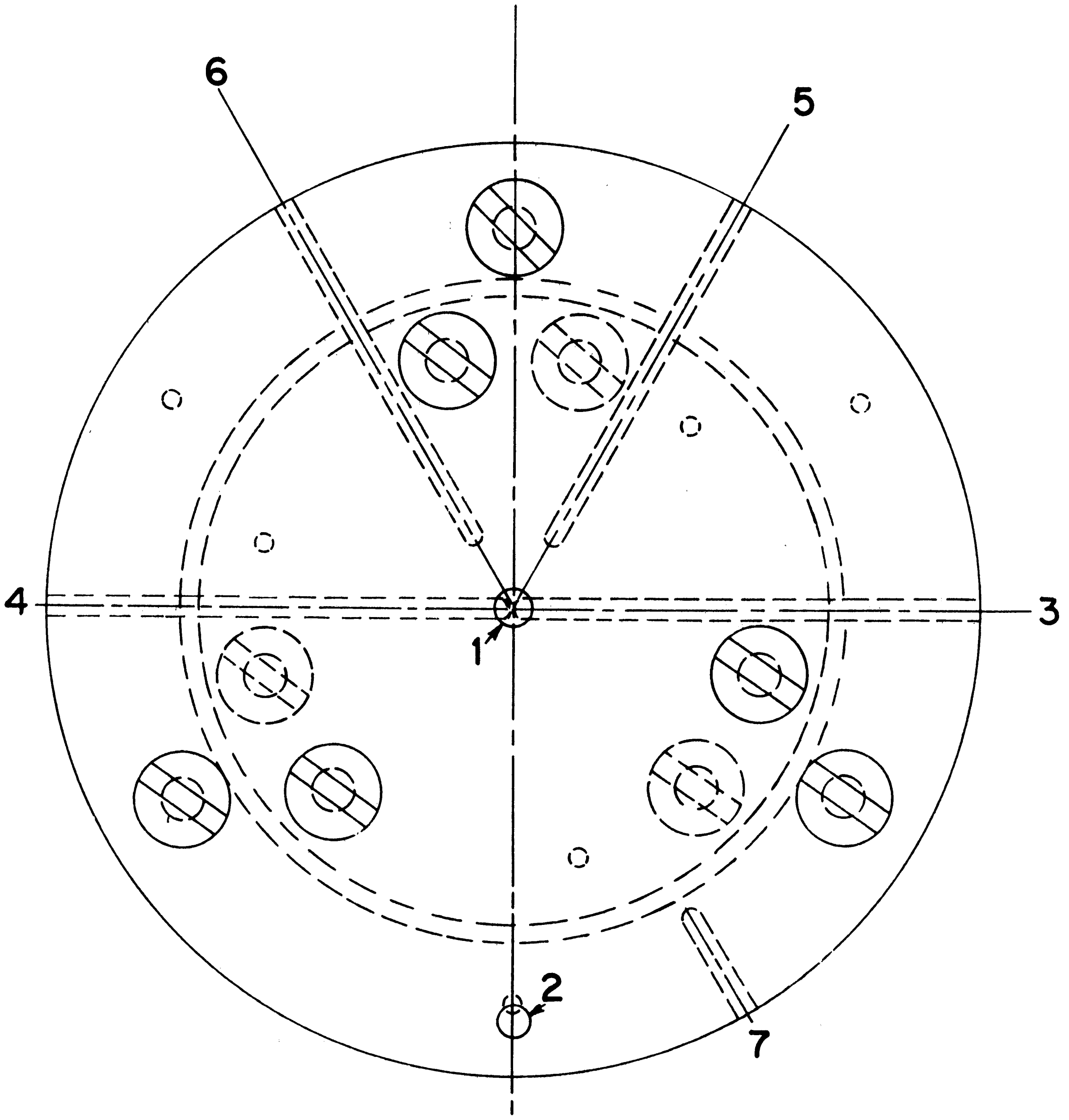


Figure 9. Top View of the Thermal Conductivity Cell Showing Exact Placement of Heaters and Thermocouples

corrosion resistant to alkali metals at elevated temperatures (3,59, 76), molybdenum has one of the highest thermal conductivities (89) (69 Btu/hr.-sq.ft.-°F/ft. at 1000°F.) and one of the lowest emissivities (89) (0.12 at 1800°F.).

The top plate assembly of the cell which is 2.0135 inches in diameter consists of two pieces held together by three number 8-32 molybdenum flat heat machine screws as shown in the lower portion of Figure 7 and in Figure 8.

Each piece is 0.246 inches thick. The cell heater fits into a 1.500 inch diameter by 0.070 inch thick cavity formed by the two pieces when screwed together.

A molybdenum guard cover assembly consisting of two pieces which contain the guard heater fits over the top plate. The assembly is 3.0135 inches in diameter. The top piece is 0.2515 inches thick and the bottom piece is 0.8701 inches thick at the outer edge, the center portion being machined out to a depth of 0.5403 inches to receive the top plate assembly. The two pieces when screwed together with three number 8-32 molybdenum flat head machine screws form a 2.745 inch diameter by 0.078 inch thick cavity within which the guard heater is situated. Figure 7 shows a disassembled view of the guard plate assembly and Figures 8 and 9 give additional representations.

It is the function of the guard cover assembly to prevent the transfer of heat from the top plate assembly in every direction except toward the lower plate of the cell. This was accomplished by providing a vapor space between the top plate assembly and the guard cover assembly to increase the resistance to heat transfer in those directions and by employing a guard heater to keep the guard cover assembly at or very close to the top plate assembly temperature. The top plate assembly is held in place within the guard cover assembly by three number 8-32 molybdenum flat head machine screws which extend through the top plate as shown in Figure 8. Three 1/16 inch diameter synthetic sapphire balls (99.99 percent Al_2O_3) placed between the guard cover and top plate as shown in Figure 8 maintain a vapor gap of 0.0483 inches in the vertical direction. Small indentations were made in the guard cover to receive the sapphire balls and prevent movement and misalignment. The radial vapor gap spacing is 0.0557 inches. Although the molybdenum screws constitute a potential path for heat transfer the effect is minimal when the top plate assembly and the guard cover assembly are maintained at the same temperature. Synthetic sapphire balls were selected as the spacer material because they are resistant to potassium at temperatures up to 1500°F. (26)

Upon completion of the machining of all the individual parts of the top plate and guard cover, the pieces were assembled and the bottom surface of the top plate and guard cover were surface ground to give a flat surface. The surface was then lapped with Linde A abrassive until a mirror like surface resulted.

A 3.0135 inch diameter and 1.0088 inch thick piece of molybdenum constitutes the lower plate of the cell. The top and bottom plates of the cell are separated by three 1/32 inch diameter synthetic sapphire balls as shown in Figure 8. Because of the indentations in the guard cover surface, the vapor gap distance between plates is 0.0182 inches. The top surface of the lower plate was also surface ground and lapped.

A stainless steel yoke holds the assembled thermal conductivity cell together as shown in Figure 10. The cell rests upon three 1/16 inch diameter stainless steel balls which in turn rest upon the lower yoke plate. The top yoke plate rests upon the top of the guard cover assembly. Three 1/8 inch diameter stainless steel rods pass through the two yoke plates and hold the cell in the proper place. The bottom yoke plate is welded to the rods so that the bottom of the cell is approximately 1/2 inch above the bottom of the cell container. The upper portion of the rods are threaded for 8-32 machine screw nuts which hold the top yoke plate tightly against the top of the cell. The point contacts between the yoke and bottom plate are essential in reducing the undesirable heat transfer paths between the upper and lower plates.

Heaters for the cell were manufactured by Pyro Electric. Inc. The main top plate heater consists of two 0.0095 inch diameter nichrome wires insulated from each other by magnesium oxide and enclosed in a 1/16 inch diameter stainless steel sheath and coiled tightly with the lead wires in the center as shown in Figure 7. Nickel lead wires of the same diameter were welded to the nichrome wires at approximately the point where the coiling stops and the straight lead section begins. This was done at the time the wires

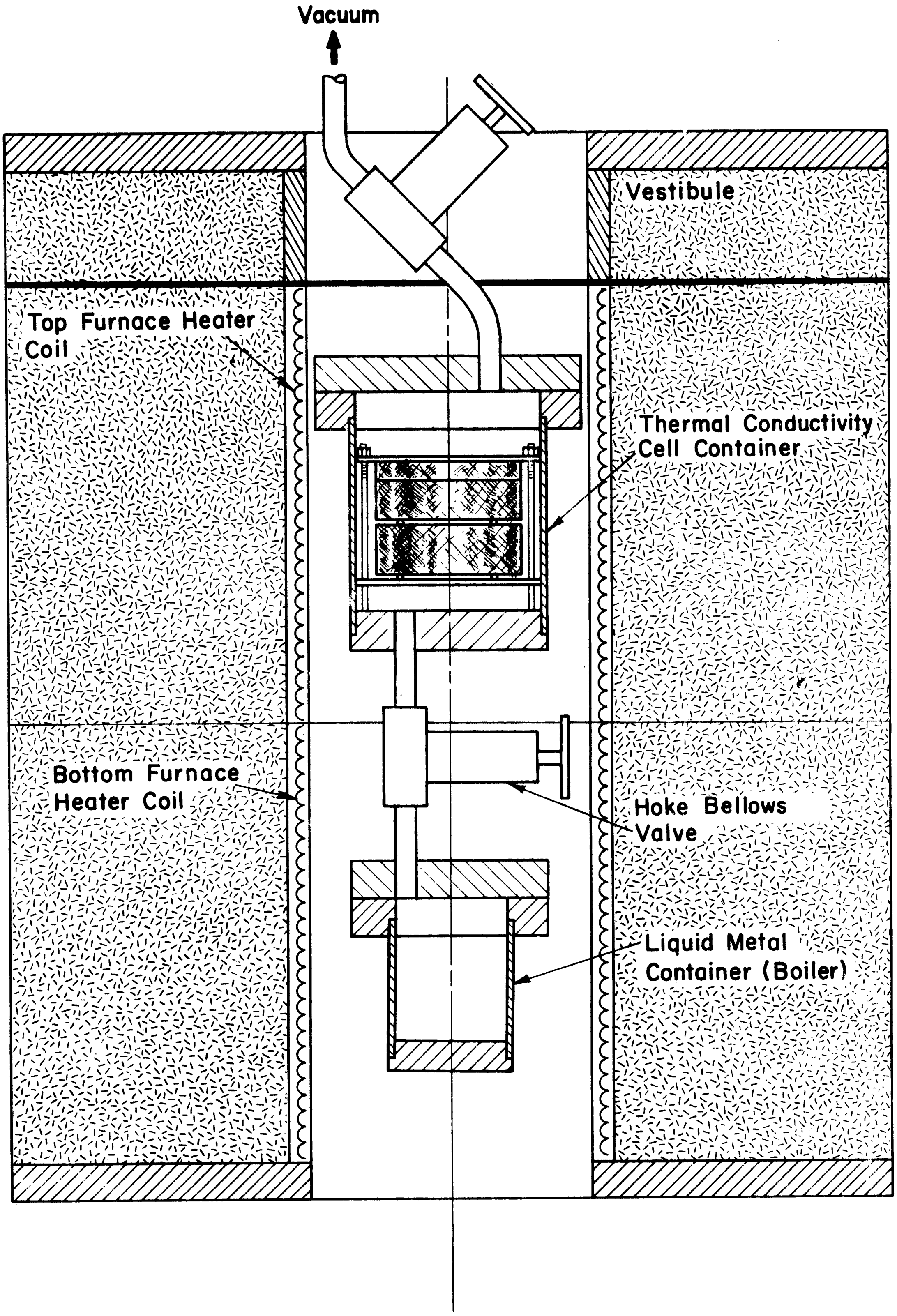


Figure 10. Schematic View of Thermal Conductivity Equipment

were inserted into the sheath and prior to coiling. The total resistance of the top plate heater is approximately 32 ohms with the greatest portion of the resistance occurring within the coil. The nickel lead wires are each 10 3/8 inches long from the coil to the point where the voltage taps are connected. The guard heater was manufactured similarily to the top plate heater except that the heating element was made of alumel and the coil was wound such that the lead wires were at the outer edge of the coil. Figure 7 shows a view of the guard heater which has a resistance of approximately 9 ohms.

A Kepco Model SC-32-5, 0-32 DC semi-conductor voltage regulated power supply provides the direct current power for the main and guard heaters. The power supply and heaters are connected as shown schematically in Figure 11. The trim rheostats shown in the main heater circuit consist of two 10-turn 0-25 ohm potentiometers and a 0-4000 ohm resistance box. A Honeywell Type NBS 0.99998 ohm standard resistor is also located in the circuit to provide an accurate way to measure the current through the main heater. A 10-turn 0-25 ohm potentiometer is located in the guard heater circuit to facilitate the balance between the main and guard heater circuits. The current through the main heater is determined by measuring the voltage drop across the standard 1 ohm resistor with a Leads and Northrup K-3 potentiometer and null detector. The voltage drop across the main heater is measured with the potentiometer when the voltage drop is less than 1.60 volts or with a 0-5 volt D.C. Simpson volt meter when

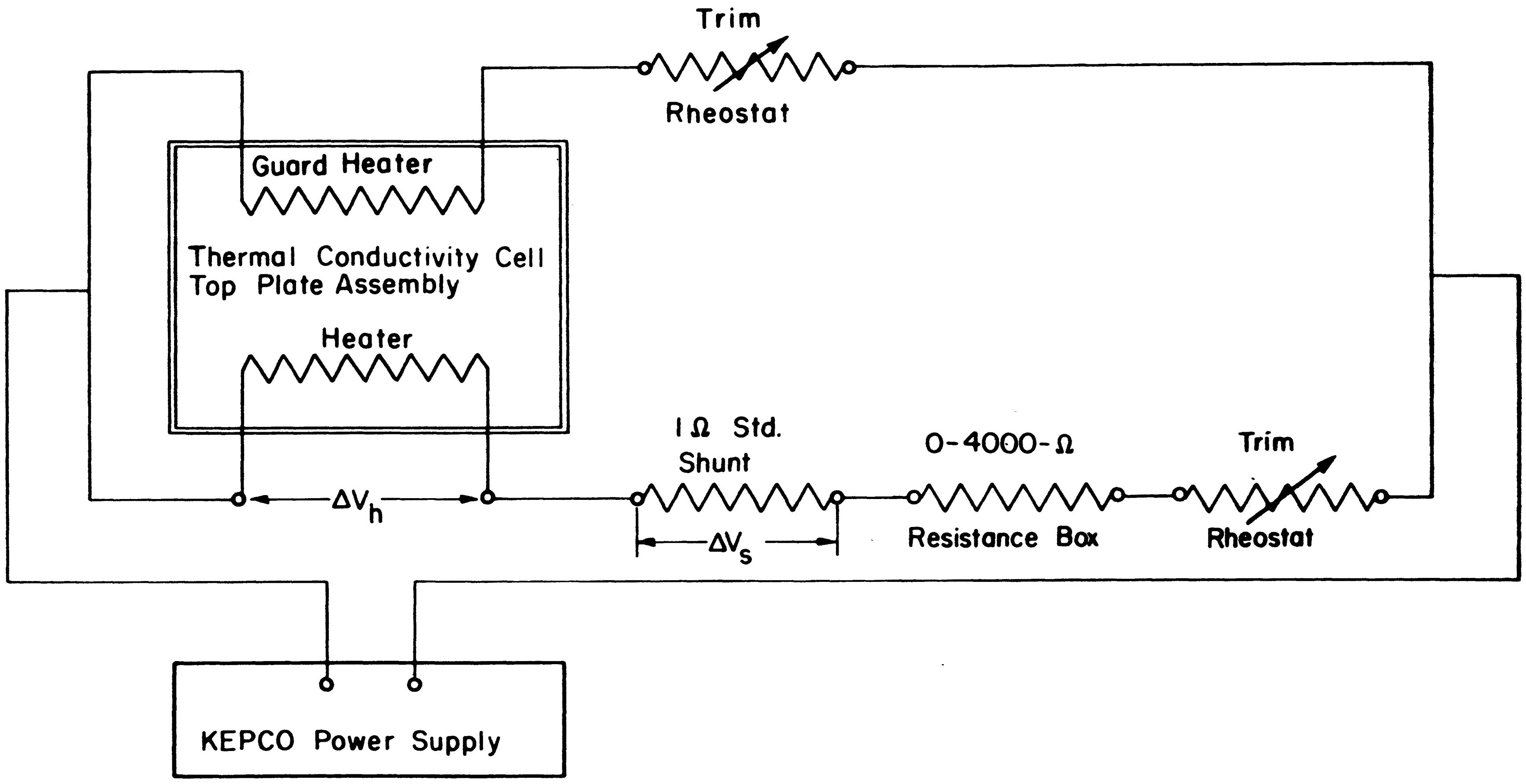


Figure 11. Thermal Conductivity Cell Heater and Guard Heater Wiring Circuit

the voltage drop is greater. A 0-10 volt Simpson D.C. volt meter and a 0-2 ampere Simpson D.C. ampere meter are used to measure the voltage drop across the guard heater and the amperage through the guard heater, respectively.

Ungrounded chromel-alumel thermocouples placed as indicated in Figures 8 and 9 are used to determine the temperatures at the desired locations. Each thermocouple contains 28 gauge wires within a 1/16 inch diameter stainless steel sheath. Cold junction thermocouples of a similar design are connected to each thermocouple with the positive lead going to a selector switch. The e.m.f. generated by each thermocouple is measured with the K-3 potentiometer and null detector.

Thermocouples 3 and 4 are located within 1/8 inch of the surface of the top and bottom plates respectively and are used to determine the temperature difference between the two plates. Thermocouples 3, 5,6 and 7 are used to determine a null temperature reading for the top plate and guard cover assemblies. Two additional thermocouples pass through the top of the cell container with the tips of the thermocouples approximately 1/8 inch from the top of the guard cover. One is used to determine the vapor temperature and the other is connected to the furnace temperature control system.

The thermal conductivity cell is housed in a container constructed of a 4 inch length of 4 inch diameter, 0.083 inch wall thickness Type 304 stainless steel tube. Three-quarter inch thick pieces of

Type 304 stainless steel round stock form the bottom and top of the container as shown schematically in Figure 10. Type 316 stainless steel Swagelok fittings were welded into the top of the container to permit the thermocouple and heater leads to pass out through the top of the cell container and to provide a leak tight seal. A 3/8 inch diameter type 316 stainless steel tube vapor line and a high temperature Hoke bellows valve, Type THY442 were also welded to the cell container as shown in Figure 10. The vapor line connects to the vacuum system.

A liquid metal boiler is connected to the cell container. The boiler is constructed of a 3 1/4 inch long section of 3/16 inch wall, Type 304 stainless steel. One-half inch thick sections of Type 304 stainless steel round stock form the bottom and top of the boiler. A 3/8 inch diameter vapor line, a 3/8 inch diameter alkali metal fill tube and a thermocouple Swagelok fitting are welded to the top of the boiler. The vapor line is connected to a 3/8 inch diameter tube on the bottom of the cell container with a Swagelok union. A high temperature Hoke bellows valve, Type 445, is connected into the line between the two containers. The fill line was capped off with a Swagelok cap after charging the container with potassium. A chromel-alumel thermocouple similar to those used in the thermal conductivity cell is used to determine the alkali metal liquid temperature in the boiler. The potassium pressure in the cell and boiler is determined using the boiler temperature and the vapor pressure data of NRL (33).

The thermal conductivity cell container and liquid metal container (boiler) rest upon a stainless steel frame within a Lindberg/Hevi-Duty Type M-6018-S vertical hinged combustion tube furnace. The furnace contains two 9 inch long heating zones, each rated at 2800 watts and a 3 inch long vestibule at the top of the furnace as shown in Figure 10. The heating chamber is 5 3/4 inches in diameter. A high temperature insulation was placed around the thermocouple and cell heater leads coming out of the cell container. The insulation fills most of the space between the top of the cell container and the top of the vestibule and reduces convection heat losses from the top of the furnace. Transite was placed over the vestibule to further reduce convection losses.

Figure 12 shows schematically the furnace heating circuit and temperature controller. Control of the temperature within the thermal conductivity cell container is accomplished with a Wheelco Model 407 Capitrol null seeking galvanometer, a Wheelco Model 350 reference voltage source and a Wheelco Model 610A pilot amplifier. A chromel-alumel thermocouple within the cell container is connected to the galvanometer where the difference in e.m.f. between the thermocouple and reference voltage is indicated by the galvanometer and becomes the input signal to the pilot amplifier which produces a direct current output to control the 5 KVA Lindberg saturable reactor. A variable transformer is located in the lower heating zone to permit adjustment of the temperature level in the lower portion of the

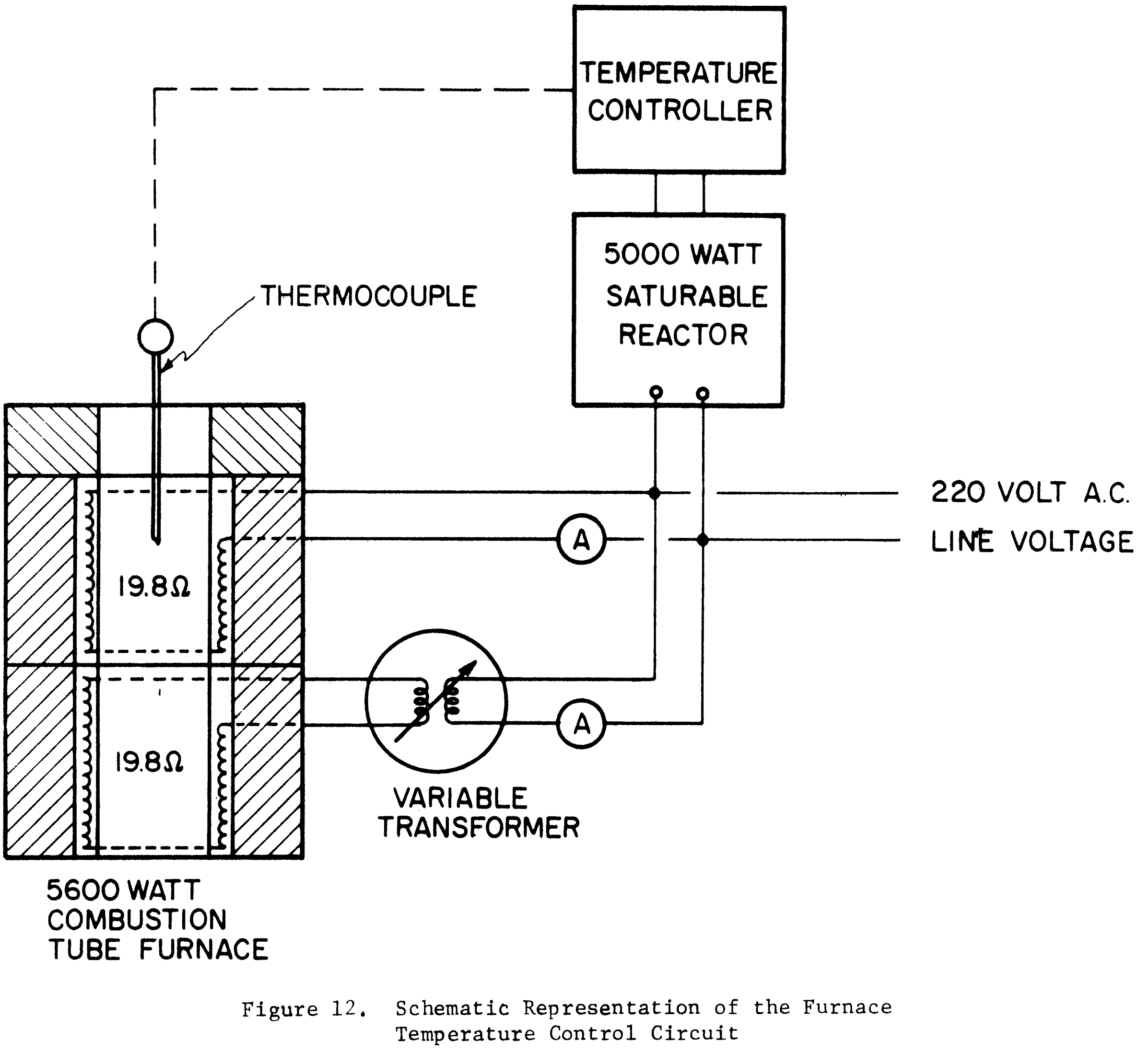


Figure 12. Schematic Representation of the Furnace Temperature Control Circuit

furnace with respect to the upper half. This is necessary to insure that the temperature within the thermal conductivity cell is always sufficiently above the saturation temperature of potassium to prevent condensation in the cell.

The vacuum system is connected to the vapor line leading from the top of the thermal conductivity cell with a 3 foot length of flexible copper tubing. A Welch Duo-Seal No. 1405H vacuum pump is the forepump for a Consolidated Vacuum Corporation two-stage oil diffusion pump, type VMF-20 (air cooled) operating with Dow Corning 704 Silicone Oil. A calibrated RCA 1946 thermocouple type vacuum gauge was used to determine the pressure. Gas pressures of 1-2 microns were readily obtained with the vacuum system. The accuracy of the vacuum gauge below 1-2 microns is limited because of the steepness of the calibration curve.

An overall view of the equipment is given in Figure 13.

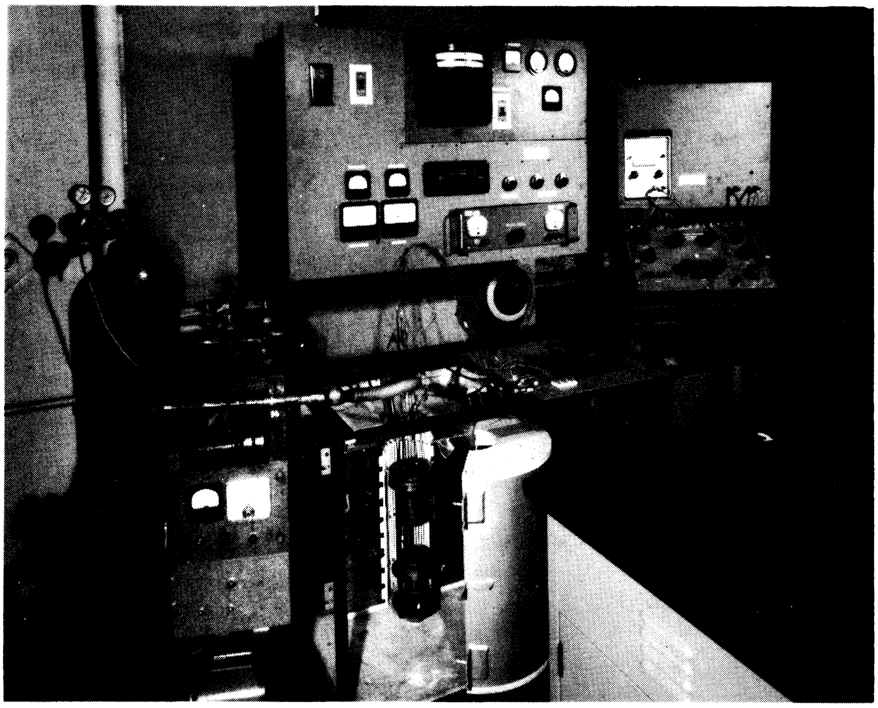


Figure 13. Overall View of the Experimental Equipment

CHAPTER IV

EXPERIMENTAL PROCEDURES

As originally planned the equipment was designed to obtain an individual thermal conductivity value from two sets of data, one set for isothermal conditions and the second for heated conditions. The isothermal data would be required to establish the temperature profile in the top and guard plate and to determine the temperature difference between the top plate and bottom plate under "isothermal conditions". Since, as will be discussed later, the thermal conductivity cell was apparently never at a uniform temperature when only the furnace heater was used, the temperature profile or null between the top and guard plates and the temperature difference between plates were needed. Isothermal conditions always refer to conditions where neither the top plate heater or guard heater are being heated. As further planned, data for the second phase of an experiment would be taken with the passage of a direct current through the top plate heater. The heater input would provide the heat flux for the cell and would cause an increase in the temperature difference between top and bottom plates. The guard heater would be used to establish the same temperature profile or null between the top plate and the guard plate as existed during the isothermal portion of the experiment. The actual temperature difference due to the top plate heater input would be the net increase in the temperature difference between the top and bottom plates over the temperature difference under isothermal conditions. The total heat transfer rate in terms of an apparent thermal conductivity would then be

$$k_t = \frac{Q_t X_s}{A \Delta t} \tag{72}$$

The apparent thermal conductivity would include the effects of radiation and conduction through the spacers.

Because of operational difficulties with the furnace, the proposed operating procedure could not be used. The experimental procedure actually used for the vacuum, nitrogen and potassium data was established after several weeks of experimentation to determine the operating characteristics of the equipment. During initial tests, the furnace temperature control system was found to be less than satisfactory. In order to obtain the best possible furnace temperature control conditions, extensive trials were performed to establish the best proportional control setting, to determine the effect of insulation both inside and outside of the furnace and to find the optimium location for the furnace control thermocouple. Under the best possible conditions the variation in the cell temperature over a 24-hour period was as much as 7°F. During the duration of a 30-minute run, the maximum variation in temperature from the mean temperature was generally no more than 0.2°F. but upon occasion varied by as much as 1-2°F. depending upon the time of day and line voltage fluctuations.

The most stable operating conditions were obtained with a proportional control band setting of 1.5 percent of meter span with extensive insulation around the outer edge of the vestibule and upon the top of the furnace and with the control thermocouple located within the cell container. The top of the furnace was covered with pieces of Transite cut to fit around the thermocouples and Fiberfrax was placed upon the Transite to minimize the loss of heat from the furnace by bulk convection.

During preliminary runs thermocouples 3 and 6 in the top plate and thermocouples 5 and 7 in the guard plate were connected together to give a null value with a single potentiometer reading. In effect the single reading was the difference in e.m.f. between the averages of the e.m.f's of thermocouples 3 and 6 and thermocouples 5 and 7. The potentiometer millivolt reading can be converted directly into a null temperature difference.

Similarly thermocouples 3 and 4 were connected to give the difference in e.m.f. generated by the two thermocouples. This difference can be converted to a difference in temperature between the upper and lower cell plates.

A switching arrangement was used to permit the use of thermocouples 3 in both the null and temperature difference circuits. The wiring diagram is given in Reference (10). All the thermocouples used in the two circuits were manufactured with ungrounded hot junctions to prevent short-circuiting between thermocouples through thermocouple sheaths and cell connections.

It was during these preliminary runs that the null was found to be larger than the null values that one might predict from the thermocouple calibration data. Preliminary calibration indicated a maximum null of +0.1 °F. at 1200°F. In addition, the null fluctuated and varied considerably during the run. Apparently the fluctuations were due to the furnace temperature variations. The temperature difference between plates varied but not nearly as much as the null temperature.

Because of the unexpected magnitude of the null temperature (∿20°F.) and the difference in temperature between plates under isothermal conditions as well as fluctuations in the readings, the two thermocouple circuits were disconnected and each thermocouple was connected individually to a selector switch with each thermocouple having its own cold junction. Several runs were made which verified that the null and temperature difference between plates were the same as previously measured with the two thermocouple circuits. Subsequent runs indicated that a temperature gradient existed along the length of the furnace and that the thermocouple e.m.f. characteristics may have changed somewhat since being calibrated probably due to the bending that was required in assembling the thermal conductivity cell. The change in calibration was not of major importance since the most important measurements involved the difference in two temperatures and the temperature differences were accurately determined in the method by which the data were taken. The accuracy of any absolute temperature was probably within 5-10°F. This estimate was based on the fact that all thermocouples generated approximately the same e.m.f. except for thermocouple 6 which was consistently lower by approximately 25-40°F. depending upon the temperature level. The e.m.f.'s generated by the thermocouples were always consistent with respect to each other during the course of a series of runs at the same general conditions, but frequently changed when the temperature level and heating conditions were changed.

Before the final operating procedure was established it was decided that each thermocouple would be left connected to an individual post on the selector switch with its own cold junction rather than connecting the thermocouples into the two circuits described previously. This procedure had a slight disadvantage in that the precision of a single temperature difference would be less because of the one less significant figure indicated on the potentiometer. However, fluctuations in the temperature differences during the course of a run were generally such that the advantage obtained when using the two circuits was small. By taking individual thermocouple readings it was possible to obtain much more information about the temperature profile in the cell and to develop some history for each thermocouple. In this way the system behavior was better understood and abnormal behavior if any could be more quickly noticed. Sufficient data were always taken and averaged so that the accuracy of any run taken with individual thermocouples was comparable to data obtained with the two thermocouple circuits.

Operating-Procedure The experimental procedure used for obtaining thermal conductivity data for nitrogen and potassium and for obtaining the radiation effects for vacuum conditions was the same once the cell was charged or evacuated. The furnace temperature controller was set at the desired temperature and the controller and furnace turned on. Steady state conditions were reached in approximately 6-8 hours. Once steady state was reached as indicated with thermocouple 3, the isothermal data runs could be begun. Each run consisted of 10 sets of readings and each set consisted of reading the e.m.f. of thermocouples 3,4,5,6,7,8 in order. The potassium boiler temperature, as indicated with thermocouple 9, was also determined when potassium data were being taken. A typical run for potassium is given in Table I.

The raw data were reduced by averaging the potentiometer millivolt readings for each thermocouple as shown in Table I. Next the millivolt reading of thermocouple 3 was subtracted from the millivolt readings of thermocouples 4,5,6,7, and 8 respectively.

Table I. Representative Sample of Original Data for Potassium Run 206955, Data Set 32

	Thermocouples - mv							Heater	
	3	4	5	6	7	8	Boiler	Volts	Amps
	24.671	24.538	24.480	24.341	23.735	24.741	17.492	3.10	0.09568
	24.669	24.535	24.484	24.336	23.736	24.745	17.496		
	24.670	24.540	24.485	24.341	23.740	24.746	17.496		
	24.674	24.539	24.488	24.339	23.743	24.745	17.502		
	24.673	24.544	24.483	24.335	23.742	24.750	17.500		
	24.672	24.544	24.489	24.345	23.745	24.750	17.504		
	24.678	24.542	24.488	24.348	23.750	24.750	17.504		
	24.679	24.545	24.481	24.351	23.746	24.746	17.504		
	24.677	24.544	24.492	24.348	23.745	24.751	17.501		
	24.677	24.547	24.495	24.349	23.735	24.751	17.504	3.10	0.09568
Avg.	24.6740	24.5418	24.4865	24.3433	23.7417	24.7475	17.5003	3.10	0.09568
	3-3	4-3	5-3	6-3	7-3	8-3			
	0	-0.1322	-0.1875	-0.3307	-0.9323	+0.0735	mv		
	0	-5.608	-7.944	-14.012	-39.504	+3.114	°F		

Null = +33.436 Guard Heater: 7.15 Volts 0.42 Amps

These differences were then divided by the millivolts/°F. at the absolute temperature of thermocouple 3 to give the temperature difference in °F. between each thermocouple and thermocouple 3. This in effect made thermocouple 3 the base thermocouple and all the cell temperatures were determined relative to thermocouple 3. Since the millivolts/°F. generated by the thermocouples is rather constant over a wide range of temperatures, temperature differences are much more accurate than absolute temperature measurements. This procedure served as a continuous calibration check of the thermocouples. Preliminary thermocouple calibrations against a N.B.S. calibrated thermocouple indicated a very close agreement between thermocouples and a maximum deviation from the standard of approximately 3°F. at 1200°F.

A null temperature was calculated from

$$\text{Null} = (t_3 + t_6) - (t_5 + t_7) \tag{73}$$

where the subscripts refer to the thermocouple number.

The temperature difference between plates was calculated from

$$\Delta t = (t_3 - t_4) \tag{74}$$

The null and temperature differences were plotted for 5-10 runs as shown in Figure 14. Because of the temperature variations within the furnace, runs were taken at the same temperature set

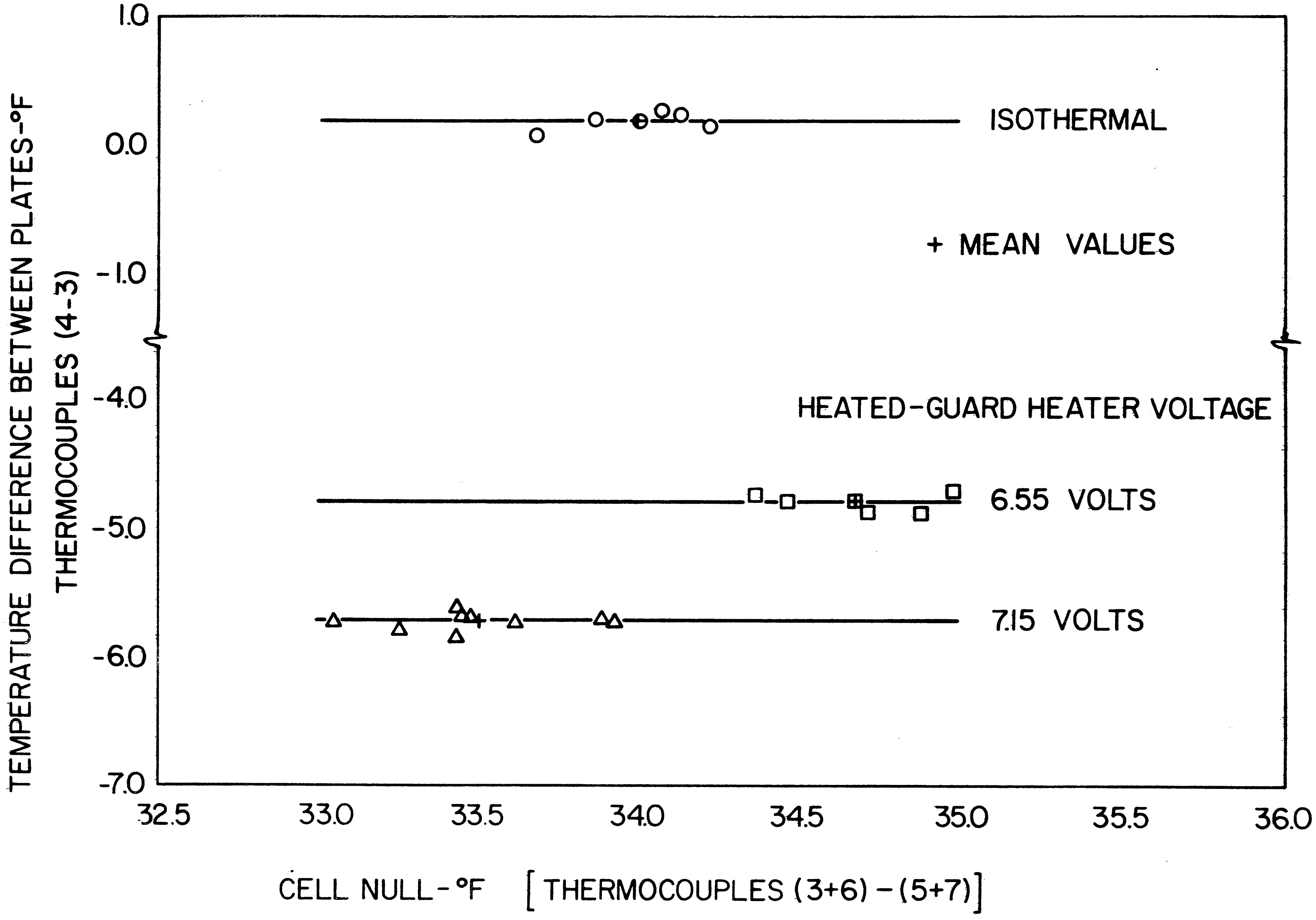


Figure 14. Typical Experimental Results for Potassium Vapor Thermal Conductivity - Data Set 32

point until a definite null temperature difference relationship was determined. Each run required approximately 30 minutes to take and approximately 10 minutes to calculate the null and temperature difference.

Once the null temperature difference relationship was established for the isothermal runs, the heated top plate data runs could be begun with the furnace at the same temperature set point. The constant voltage direct current power supply was turned on and set at the desired voltage. The top plate trim potentiometers as shown in Figure 11 were adjusted to give the desired voltage drop across the top plate heater. The guard plate trim potentiometer was then adjusted so that the voltage drop across the guard heater would result in a heat input per unit surface area comparable to that generated in the top plate heater. When steady state was reached, several runs were taken as in the isothermal case to establish the null temperature difference relationship for the heated top plate condition. If after the first few runs, it was apparent that the guard heater voltage was incorrectly set because of a significantly different null as compared to the isothermal case, the guard plate trim potentiometer was adjusted to compensate for the discrepancy and the runs continued after steady state was again reached. In addition to the thermocouple readings, voltage drops across the top plate heater, the guard plate heater and the 1 ohm standard shunt were measured and recorded. The current through the top plate heater was calculated from the voltage drop across the 1 ohm standard shunt and the current through the guard heater was measured with an ampere meter.

Data for the heated top plate were plotted in the same figure as the isothermal data as shown in Figure 14. If the guard voltage drop had been properly adjusted, the null values for the isothermal and heated top plate conditions would be identical as indicated by either the range of null values or the average of the null values. Two series of runs having the same range of null values will generally have the same average null if the runs are evenly spaced with time and 6-8 runs are taken. Because of the time required for a single run and for a series of runs, it was not always possible to space the runs evenly with time. Whenever the average nulls for the isothermal and heated top plate conditions were within 0.2°F. the range of null values was generally coincidental with the same midpoints.

The null temperature as defined in Equation 73 is equal to twice the temperature difference between the average temperatures of the top plate and the guard plate.

When after a series of runs the null values for the heated conditions differed significantly from those under isothermal conditions, the guard heater trim potentiometer was adjusted to bring the two null points closer together and another set of runs taken. All the data for a single operating condition were then plotted as in Figure 14.

Vacuum Runs Upon initiation of a series of vacuum runs, the valve between the potassium boiler and the cell was closed and the valve between the cell and the vacuum system opened. The cell and vacuum system were allowed to out-gas at ambient temperatures for approximately one day before heating the thermal conductivity cell. The furnace was then turned on and brought up to temperature (900-1200°F.) slowly over a period of a half day. During all the vacuum runs the vacuum system was always open to the cell. The absolute pressure within the system was measured with a calibrated thermocouple type vacuum gauge.

During vacuum runs the low absolute pressure greatly reduced the heat transfer by convection and conduction within the cell container. As a result the temperature fluctuations and the temperature difference between thermocouples were substantially greater than during the nitrogen and potassium runs.

A set of vacuum runs was taken prior to each set of nitrogen data during the cell calibration phase of the investigation. The vacuum runs were used to measure the combined contribution of radiation and spacer conduction.

Nitrogen Runs The nitrogen used in the investigation was manufactured by Liquid Carbonic Division of General Dynamics and had a minimum purity of 99.7%. The nitrogen was admitted to the cell through the vacuum system with the system initially under a vacuum and at ambient temperature. The nitrogen was then removed by evacuation and additional nitrogen added until the pressure was slightly above atmospheric pressure. This process was repeated several times to insure a minimum amount of impurities. The system was left under a pressure of approximately 1000 mm Hg pressure. The pressure was measured with a calibrated compound Bourdon tube gauge.

Potassium Runs The potassium used in the investigation was a high purity potassium (less than 10 ppm oxygen and less than 50 ppm sodium) obtained from Mine Safety Appliances Company in a stainless steel shipping container. The container was designed to facilitate the transfer of potassium to other containers.

The potassium boiler, the potassium shipping container, the vacuum system and a helium gas cylinder were connected together with tubing and fittings to effect the transfer of the desired amount of potassium to the boiler. A vacuum was pulled on the entire system except for the shipping container and the system checked for leaks. When found leak free, the boiler and the shipping container and the line between the two containers were then heated to approximately 200°F. with electrical heating tapes to melt the potassium (melting point 146°F.) and to keep the transfer lines above the melting point. The load valve on the potassium container was opened and the helium in the container evacuated and then refilled with helium to a pressure of approximately 780 mm Hg. The load valve was then closed. The empty boiler was next filled with helium to a pressure of 350 mm Hg and the valve leading to the boiler closed. By slowly opening the valve in the fill line which connected the potassium container and boiler, potassium began to flow into the boiler because of the small pressure differential and continued to flow until the helium being compressed in the boiler was at the same pressure as the helium in the container. After the pressures had equalized the valve in the fill line was closed and the helium pressure in the boiler increased to approximately 1500 mm Hg. Residual potassium in the fill line was then forced back into the container by the pressurized helium in the boiler by opening the fill line valve. The entire system was then cooled down to room temperature.

With a helium pressure on the system slightly above atmospheric pressure, the boiler was removed and capped for weighing. The weight of the boiler before and after filling indicated that 3 1/4 ounces of potassium had been added to the boiler. This was sufficient potassium to fill 3/4 of the container at operating conditions and more than sufficient to keep the top of the thermocouple sheath submerged in liquid potassium.

The cap was then removed from the boiler and the boiler connected to the thermal conductivity cell container which had also been filled with helium. A vacuum was then pulled on the system and the system flushed with helium several times. The valve between the cell container and the boiler was then closed leaving helium in the vapor space of the boiler at essentially atmospheric pressure.

The thermal conductivity cell and vacuum system was thoroughly out-gassed and a set of vacuum runs taken at 1000°F.-data set 9.

It has been planned to determine the radiation effects under vacuum conditions prior to each set of potassium data, but when the equipment was cooled down the valve between the boiler and cell container could not be opened. The valve stem was sheared twice attempting to open the valve because of seizing of the valve stem threads. Before any additional attempts to open the valve, three additional vacuum data sets were then taken at 1100, 1200, and 1300°F.-data sets 10-12.

Upon completion of the vacuum runs, the cell container and boiler were removed from the furnace and the valve bonnet and the residual valve stem plug removed from the valve body. With the plug removed the bellows was free to expand - opening the valve. An identical Hoke Type TY445 valve was purchased in order to obtain a new bonnet and valve stem plug. A thread lubricant and anti-seize compound sold by Crawford Fitting Company under the name of Silver Goop was applied to the valve parts and the old valve rebuilt. The secondary valve packing was left out upon reassembly because it had charred previously contributing to the valve trouble. The valve operated satisfactorily after reassembly.

The cell container and boiler were than placed back into the furnace and connected to the vacuum system. The thermocouples and the heater circuits were also reconnected. Upon completion of a thorough out-gassing the system was ready to begin a series of potassium runs.

Potassium runs were made with the valve between the cell container and the vacuum system closed and the valve between the cell container and the boiler opened. The furnace was brought up to temperature slowly. Once close to the desired cell temperature, the furnace temperature controller was allowed to operate normally. The temperature of the liquid potassium in the boiler was brought to the desired level by adjusting the variable transformer in the lower heating element circuit of the furnace as shown in Figure 12. The boiler temperature was maintained at a temperature approximately 100°F. less than the cell temperature to insure that only potassium vapor was present in the cell. The pressure of the potassium vapor in the cell was assumed to be equal to the vapor pressure of the liquid potassium in the boiler as determined from the boiler temperature and the vapor pressure data of Ewing (33).

Two sets of potassium data were taken at 1000°F., data sets 13 and 14, and with the boiler temperatures at approximately 800 and 930°F., respectively. Upon completion of these runs the system was cooled down to room temperature and the top valve opened to determine if there had been any leakage into the system during the week that data were being taken. No significant leakage was apparent as indicated on the thermocouple vacuum gauge. The top valve was again closed and the system out-gassed and heated to 1100°F. for additional potassium data. Upon completion of each data set at 1100°F., data sets 15-17, preliminary calculations were made to determine the total thermal conductivity k_t. The value of k_t for data set 15 was lower than that obtained for a corresponding pressure condition at 1000°F, and the values became progressively less for data sets 16 and 17 which were at higher cell pressures. Since this was contrary to what was expected, it was postulated and later verified that the emissivity of the molybdenum surface had changed since the beginning of the potassium runs. Additional runs at 1200°F. were made with the hope that the proper radiation correction could be found later.

The top high temperature valve became inoperable after the completion of data set 20. Fortunately the valve was taken apart without serious damage to the bonnet and valve stem plug. After repairs were effected and the valve parts coated with Silver Goop and reassembled, the valve worked satisfactorily during the balance of the investigation.

The runs for data set 21 were then taken at the same temperature and pressure conditions as data set 13. The calculated valve of the total thermal conductivity k_t for data set 21 was substantially less than the value for data set 13. The system was cooled down and the valve between the cell and the boiler closed. Checks to determine if the two high temperature valves were functioning properly revealed that potassium was in the short length of 3/8 inch diameter tubing connecting the top high temperature valve to the cell container. After some initial attempts to evacuate the potassium through the vacuum system were unsuccessful, the line between the top valve and the vacuum system was wrapped with heating tape and the furnace heated to 1300°F. The system was out-gassed under these conditions for several days. A later check indicated that the line was substantially free of potassium at that time. This was again verified when vacuum data runs were taken at 1000 and 1200°F.-data sets 24 and 25.

Vacuum runs taken at 1000°F. and 1200°F. for data sets 24 and 25 revealed that the apparent thermal conductivity under vacuum conditions $k_{rad.}$ was significantly lower than in the vacuum runs taken prior to the potassium runs. This verified that the emissivity of the molybdenum surface had changed. When the appropriate values of $k_{rad.}$ were subtracted from the values of the total thermal conductivity k_t for data sets 13 and 21, the values of the thermal conductivity of potassium vapor k_c for the two data sets were in good agreement.

A small heater was constructed of nichrome wire and ceramic insulators and attached to the 3/8 inch diameter tube between the top valve and the cell container. During the balance of the potassium runs, data sets 26-32, the heater was used to keep the tube hot and prevent condensation in the line. The heater kept the temperature in the vestibule considerably hotter than before, but if the voltage drop across the heater was too great, the temperature fluctuations in the cell became excessive. This was quite apparent for data sets 26 and 27. The voltage drop across the heater was normally kept at about 20 volts.

CHAPTER V

EXPERIMENTAL DATA AND ANALYSIS

The experimental data were processed to the extent illustrated in Table I and Figure 14 at the time the data were taken. This step consisted of averaging the thermocouple millivolt readings and computing the average temperature differences between each cell thermocouple and thermocouple 3. The cell null temperature was also computed. These data and results are given in Appendices A and B.

Each data set was processed in a similar method whether for vacuum, nitrogen or potassium runs. From each set of data it was necessary to determine the mean overall temperature differences between the top and bottom plates due to conduction and radiation and to determine the net heat input to the top plate.

The mean temperature difference Δt between the top and bottom plates due to conduction and radiation from the heated top plate was determined by a statistical analysis of the data. For each guard heater voltage value, least squared deviation lines of equal slope were placed through the isothermal data points and the heated top plate data points as previously illustrated in Figure 14 for data set 32. Although the lines through the data of data set 32 are nearly horizontal, lines of definite positive or negative slopes were obtained for other data sets depending upon the gas or vapor and the furnace temperature conditions. The difference in the ordinate values of the two lines is the mean temperature difference between plates. The equations of the lines, the temperature difference, the mean error in the temperature difference, the mean temperatures and the mean null temperatures were computed using the Ford Motor Company's GE 265 computer. The computer program and a typical output is given in Appendix C. Table II gives a summary of the operating conditions for all the data sets and the preliminary results as processed with the digital computer.

The net heat input to the top plate by the top plate heater was found by a four part process. As indicated in the discussion of equipment, the heater consisted of a heating coil and two nickel lead wires which extended from the coil to a point approximately 10 inches from the coil and outside the cell container. First, the total resistance of the top plate heater and lead wires as listed in Table III was calculated using the average voltage drop across the heater and lead wires and the average current through the heater and lead wires. Next the resistance of the lead wires were estimated from Figure D.3 in Appendix D using the temperature indicated by thermocouple 8 which was positioned in the cell container immediately above the cell. The heater resistance was found by subtracting the lead wire resistance from the total resistance. Lastly, the heat input to the top plate by the top plate heater was determined from

Table II. Summary of Operating Conditions for the Experimental Data - Data Sets 1-32

Data Set	Gas or Vapor	Top Plate Temp. °F	System Pressure mm Hg	Average Null Isothermal °F	Guard Heater Voltage Volts d.c.	Average Null Heated Top Plate °F	Heater Voltage Volts d.c.	Heater Current Amps d.c.	Δt from Heating °F	Standard Error of Δt °F
1	vac.	932.5	0.004	25.681	Isothermal					
	vac.	948.2	0.002	25.681	4.0	25.753	1.199	0.03637	9.731	0.376
2	N_2	924.3	1210	13.996	Isothermal					
	N_2	925.8	1190	13.996	5.8	13.991	3.497	0.10671	1.999	0.255
3	vac.	1031.3	0.002	27.982	Isothermal					
	vac.	1033.6	0.002	27.982	3.05	28.484	1.807	0.05630	3.652	0.231
4	N_2	1028.4	1299	16.144	Isothermal					
	N_2	1028.5	1305	16.144	5.95	15.690	3.595	0.11084	2.118	0.071
5	vac.	1117.6	0.002	30.502	Isothermal					
	vac.	1118.5	0.001	30.502	3.15	31.060	1.849	0.05729	2.599	0.351
6	N_2	1113.2	1363	17.401	Isothermal					
	N_2	1114.0	1360	17.401	5.95	17.002	3.585	0.10989	1.860	0.119
7	vac.	1211.9	0.001	30.324	Isothermal					
	vac.	1214.9	0.002	30.324	4.6	30.651	2.415	0.07435	2.776	0.292
8	N_2	1209.8	1362	20.760	Isothermal					
	N_2	1214.1	1380	20.760	6.8	20.975	3.511	0.10779	1.643	0.082
9	vac.	1005.1	0.002	34.352	Isothermal					
	vac.	1009.4	0.002	34.352	4.0	34.483	1.800	0.05508	3.617	0.103
10	vac.	1109.3	0.002	37.777	Isothermal					
	vac.	1114.1	0.002	37.777	3.9	35.571	1.900	0.05775	2.299	0.159

Table II. (continued)

Data Set	Gas or Vapor	Top Plate Temp. °F	System * Pressure mm Hg or lbs./ sq.in.	Average Null Isothermal °F	Guard Heater Voltage Volts d.c.	Average Null Heated Top Plate °F	Heater Voltage Volts d.c.	Heater Current Amps. d.c.	Δt from Heating °F	Standard Error of Δt °F
11	vac.	1201.6	0.002	39.710	Isothermal					
	vac.	1204.0	0.002	39.710	4.5	43.162	2.300	0.06960	2.605	0.131
	vac.	1208.9	0.002	39.710	5.0	40.378	2.300	0.06964	3.254	0.214
12	vac.	1298.7	0.002	43.009	Isothermal					
	vac.	1308.5	0.002	43.009	5.0	43.615	2.300	0.06932	2.202	0.132
	vac.	1304.0	0.002	43.009	5.25	42.894	2.300	0.06915	3.009	0.201
13	K	1004.5	0.168	37.189	Isothermal					
	K	1014.3	0.163	37.189	8.2	36.272	3.600	0.11065	7.061	0.059
	K	1013.4	0.166	37.189	7.6	36.873	3.600	0.11023	6.554	0.061
	K	1012.2	0.167	37.189	7.3	36.644	3.600	0.10993	6.058	0.062
	K	1012.4	0.168	37.189	6.9	37.335	3.600	0.11000	5.688	0.058
14	K	1011.6	0.630	44.225	Isothermal					
	K	1018.0	0.606	44.225	6.9	43.754	3.600	0.11044	5.762	0.042
	K	1023.3	0.646	44.225	6.5	44.604	3.600	0.11030	5.173	0.055
15	K	1105.1	0.180	35.164	Isothermal					
	K	1109.1	0.172	35.164	6.7	35.904	3.600	0.11004	5.183	0.063
	K	1109.3	0.173	35.164	8.0	35.139	3.600	0.10986	6.573	0.070
16	K	1107.7	0.517	40.452	Isothermal					
	K	1111.3	0.494	40.452	8.0	41.847	3.600	0.10997	6.870	0.038
	K	1113.8	0.501	40.452	9.0	40.259	3.600	0.11015	7.961	0.096
	K	1111.1	0.518	40.452	5.5	42.842	3.600	0.10974	4.145	0.040
17	K	1108.3	1.235	45.882	Isothermal					
	K	1117.7	1.201	45.882	8.0	44.577	3.110	0.09494	6.336	0.172
	K	1113.1	1.150	45.882	7.0	46.302	3.110	0.09518	5.151	0.074

*Pressure for vacuum runs in mm Hg; K runs in lbs./sq.in.

Table II. (continued)

Data Set	Gas or Vapor	Top Plate Temp. °F	System Pressure * mm Hg or lbs. / sq.in.	Average Null Isothermal- °F	Guard Heater Voltage Volts d.c.	Average Null Heated Top Plate °F	Heater Voltage Volts d.c.	Heater Current Amps. d.c.	Δt from Heating °F	Standard Error of Δt °F
18	K	1186.6	0.470	38.149	Isothermal					
	K	1190.4	0.459	38.149	7.0	38.149	3.100	0.09448	4.399	0.083
19	K	1187.2	1.155	43.428	Isothermal					
	K	1194.5	1.155	43.428	7.0	43.542	3.100	0.09469	4.197	0.202
20	K	1195.6	1.187	50.578	Isothermal					
	K	1203.2	1.184	40.578	7.0	50.560	3.100	0.09523	4.388	0.150
21	K	998.7	0.161	38.609	Isothermal					
	K	1005.6	0.155	38.609	6.2	39.206	3.100	0.09491	5.397	0.022
	K	1008.0	0.155	38.609	7.0	38.535	3.100	0.09455	6.474	0.028
22	vac.	997.0	0.003	36.232	Isothermal					
	vac.	999.4	0.003	36.232	5.0	36.473	2.200	0.06651	3.702	0.134
	vac	1001.2	0.003	36.232	6.0	35.897	2.200	0.06669	4.757	0.255
23	vac.	993.9	0.002	33.527	Isothermal					
	vac.	1003.3	0.002	33.527	6.5	33.939	2.600	0.07903	5.515	0.126
	vac.	1002.5	0.002	33.527	7.2	33.376	2.600	0.07906	6.779	0.157
24	vac.	998.3	0.002	29.910	Isothermal					
	vac.	1005.6	0.001	29.910	5.6	29.908	1.400	0.04269	7.621	0.208
25	vac.	1187.1	0.002	33.206	Isothermal					
	vac.	1193.0	0.002	33.206	5.6	32.789	1.400	0.04265	4.714	0.099
	vac.	1193.8	0.002	33.206	5.1	33.423	1.400	0.04268	3.825	0.096

*Pressure for vacuum runs in mm Hg; K runs in lbs./sq.in.

Table II. (continued)

Data Set	Gas or Vapor	Top Plate Temp. °F	System Pressure lbs./ sq.in.	Average Null Isothermal °F	Guard Heater Voltage Volts d.c.	Average Null Heated Top Plate °F	Heater Voltage Volts d.c.	Heater Current Amps.d.c.	Δt from Heating °F	Standard Error of Δt °F
26	K	1012.0	0.483	40.929	Isothermal					
	K	1018.9	0.450	40.929	6.95	40.599	3.110	0.09591	6.586	0.325
27	K	1010.9	0.489	40.105						
	K	1018.1	0.492	40.105	6.60	40.163	3.109	0.09553	4.658	0.469
28	K	1090.0	0.159	35.033	Isothermal					
	K	1098.4	0.158	35.033	6.8	35.676	3.098	0.09479	5.236	0.101
	K	1097.0	0.150	35.033	7.6	34.421	3.100	0.09490	6.484	0.112
29	K	1095.3	0.430	38.522	Isothermal					
	K	1103.1	0.411	38.522	7.42	38.440	3.119	0.09560	6.232	0.105
	K	1099.1	0.403	38.522	7.0	38.715	3.120	0.09570	5.933	0.078
	K	1099.3	0.405	38.522	6.6	39.358	3.110	0.09547	5.634	0.078
30	K	1185.8	0.189	33.011	Isothermal					
	K	1192.8	0.192	33.011	6.80	33.848	3.113	0.09522	4.619	0.121
	K	1194.4	0.195	33.011	7.75	33.530	3.110	0.09509	5.162	0.081
	K	1193.7	0.187	33.011	8.50	32.690	3.110	0.09508	6.302	0.062
31	K	1189.2	0.397	35.494	Isothermal					
	K	1194.1	0.394	35.494	8.50	34.176	3.114	0.09540	6.190	0.140
	K	1192.4	0.395	35.494	7.55	35.239	3.120	0.09541	5.070	0.135
32	K	1094.7	0.162	33.994	Isothermal					
	K	1101.8	0.156	33.994	7.15	33.504	3.109	0.09569	5.895	0.050
	K	1102.2	0.163	33.994	6.55	34.678	3.110	0.09561	4.974	0.045

Table III. Summary of the Top Plate Heater Temperatures and Resistances - Data Sets 1-32

Data Set	Heater Voltage Volts	Heater Current Amps	Total Heater Resistance Ohms	Heater Lead Wire Temperature °F	Lead Wire Resistance Ohms	Heater Resistance Ohms
1	1.199	0.03637	32.961	980	4.02	28.941
2	3.497	0.10671	32.771	980	4.02	28.751
3	1.807	0.05630	32.096	1070	4.19	27.906
4	3.595	0.11084	32.425	1070	4.19	28.235
5	1.849	0.05729	32.274	1165	4.36	27.914
6	3.585	0.10989	32.623	1165	4.36	28.263
7	2.415	0.07435	32.481	1265	4.54	27.941
8	3.511	0.10779	32.576	1265	4.54	28.036
9	1.800	0.05508	32.680	1013	4.11	28.570
10	1.900	0.05775	32.900	1108	4.31	28.590
11	2.300	0.06962	33.036	1197	4.47	28.566
12	2.300	0.06924	33.218	1291	4.64	28.578
13	3.600	0.11020	32.668	1005	4.10	28.568
14	3.600	0.11037	32.618	996	4.08	28.538
15	3.600	0.10995	32.742	1109	4.31	28.432
16	3.600	0.10995	32.742	1102	4.30	28.442
17	3.110	0.09506	32.716	1096	4.29	28.426
18	3.100	0.09448	32.811	1190	4.46	28.351
19	3.100	0.09469	32.738	1184	4.45	28.288
20	3.100	0.09523	32.553	1181	4.45	28.103
21	3.100	0.09473	32.725	999	4.07	28.650
22	2.200	0.06661	33.028	996	4.07	28.958
23	2.600	0.07905	32.890	1000	4.09	28.800
24	1.400	0.04269	32.795	1005	4.10	28.695
25	1.400	0.04266	32.817	1194	4.46	28.357
26	3.110	0.09591	32.426	999	4.07	28.356
27	3.109	0.09553	32.545	997	4.07	28.475
28	3.099	0.09485	32.673	1099	4.30	28.373
29	3.116	0.09559	32.598	1094	4.28	28.318
30	3.111	0.09513	32.702	1202	4.48	28.222
31	3.117	0.09541	32.671	1196	4.46	28.211
32	3.110	0.09565	32.514	1105	4.30	28.214

$$Q_t = 3.413 \ \frac{\text{Btu/hr}}{\text{watt}} \ (i^2 R_h) \tag{75}$$

Values of the heat input Q_t are tabulated in Tables IV, V, and VI for the vacuum, nitrogen, and potassium data, respectively.

As indicated in Table II for most data sets the average values of the null for the heated top plate data did not agree sufficiently close with the average value of the null for the isothermal data. When this occurred the guard heater voltage was adjusted to bring the heated top plate null closer to the null value for the isothermal data. The top plate heater voltage and current were always kept the same throughout the duration of a data set. Each guard heater voltage setting gave a definite temperature difference between plates and average null temperature as shown in Figure 14. By taking data at two or more guard heater voltages it was possible to closely estimate by interpolation the temperature difference that would exist between plates if the null values for the isothermal and heated top plate conditions were the same. The interpolated estimates of the temperature difference between plates are listed in Tables IV, V, and VI for the vacuum, nitrogen and potassium data, respectively.

The effective area of the top plate for heat transfer to the bottom plate was determined using the analog to the effective area of a Thomson condensor (75). This dilemma arises because the guard plate and top plate are separated by a radial gap while

Table IV. Experimental Results for Apparent Thermal Conductivity Under Vacuum Conditions

Data Set	T cell °F	P cell mm Hg	Q Btu./hr.	Δt °F	k Btu./hr.ft.-°F
1	943.3	0.003	0.13066	9.731	0.00089
3	1031.8	0.002	0.30189	3.652	0.00547
5	1117.2	0.001	0.31269	2.599	0.00797
7	1213.5	0.002	0.52717	2.776	0.01257
9	1007.6	0.002	0.29582	3.617	0.00541
10	1113.0	0.002	0.32543	2.299	0.00937
11	1204.7	0.002	0.47256	3.420	0.00915
12	1304.8	0.002	0.46760	2.875	0.01077
22	998.1	0.003	0.43851	4.140	0.00701
23	999.7	0.002	0.61424	6.480	0.00628
24	1001.8	0.002	0.17860	7.621	0.00155
25	1191.3	0.002	0.17613	4.129	0.00282

Table V. Experimental Results for Thermal Conductivity of Nitrogen

Data Set	T_{cell} °F	P_{cell} mmHg	Q Btu/hr.	Δt °F	k_t Btu/hr.ft.-°F	$k_{rad.}$ Btu./hr.ft.-°F	k_c Btu./hr.ft.-°F
2	924.8	1190	1.1174	1.999	0.03701	0.00391	0.03310
4	1027.4	1305	1.1839	2.117	0.03702	0.00542	0.03160
6	1113.1	1360	1.1649	1.860	0.04147	0.00727	0.03420
8	1213.3	1380	1.1118	1.643	0.04479	0.00972	0.03507

Table VI. Experimental Results for Thermal Conductivity of Potassium Vapor at Various Saturation Temperatures

Data Set	T_{cell}	T_{Boiler}	P_{cell} lbs./sq.in.	Q Btu./hr.	Δt °F	k_t Btu./hr.ft.-°F	$k_{rad.}$ Btu./hr.ft.-°F	k_c Btu./hr.ft.-°F
13	1010.1	805.6	0.166	1.1841	5.910	0.01327	0.00472	0.00855
14	1017.9	930.9	0.626	1.1865	5.410	0.01452	0.00435	0.01017
15	1105.9	809.8	0.173	1.1731	6.520	0.01191	0.00522	0.00669
16	1108.2	911.2	0.504	1.1735	7.783	0.00998	0.00461	0.00537
17	1112.6	1006.8	1.160	0.8767	5.445	0.01066	0.00409	0.00657
18	1189.9	899.7	0.459	0.8637	4.399	0.01300	0.00460	0.00840
19	1192.4	1003.4	1.155	0.8657	4.197	0.01366	0.00418	0.00948
20	1201.0	1106.5	1.184	0.8698	4.388	0.01312	0.00383	0.00929
21	1003.6	798.3	0.155	0.8775	6.360	0.00913	0.00165	0.00748
26	1015.6	897.4	0.450	0.8902	6.000	0.00982	0.00161	0.00821
27	1015.8	906.8	0.492	0.8869	4.658	0.01260	0.00161	0.01099
28	1094.8	797.9	0.154	0.8712	5.884	0.00980	0.00215	0.00765
29	1097.4	885.4	0.406	0.8831	5.950	0.00983	0.00216	0.00767
30	1190.7	817.5	0.191	0.8717	5.600	0.01020	0.00281	0.00739
31	1190.8	882.3	0.395	0.8764	4.805	0.01208	0.00283	0.00925
32	1099.2	800.8	0.160	0.8810	5.502	0.01060	0.00218	0.00842

the bottom plate is a continuous surface. The effective area is given by

$$A = \pi\left[\frac{r_g^2 + r_u^2}{2} - {\frac{r_g - r_u}{2}}^2 \left[1 + \frac{\pi d}{r_g - r_u}\left\{\ln 2\left(1 + e^{-\pi D/r_g - r_u}\right)^{-1}\right]^{-1}\right\}^{-1}\right] \tag{76}$$

where r_g = inside radius of guard plate

r_u = outside radius of top plate

D = thickness of the upper plate

d = distance between top and bottom plates

The effective area was 0.022858 sq. ft. compared to a nominal area of 0.022110 sq. ft. The distance between top and bottom plates was 0.0182 in.

Upon heating the effective area increases because of expansion but so does the thickness of the gap between plates. The two expansion factors tend to compensate for each other. Using the thermal expansion coefficient of molybdenum for the area expansion and the thermal expansion coefficient of the sapphire balls for the gap expansion, the ratio of the gap expansion to the area expansion was such that between 900 and 1400°F.

$$\frac{X_s}{A} = \frac{(0.998)(0.0182/12 \text{ ft.})}{0.022858 \text{ sq.ft.}} = 0.06621 \text{ ft.}^{-1} \tag{77}$$

with a maximum error at either temperature extreme of 0.02 percent. The constant expansion factor simplified the calculations.

For each data set, the total thermal conductivity can be calculated from

$$k_t = \frac{Q_t X_s}{A \Delta t} \tag{72}$$

where k_t includes the contribution of radiation as well as thermal conductivity.

<u>Vacuum Runs</u> Vacuum runs were made to determine the exact magnitude of the effects of radiation between plates and conduction through the spacers. Since the spacers offer nearly point contacts on at least one surface, the amount of energy transferred should be small in comparison with radiation effects at elevated temperatures. This was verified by Rothman (84).

The total heat transferred by radiation is given by

$$Q_{rad.} = \sigma A \; F_e F_a \; (T_1^4 - T_2^4) \tag{37}$$

when

$T_1 \simeq T_2$, Equation 37 can be written as

$$Q_{rad.} = 4 \; \sigma A \; F_e F_a \; (T_1^3) \; \Delta t \tag{78}$$

where $\Delta t = T_1 - T_2$ (79)

In terms of an equivalent thermal conductivity, the radiation contribution can be expressed as

$$k_{rad.} = \frac{Q_{rad.}X_s}{A\Delta t} \tag{80}$$

in which

$$k_{rad.} = 4\sigma X_s F_e F_a T_1^3 \tag{81}$$

The radiation data are given in Figure 15 and Table IV in terms of $k_{rad.}$ For infinite parallel plates (13),

$$F_a = 1 \tag{82}$$

and

$$F_e = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \tag{83}$$

which becomes for plates of equal emissivity

$$F_e = \frac{1}{\frac{2}{\varepsilon} - 1} \tag{84}$$

Therefore, $k_{rad.}$ and ε are related through Equations 81 and 84 and either quantity can be computed from a knowledge of the other.

The first set of vacuum runs prior to the first nitrogen runs gave a value of $k_{rad.}$ = 0.00089 Btu/hr.-ft.-°F. at 934°F. which agreed closely with what one would calculate using Goldsmith's (42)

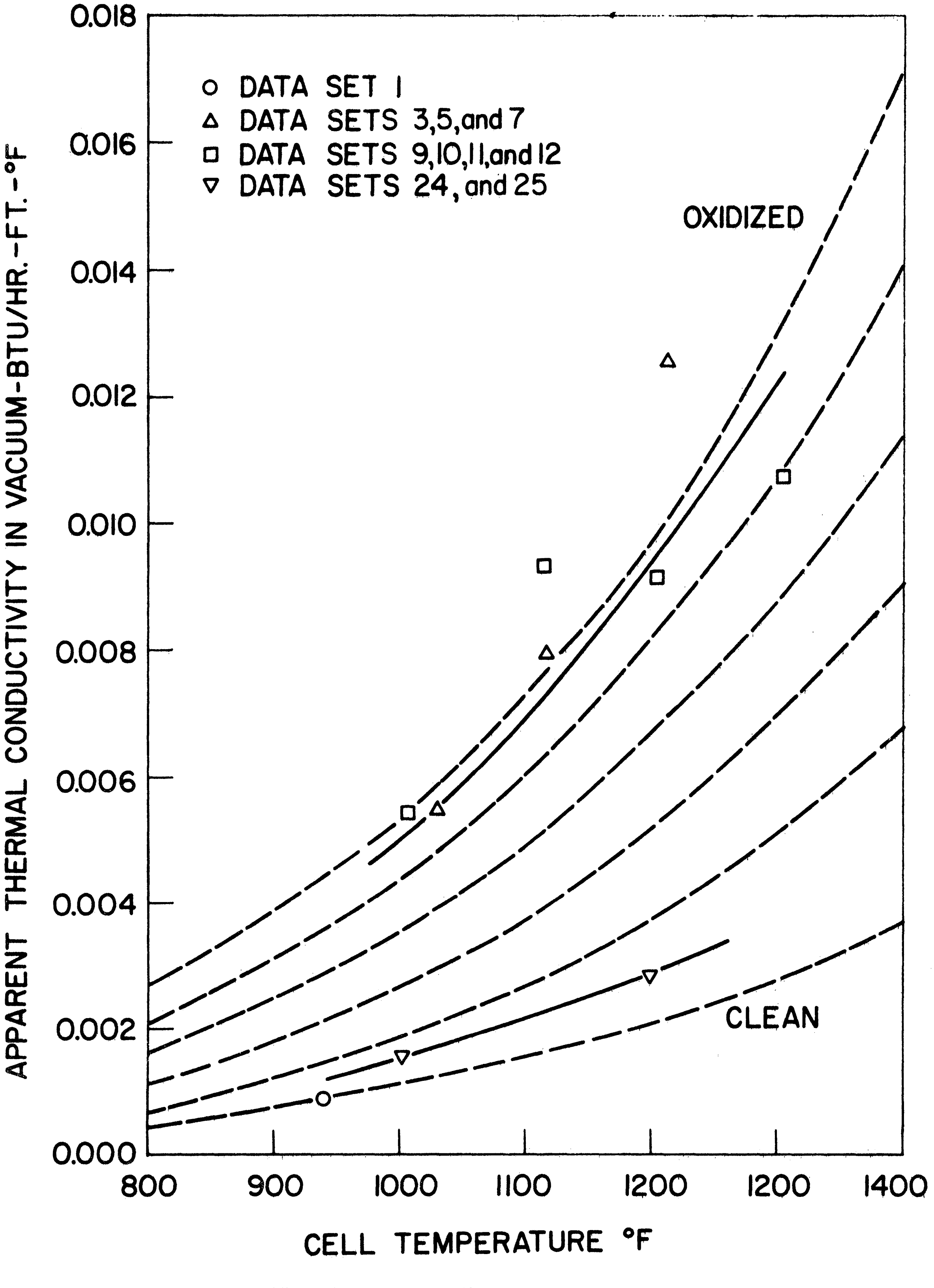


Figure 15. The Apparent Thermal Conductivity Under Vacuum Conditions

emissivity values for a clean molybdenum surface. Subsequent vacuum runs, data sets 3,5, and 7, gave values of $k_{rad.}$ considerably higher than one would predict for a clean surface. The surface had apparently been oxidized by the small amount of oxygen present in the nitrogen.

In order to analyze and correlate the radiation data, Goldsmith's (42) emissivity data for oxidized molybdenum surfaces was used. For a surface which is partially oxidized, emissivity increases slightly with temperature. Using the same temperature effect as for the data of Goldsmith, a series of lines were drawn which represented emissivity versus temperature for various degrees of oxidization. From these curves, the dashed lines in Figure 15 were computed using Equations 81 and 84. The top line in Figure 15 for a partially oxidized surface represents a variation in emissivity from 0.260 at 940°F. to 0.385 at 1340°F. The bottom line for a clean surface represents a variation in emissivity from 0.059 at 940°F. to 0.101 at 1340°F.

The vacuum runs taken prior to the exposure of the cell surface to potassium revealed more or less a consistent pattern. The best curve through these data is shown as the upper smooth curve in Figure 15. There is a fair amount of scatter in these data. The temperature fluctuations are much more severe for low pressure runs because of the reduced heat transfer and the results are apt to be less consistent. The standard error of Δt for these data sets was in the order of 0.3°F. for a Δt of 3.0°F. After the molybdenum surface had been exposed to potassium for some time the surface emissivity decreased. This was verified by the results obtained from data sets 24 and 25 which gave a consistent picture with a minimum of temperature fluctuations. The standard error in Δt was 0.2 for a Δt of 7.6 for data set 24 and 0.1 for a Δt of approximately 4.0 for data set 25. The results shown in Figure 15 indicated that the surface was nominally oxide free--giving values of $k_{rad.}$ comparable to those for a clean surface.

Nitrogen Runs A series of nitrogen runs was made between 900 and 1200°F. to serve as a calibration of the cell and to check on the method of analysis. A summary of the operating conditions is given in Table V. The nitrogen pressure for the runs was approximately 1.5 atmospheres.

The total rate of heat transfer in terms of a thermal conductivity was calculated from

$$k_t = \frac{Q_t X_s}{A\Delta t} \qquad (72)$$

The thermal conductivity of nitrogen was then obtained from

$$k_c = k_t - k_{rad.} \qquad (85)$$

Where $k_{rad.}$ was taken from the top solid line of Figure 15 at the cell temperature. Values of the thermal conductivity of nitrogen for the test conditions are given in Table V and in Figure 16. As

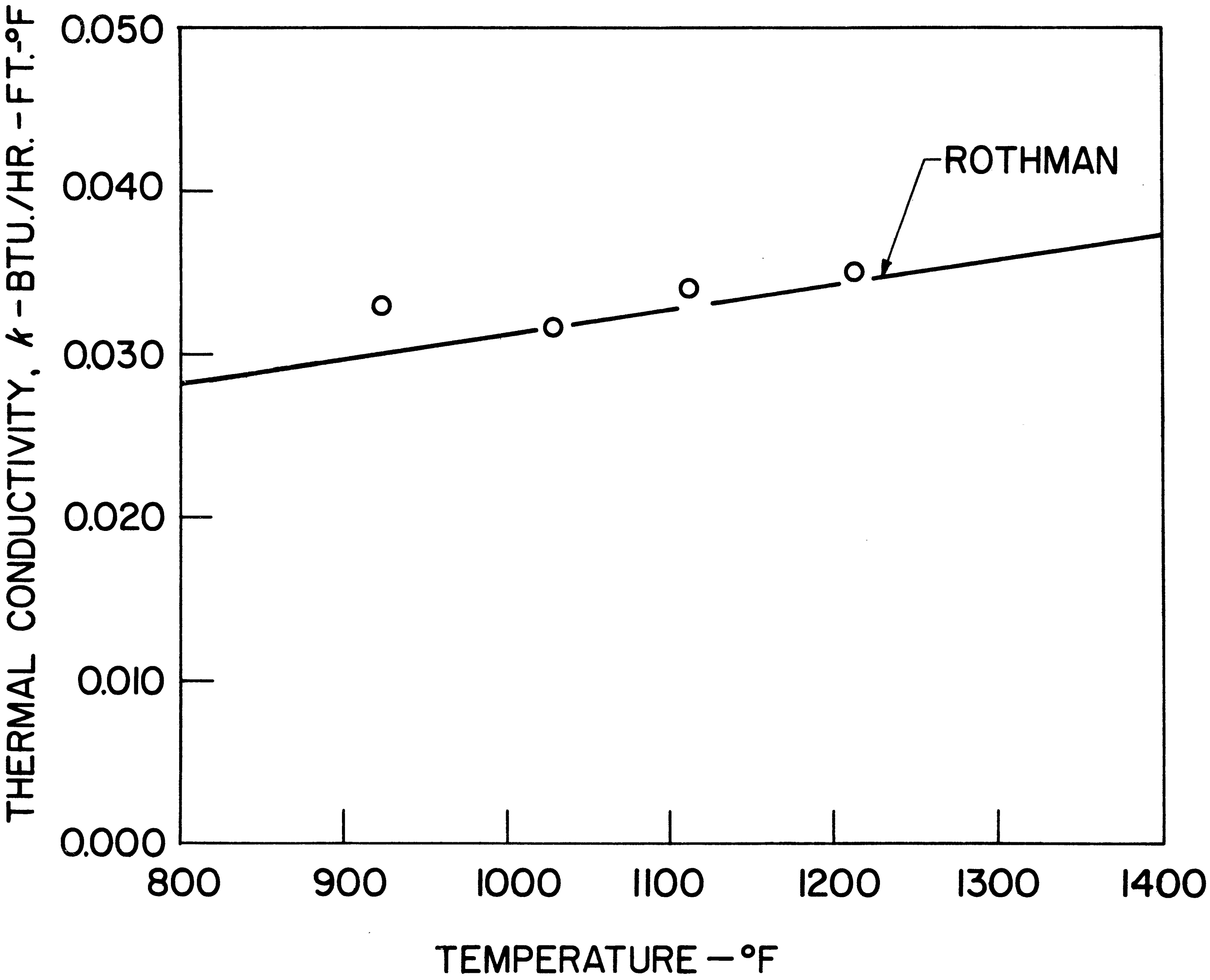


Figure 16. Comparison of the Experimental Thermal Conductivity Results for Nitrogen with the Results of Rothman (84)

can be seen from Figure 16, there is very good agreement with the data of Rothman (84) at 1 atm. Rothman's data is in very close agreement with the data of other investigators.

Since the thermal conductivity of gases increases with pressure about 1 percent per atmosphere in the range from roughly 1 mm to 10 atm., the data should be nominally 1/2 percent higher than the data of Rothman. If this correction were applied to the data in Figure 16, the agreement would be even better than indicated.

The exceptionally good agreement of the experimental thermal conductivity values for nitrogen with the data of Rothman and others, demonstrated that the method of taking and analyzing the data was satisfactory. The standard error in the determination of Δt for the nitrogen data was approximately 6 percent. Except for the first nitrogen set, the average deviation from the data of Rothman is +1 percent.

Potassium Runs The thermal conductivity of potassium at each test condition was obtained from Equations 72 and 85 as in the case of nitrogen. The results are given in Table VI and Figure 17.

Because of the change in emissivity of the molybdenum surface during some intermediate potassium runs, there was some question of the value of $k_{rad.}$ as given in Table VI for data sets 15-20 and especially those of data sets 15-17. For data sets 13 and 14, the apparent contribution of radiation $k_{rad.}$ to the total conduction,

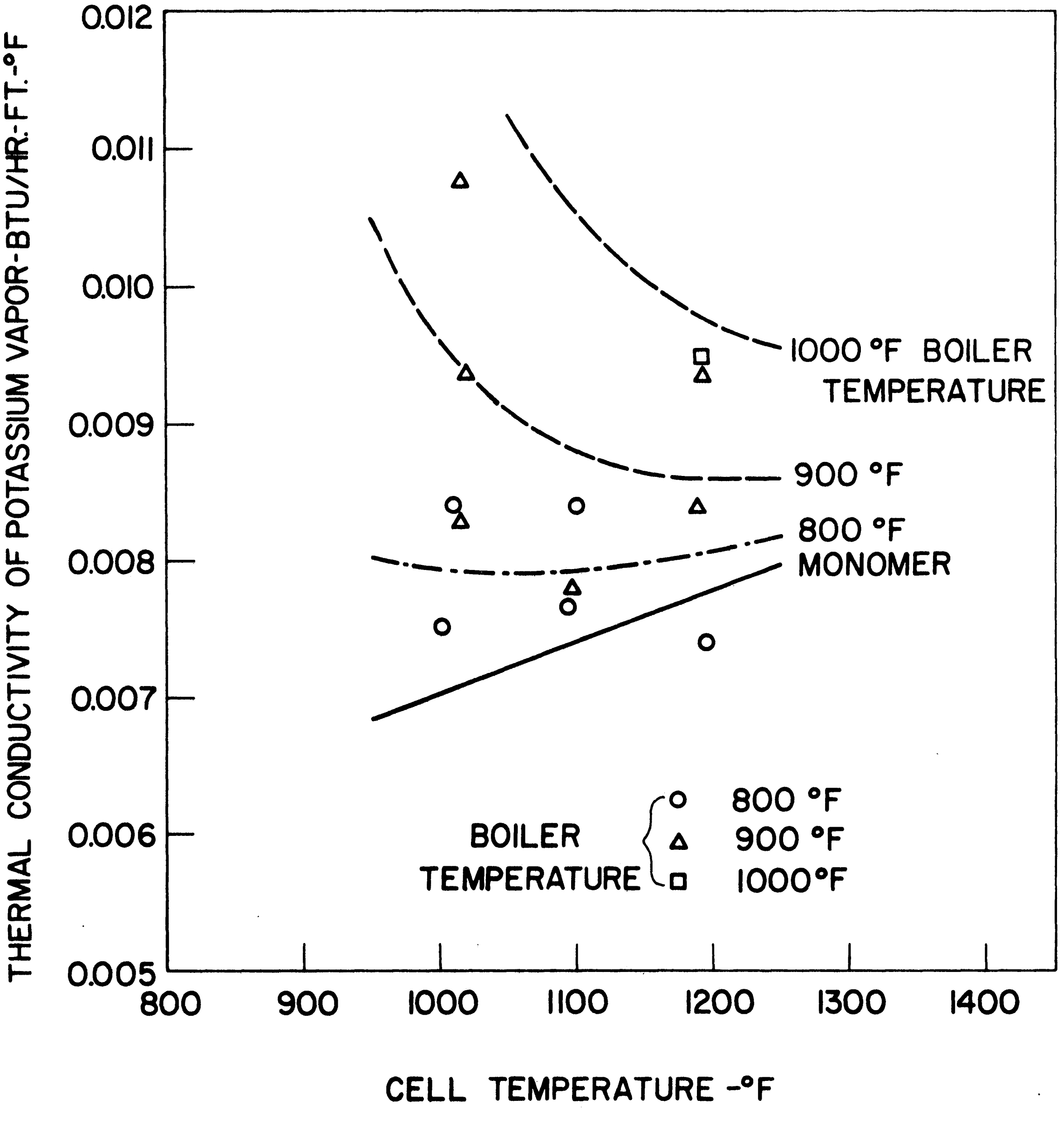


Figure 17. Experimental Thermal Conductivity Results for Potassium Vapor

k_t, was taken from the top solid line of Figure 15 for the partially oxidized surface. For data sets 21 and 26 through 32, $k_{rad.}$ was taken from the bottom solid line of Figure 15 for the nominally clean surface at the cell temperature. For the intermediate runs, data sets 15-20, values of $k_{rad.}$ were predicted based on the knowledge that the surface emissivity would be changing with time such that in Figure 15 one would always go for a higher dashed line to a lower such line. Based upon the elapsed time between the start of data set 15 and the completion of data set 20, values of $k_{rad.}$ were interpolated between the two solid lines of Figure 15 at the cell temperature. Except for the intermediate runs at a cell temperature of 1100°F., the results agree closely with the balance of the data. Apparently there was a much greater change in the surface emissivity initially followed by a gradual change in time until the surface had stabilized.

Except for the data in data sets 26 and 27, the mean standard error in Δt was approximately 1 1/2 percent for all the potassium data. The lower deviations as compared to the nitrogen data was due to improvements in furnace control and stability as a result of the experience gained in operating the system. The range of the cell null values was also substantially less because of improved control. During the runs for data sets 26 and 27, the small heater attached to the tube between the top valve and cell container was operated with a voltage drop of 40-60 volts to prevent condensation of potassium in the line while running at conditions close to the saturation temperature in the vestibule area. These higher voltages resulted in greater temperature fluctuations in the cell - the standard error in Δt being 5 percent for data set 26 when a voltage drop of 40 volts was used and being 10 percent for data set 27 when a voltage drop of 60 volts was used.

There is, as evidenced from the data in Figure 17 and predicted from fundamental considerations, a significant effect of pressure on the conductivity of potassium vapor. This effect is due to the heat of reaction involved with the association - dissociation reactions in potassium vapor as discussed in the section on thermal conductivity of gas mixtures in chemical equilibrium. Because of the significance of pressure, the data in Figure 17 were corrected to constant values of cell pressure which is equivalent to constant boiler temperatures. The magnitude of the corrections, listed in Table VII, were based on theoretical considerations.

There is a fair amount of scatter in the potassium data as shown in Figure 17. In order to present a valid correlation of the data, it was felt that any correlating curves through the data for constant boiler temperatures would be consistent with kinetic theory. Kinetic theory was used in conjunction with the experimental data to determine the shape and the relative position of

Table VII. Correction of Experimental Values of Thermal Conductivity of Potassium Vapor to Constant Boiler Temperature and Comparison to Correlating Curve

Data Set	T_{Cell}	T_{Boiler}	k_t Btu./hr.ft.-°F	Correction to constant T Boiler Btu./hr.ft.-°F	k_{corr} Btu./hr.ft.-°F	Deviation from Correlating Curve Btu./hr.ft.-°F
13	1010.1	805.6	0.00855	-0.00014	0.00841	+0.00050
21	1003.6	798.3	0.00748	+0.00004	0.00752	-0.00039
28	1094.8	797.9	0.00765	+0.00002	0.00767	-0.00022
30	1190.7	817.5	0.00739	-0.00009	0.00730	-0.00074
32	1099.2	800.8	0.00842	-0.00001	0.00841	+0.00051
						σ =0.00056
14	1017.9	930.9	0.01017	-0.00082	0.00935	-0.00001
18	1189.9	899.7	0.00840	+0.00000	0.00840	-0.00020
26	1015.6	897.4	0.00821	+0.00007	0.00828	-0.00109
27	1015.8	906.8	0.01099	-0.00022	0.01077	+0.00134
29	1097.4	885.4	0.00767	+0.00013	0.00780	-0.00098
31	1190.8	882.3	0.00925	+0.00011	0.00936	+0.00075
						σ= 0.00095
19	1192.4	1003.4	0.00948	-0.00007	0.00941	-0.00036

the correlating isotherms through the data in Figure 17. Before kinetic theory could be used, the composition of the vapor and the force constants σ and ε for the Lennard-Jones potential had to be found.

The composition of potassium vapor at various degrees of superheat was determined from Equations 67, 68 and 71 using the Ford Motor Company's GE 265 computer. The results are tabulated in Table VIII. As can be seen in Table VIII the mole fractions of the tetramer of potassium at the operating conditions in this investigation were negligible. This permitted the system to be treated as a binary mixture.

Values of the force constants σ and ε were estimated from viscosity, vapor pressure, and normal boiling point data. From the saturated vapor viscosity data of Stefanov _et al._ (93), using the technique suggested by Hirschfelder, Curtiss and Bird (56), ε/k and σ_{12} were found to be 430°K and 5.32 A°, respectively. Since both the monomer and dimer are present for these data, the computed values of ε/k and σ_{12} are taken as being the mean values for the binary mixture. An attempt was made to compute the force constants from the monomeric viscosity data of Stefanov _et al._ (93), but the method of Hirschfelder, Curtiss and Bird (56) would not give a convergent solution. From the second virial coefficient data of Ewing _et al._ (33), ε/k and σ_{12} were computed by a method

Table VIII. Equilibrium Vapor Composition of Potassium

T cell °F	T boiler °F	P atm.	X_1	X_2	X_4	Mol. Wt.
			mol fractions			
1000	800	0.0106	0.9938	0.0062	$2x10^{-7}$	39.346
1000	900	0.0302	0.9825	0.0175	$5x10^{-6}$	39.786
1100	800	0.0106	0.9963	0.0037	$5x10^{-8}$	39.246
1100	900	0.0302	0.9896	0.0104	$1x10^{-6}$	39.508
1100	1000	0.0745	0.9751	0.0249	$2x10^{-5}$	40.077
1200	800	0.0106	0.9977	0.0023	$1x10^{-8}$	39.192
1200	900	0.0302	0.9935	0.0065	$4x10^{-7}$	39.357
1200	1000	0.0745	0.9842	0.0158	$5x10^{-6}$	39.721
1200	1100	0.1641	0.9665	0.0335	$5x10^{-5}$	40.417

outlined by Hirschfelder, Curtiss, and Bird (56). The values of ε/k and σ_{12} were found to be 380°K and 3.48 A°, respectively. The normal boiling point and liquid potassium density data of Ewing _et al_. (33) gave values of ε/k and σ_{12} of 1430°K and 4.60 A°, respectively, when calculated by the procedure suggested by Wilke and Lee (104). There is a significant difference in the values as computed from the three sets of data. Hirschfelder, Curtiss and Bird (56) indicate that the results from viscosity data are preferable for computing transport properties from kinetic theory.

From the three sets of computed values of the force constants, the collision integral Ω_D and the product $\sigma_{12}^2\Omega_D$ were found and tabulated in Table IX for temperatures of 1000, 1100 and 1200°F. The diffusion coefficients D_{12} for these temperatures and vapor pressures corresponding to saturated vapor temperatures of 800, 900, 1000, and 1100°F. were computed from Equation 18.

$$D_{12} = \frac{0.001858\ T^{3/2}\left[(M_1+M_2)/M_1M_2\right]^{1/2}}{P\ \sigma_{12}^2\ \Omega_D} \qquad (18)$$

For these same conditions and using the compositions listed in Table VIII, the heat of reaction contribution to conduction k_r was determined from Equation 86.

$$k_r = D_{12}\frac{P}{RT}\ \frac{\Delta H_2^2}{RT^2}\ \frac{x_1\ x_2}{\left(2x_2+x_1\right)^2} \qquad (86)$$

which is the same form as Equation 28.

Table IX. Summary of Force Constants for Lennard-Jones 6-12 Potential Predicted from Experimental Results

T °F	T °K	$\frac{kT}{\varepsilon}$	Ω_D	$\sigma_{12}^2\Omega_D$
Constants predicted from 2nd virial coefficient data (33)				
ε/k = 380°K; σ_{12}= 3.48 A°				
1000	811.1	2.134	1.052	12.74
1100	866.7	2.281	1.028	12.45
1200	922.2	2.427	1.007	12.20
Constants predicted from saturated vapor viscosity data (93)				
ε/k = 430°K; σ_{12} = 5.32 A°				
1000	811.1	1.886	1.096	31.02
1100	866.7	2.016	1.072	30.34
1200	922.2	2.145	1.050	29.72
Constants predicted from normal boiling point data (33)				
ε/k = 1430°K; σ_{12} = 4.60 A°				
1000	811.1	0.567	1.930	40.84
1100	866.7	0.605	1.860	39.36
1200	922.2	0.645	1.805	38.19
Constants predicted from best fit with experimental thermal conductivity data				
ε/k = 400°K; σ_{12} = 5.17 A°				
1000	811.1	2.028	1.070	28.55
1100	866.7	2.167	1.046	27.91
1200	922.2	2.306	1.025	27.35

The frozen thermal conductivity k_f was computed from Equation 13 using the force constants listed in Table IX

$$k = 1.9891 \times 10^{-4} \frac{(T/M)^{1/2}}{\sigma^2 \Omega_v} \tag{13}$$

The collision integral Ω_v is tabulated in Reference (82) as a function of kT/ε. The molecular weight of the monomer was used in Equation 13. This is believed to be justified because of the relatively small amount of the dimer which exists at the operating conditions--less than 2 percent. It also should be noted in Equation 15 that the increased molecular weight for the dimer and the Eucken factor are self-compensating which tends to reduce the effect of the molecular weight increase when estimating thermal conductivities of diatomic molecules. Further, it is not possible, to assign independent values of the force constants from the calculated values of σ and ε in Table IX. Finally, the method of averaging thermal conductivities (82) is such that with such a small fraction dimer the average thermal conductivity would be essentially equal to the thermal conductivity of the monomer at the same temperature. Therefore, the frozen thermal conductivity and the monomeric thermal conductivity are essentially identical for the operating conditions encountered in this investigation.

The total effective thermal conductivity k_c of potassium vapor as estimated from kinetic theory for the various conditions was computed from Equation 26. The results for the three sets of estimated force constants are given in Tables X, XI, and XII. These results were then compared with the data in Figure 17. As can be seen from the values of k_c listed in Tables X, XI, and XII, the predicted values based on the viscosity data as recommended by Hirschfelder, Curtiss, and Bird (56) are in closest agreement with the experimental data although somewhat low. By interpolation from plots of ε/k and σ_{12} versus $\sigma_{12}^2\Omega_D$ for the three sets of values, it was possible to estimate values of the force constants which, when used as before, gave predicted values of k_c which fit the experimental data with a least mean squared deviation. The values of ε/k and σ_{12} were 400°K and 5.17 A°, respectively, as indicated in Table IX. The values of k_c predicted from the constants above are given in Table XIII and are plotted in Figure 17. Taking the predicted values of k_c for the vapor pressures corresponding to saturated vapor pressures of 800, 900, and 1000°F., the experimental potassium data were corrected to either a 800, 900 or 1000°F. boiler temperature. The correction, the corrected values k_{corr} and the deviation from the predicted values are given in Table VII. Standard deviations between the corrected and predicted values of k_c for the 800 and 900°F. boiler isotherms are 0.00056 and 0.00095 Btu/hr.-ft.-°F., respectively, which correspond to standard errors of k_c of 7 and 10 percent.

Table X. Predicted Values for the Thermal Conductivity of Potassium Vapor Based Upon Lennard-Jones Force Constants Determined from the Second Virial Coefficient

T_{cell} °F	T_{Boiler} °F	P_{cell} Atm.	$\sigma^2_{12}\Omega_D$	D_{12} sq.ft./hr.	$\frac{k_r}{D_{12}} \times 10^{+5}$ $\frac{Btu}{ft.^3-°F}$	k_r Btu./hr.ft.-°F	k_f Btu./hr.ft.-°F	k_c Btu./hr.ft.-°F
1000	800	0.0106	12.74	241.50	0.84	0.00203	0.01570	0.01773
1000	900	0.0302	12.74	84.78	7.02	0.00595	0.01570	0.02165
1100	800	0.0106	12.45	273.10	0.41	0.00112	0.01661	0.01773
1100	900	0.0302	12.45	95.86	3.26	0.00313	0.01661	0.01974
1100	1000	0.0745	12.45	38.86	18.45	0.00717	0.01661	0.02378
1200	800	0.0106	12.20	305.80	0.21	0.00064	0.01748	0.01814
1200	900	0.0302	12.20	107.30	1.71	0.00183	0.01748	0.01931
1200	1000	0.0745	12.20	43.51	9.98	0.00434	0.01748	0.02182
1200	1100	0.1641	12.20	19.75	44.24	0.00874	0.01748	0.02622

Table XI. Predicted Values for the Thermal Conductivity of Potassium Vapor Based Upon Lennard-Jones Force Constants Determined from Saturated Vapor Viscosity Data

T_{cell} °F	T_{Boiler} °F	P_{cell} Atm.	$\sigma_{12}^2\Omega_D$	D_{12} sq.ft./hr.	$\frac{k_r}{D_{12}}\times 10^{+5}$ $\frac{Btu}{ft.^3-°F}$	k_r Btu./hr.ft.-°F	k_f Btu./hr.ft.-°F	k_c Btu./hr.ft.-°F
1000	800	0.0106	31.02	99.20	0.84	0.00083	0.00645	0.00728
1000	900	0.0302	21.02	34.82	7.02	0.00244	0.00645	0.00889
1100	800	0.0106	30.34	112.02	0.41	0.00046	0.00682	0.00728
1100	900	0.0302	30.34	39.32	3.26	0.00128	0.00682	0.00810
1100	1000	0.0745	30.34	15.94	18.45	0.00294	0.00682	0.00976
1200	800	0.0106	29.72	125.52	0.21	0.00026	0.00718	0.00744
1200	900	0.0302	29.72	44.06	1.71	0.00075	0.00718	0.00793
1200	1000	0.0745	29.72	17.86	9.98	0.00178	0.00718	0.00896
1200	1100	0.1641	29.72	8.11	44.24	0.00359	0.00718	0.01077

Table XII. Predicted Values for the Thermal Conductivity of Potassium Vapor Based Upon Lennard-Jones Force Constants Determined from Normal Boiling Point Data

T_{cell} °F	T_{Boiler} °F	P_{cell} Atm.	$\sigma_{12}^2\Omega_D$	D_{12} sq.ft./hr.	$\frac{k_r}{D_{12}} \times 10^{+5}$	k_r Btu./hr.ft.-°F	k_f Btu./hr.ft-°F	k_c Btu./hr.ft.-°F
1000	800	0.0106	40.84	75.35	0.84	0.00063	0.00490	0.00553
1000	900	0.0302	40.84	26.45	7.02	0.00186	0.00490	0.00676
1100	800	0.0106	39.36	86.35	0.41	0.00035	0.00525	0.00560
1100	900	0.0302	39.36	30.31	3.26	0.00099	0.00525	0.00624
1100	1000	0.0745	39.36	12.29	18.45	0.00223	0.00525	0.00748
1200	800	0.0106	38.19	97.68	0.21	0.00021	0.00558	0.00579
1200	900	0.0302	38.19	34.29	1.71	0.00059	0.00558	0.00617
1200	1000	0.0745	38.19	13.90	9.98	0.00139	0.00558	0.00697
1200	1100	0.1641	38.19	6.31	44.24	0.00279	0.00558	0.00837

Table XIII. Predicted Values for the Thermal Conductivity of Potassium Vapor Based Upon Lennard-Jones Force Constants Which Give a Least Squared Deviation Fit with the Experimental Data

T_{cell} °F	T_{Boiler} °F	P_{cell} Atm.	$\sigma_{12}^2\Omega_D$	D_{12} sq.ft./hr.	$\frac{k_r}{D_{12}}$ x10^{+5} $\frac{Btu}{ft.^3-°F}$	k_r Btu./hr.ft.-°F	k_f Btu./hr.ft-°F	k_c Btu./hr.ft.-°F
950	800	0.0106	28.90	101.05	1.19	0.00120	0.00684	0.00804
950	900	0.0302	28.90	35.47	10.19	0.00361	0.00684	0.01045
1000	800	0.0106	28.55	107.80	0.84	0.00091	0.00702	0.00793
1000	900	0.0302	28.55	37.83	7.02	0.00266	0.00702	0.00968
1050	800	0.0106	28.21	114.73	0.61	0.00070	0.00723	0.00793
1050	900	0.0302	28.21	40.27	4.62	0.00186	0.00723	0.00909
1050	1000	0.0745	28.21	16.32	24.50	0.00400	0.00723	0.01123
1100	800	0.0106	27.91	121.78	0.41	0.00050	0.00741	0.00791
1100	900	0.0302	27.91	42.74	3.26	0.00139	0.00741	0.00880
1100	1000	0.0745	27.91	17.33	18.45	0.00320	0.00741	0.01061
1150	800	0.0106	27.62	129.01	0.30	0.00039	0.00760	0.00799
1150	900	0.0302	27.62	45.28	2.35	0.00106	0.00760	0.00866
1150	1000	0.0745	27.62	18.36	13.48	0.00247	0.00760	0.01007
1200	800	0.0106	27.35	136.40	0.21	0.00029	0.00779	0.00808
1200	900	0.0302	27.35	47.87	1.71	0.00082	0.00779	0.00861
1200	1000	0.0745	27.35	19.41	9.98	0.00194	0.00779	0.00973
1200	1100	0.1641	27.35	8.81	44.24	0.00390	0.00779	0.01169
1250	800	0.0106	27.07	144.09	0.15	0.00022	0.00797	0.00819
1250	900	0.0302	27.07	50.57	1.25	0.00063	0.00797	0.00860
1250	1000	0.0745	27.07	20.50	7.74	0.00159	0.00797	0.00956

CHAPTER VI

DISCUSSION OF RESULTS

The thermal conductivity of potassium vapor in the temperature range of 1000 to 1200°F. and the pressure range of 0.01 to 0.075 atmospheres is given in Figure 17. There is as predicted from theory, a significant effect of pressure on the thermal conductivity of potassium vapor. This is caused by the heat of reaction associated with changes in equilibrium composition with pressure and temperature. The mean values presented in Figure 17, for saturated pressures corresponding to 800, 900 and 1000°F. are estimated to have an accuracy of ± 10 percent.

Kinetic theory was used to establish the mean values through the experimental data. Although limited in absolute accuracy kinetic theory does provide tremendous insight into the relative effects of pressure and temperature once the absolute magnitude of the thermal conductivity is established by experimental results. Some will argue that the Lennard-Jones (6,12) potential as used for the intermolecular force potential does not apply to potassium. If, however, the force constants are obtained from experimental data for the same temperature range as the values to be predicted, the theory should give a reasonable approximation to the effect of pressure and temperature providing the temperature range is not too great. As can be seen from Equations 13 and 18, the most significant consequence in the choice of the intermolecular force potential is in the values of the two collision integrals which are only slightly a function of temperature. This temperature effect of the collision integrals is small when compared to the effects of the absolute temperature in the theory. The variation of the vapor composition for the operating conditions of this investigation are also quite small which support the validity of the theory.

The values of the monomeric vapor (or the frozen thermal conductivity of the vapor at lower pressures) estimated from the theory and the experimental results agree closely with the experimental data of Stefanov et al. (93) and the theoretical estimates of Weatherford et al. (102) over the temperature range of this investigation. A comparison of the data is given in Figure 18. The maximum deviation is -6 percent when compared to the results of Stefanov at 1200°F. It should be noted that the thermal conductivity of the monomeric vapor and the frozen thermal conductivity of the vapor are not synonymous except for low pressures where the equilibrium composition consists predominately of the monomer. The maximum deviation in the total effective thermal conductivity when compared to the data of Stefanov is -8 percent. Stefanov indicated a maximum average error in his data of 20 percent.

There were several factors which could have contributed to the scatter in the experimental data. The most significant of these are those related to the temperature variations and fluctuations in the furnace during operation. The standard error between the

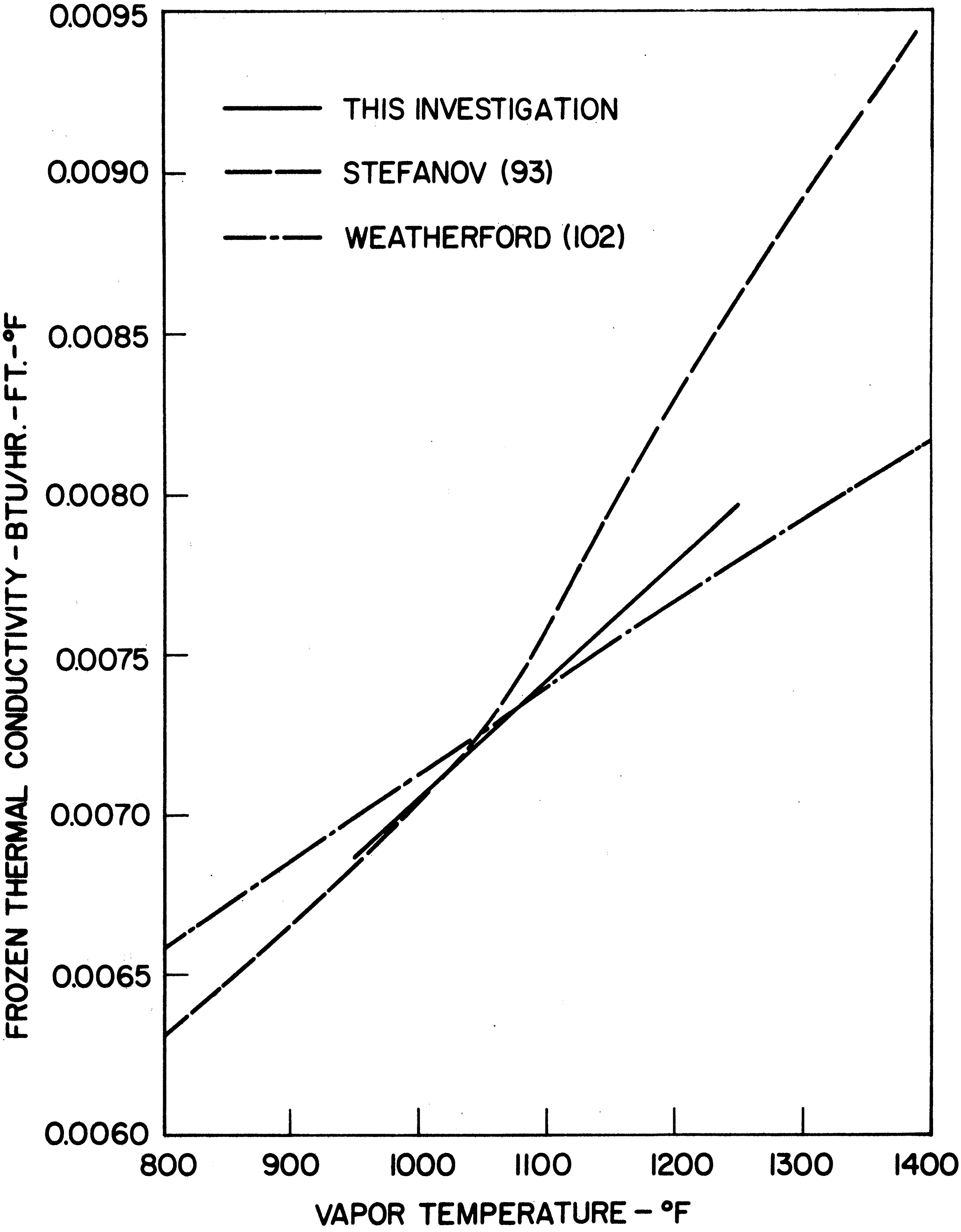


Figure 18. Comparison of Thermal Conductivity Data for Potassium Monomer with Results of Stefanov (93) and Weatherford (102)

data and correlating lines for the temperature difference between plates versus null for the potassium runs as illustrated in Figure 14 were on the average 1.5 percent. The standard error for data sets 26 and 27 was higher because of the high voltage drop across the auxiliary heater in the furnace vestibule. Since the standard error applies to both the isothermal and heated top plate lines, the total error in the mean temperature difference Δt is estimated to be 3 percent. The average null values are estimated to be accurate to 0.2°F. Upon interpolation for Δt as indicated in Chapter IV, this could lead to an additional error in the Δt of approximately 4 percent. Any thermocouple drift or errors in reading the potentiometer would be included in the estimated errors of the Δt and the null temperature.

The measured values of the voltage drop across the heater and the standard 1 ohm shunt are accurate to 0.2 percent--with the greatest error being in the voltage drop across the heater. A 10 percent error in the estimate of the lead wire resistance would represent only a 1.4 percent error in the calculation of the value of the heat generated in the top plate heater because of the relative magnitude of the resistances. The actual error in the amount of heat generated by the top plate heater is estimated to be less than 0.5 percent. Any additional effect on the calculated value of the heat input Q_t due on imbalance between the top plate temperature and the guard plate temperature should already be accounted for in the estimate of the null error.

The only additional factors which come into the calculation of the total heat transfer from Equation 72 are the area and the plate spacing. Both are accurate to within 1 percent. The estimated errors in Δt, null, Q_t, A, and X_s were used as indicated by Equation 72 to obtain the maximum estimated error in the total conductivity k_t. The maximum error of k_t was found to be 9.8 percent.

The pressure in the thermal conductivity cell was determined by measuring the temperature of the liquid potassium in the potassium boiler with a thermocouple and then computing the vapor pressure from the vapor pressure data of Ewing et al. (33). Errors in the thermocouple readings could cause a deviation of 1 to 2 percent in the reported values as shown in Figure 17. Two additional potential sources of difficulty were the valve between the cell and boiler and the surface condition of the liquid potassium. Temporary plugging of the valve due to condensation or liquid surface oxidation could cause variations in the vapor pressure from the predicted values.

Since the radiation contribution must be subtracted from the total apparent thermal conductivity to obtain the actual value of k_c the errors in radiation values are extremely important. Based on the results presented in Figure 15 and the standard errors in the Δt's, the radiation data for the partially oxidized surface and the nominally clean surface are estimated to be accurate to within 10 percent. In terms of the error to the effective thermal conductivity k_c, the radiation errors represent possible errors in

k_c of 9 percent and 2.5 percent for the partially oxidized surface and the nominally clean surface, respectively.

As it is unlikely for all the errors to occur at the same time in a way which maximizes the absolute error, an experimental error of ± 10 percent seems reasonable. This is also consistent with the deviations from the least squared deviation isotherms predicted from kinetic theory.

Estimates of the temperature jump caused by the accomodation coefficient of the cell surface calculated from Equation 22 indicated that the measured thermal conductivities could be lower than the actual value of the thermal conductivity because of the small distance between plates. For a boiler temperature of 800°F. or a pressure of 0.0106 atmospheres, the estimate is 2.5 to 5.9 percent lower for accomodation coefficients of 1.0 and 0.57, respectively. At a boiler temperature of 900°F. or a pressure of 0.0302 atmospheres the estimate is 1 to 2.5 percent lower for accomodation coefficients of 1.0 and 0.57, respectively.

For a given vapor temperature, kinetic theory would indicate, from Equations 13, 18, and 86, that the difference in the effective thermal conductivity k_c between two different pressure levels is caused by the difference in the heat of reaction effect k_r because of the change in the equilibrium composition. The products $D_{12}P$, $\sigma_{12}^{2}\Omega D$, and $\sigma_{12}\Omega v$ remain constant independent of pressure. Since the experimental data show good correlation with respect to the deviation from the predicted values in Table VII (no bias), it is concluded that any reduction in thermal conductivity because of the surface temperature jump is small and consistent with the higher values of the accomodation coefficient.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The guarded top plate, parallel plate thermal conductivity cell developed and used in this investigation is a satisfactory cell for accurate measurements of the thermal conductivity of alkali metal vapors at elevated temperatures. This steady state method requires longer operating periods to obtain experimental data compared to the transient techniques, but does have the advantage that no bare electrical wires have to be insulated from the cell walls in the presence of alkali metal vapors as is true for the hot wire cell and the dynamic probe method.

There are several equipment changes which would improve the operation of the cell and would greatly reduce the time necessary to take the data. There should be separate furnaces or constant temperature baths for the cell and the liquid metal boiler. High temperature molten salt baths would be preferable but furnaces which are insulated from all sides and both ends would be satisfactory. Furnace temperature control is extremely important. Ideally the temperature variation should not exceed 0.2 to 0.3°F. during the period of a day. The furnace temperature control in this investigation was inadequate and as a result of the temperature variations and fluctuations it frequently took 4 or 5 days to obtain a single data set.

The vapor line connecting the cell and the boiler, located in separate furnaces, should have an inside diameter of at least 1/2 inch and should contain an appropriately large high temperature bellows valve. Connections to the vacuum system should be made to this line between the cell and bellows valve. This would eliminate potential problems of vapor condensation with any condensation occurring in the lines below the cell where no harm would result. The vacuum line should contain a large high temperature bellows valve placed as close as possible to the vapor line. All the lines and the valve bodies should be thoroughly insulated and heated as necessary.

Chromel-alumel thermocouples were used in the cell. No significant thermocouple drift was ever apparent during the investigation or at least none could be distinguished from the furnace temperature variations. There are some changes in the thermocouples as a result of bending when the cell was fabricated. The magnitude of the change could not be accurately determined because the furnace was incapable of maintaining an isothermal condition throughout the length of the cell container. Chromel-alumel thermocouples do generate a higher emf/°F. than platinum - platinum rhodium thermocouples, but the possible advantage of chromel-alumel thermocouples because of the greater accuracy in reading is balanced by the possible drift. In future investigations platinum - platinum rhodium thermocouples are recommended.

A high temperature corrosion resistance pressure transducer would be very beneficial for measuring the pressure in the cell. This would provide an independent check on the conditions in the cell in the event of oxidation of the liquid potassium surface or plugging of the valve between cell container and boiler.

APPENDIX A

ORIGINAL DATA

Table A.1 Original Data for Data Set 1--Vacuum Runs at 943°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
199465	20.5570	19.9231	20.6471	20.4644	19.7936	21.6574		
199466	20.7126	20.0838	20.7845	20.6112	19.9052	21.6758		
199467	20.7450	20.0910	20.8162	20.6518	19.9448	21.7463		
199468	20.5251	19.8782	20.5933	20.4157	19.7490	21.6184		
199469	20.7022	20.0492	20.8123	20.6142	19.9100	21.8344		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 4.0 VOLTS							
199472	21.0702	20.1873	21.1557	20.9996	20.3167	22.0372	1.191	0.03612
199474	21.1768	20.2961	21.2387	21.0780	20.4066	22.0544	1.179	0.03571
199475	20.8261	19.9685	20.9018	20.7595	20.0597	21.6659	1.227	0.03729

Table A.2 Original Data for Data Set 2--Nitrogen Runs at 925°F.

RUN	THERMOCOUPLES						HEATER	
	3 mV	4 mV	5 mV	6 mV	7 mV	8 mV	Volts	Amps
	ISOTHERMAL							
199488	20.4485	20.5556	20.5200	20.2474	18.8421	21.4979		
199489	20.8595	20.9854	20.9632	20.6776	20.2117	21.9881		
199490	20.7966	20.8936	20.8531	20.5316	20.1897	21.9828		
199491	20.5527	20.6775	20.6662	20.3835	19.9307	21.6702		
199494	20.2001	20.3066	20.2904	20.0176	19.5609	21.3039		
199495	20.1975	20.2969	20.2847	20.0003	19.5852	21.3105		
199497	20.2669	20.3753	20.3589	20.0756	19.6689	21.3677		
199498	20.2886	20.3996	20.4147	20.1401	19.6910	21.4079		
199499	20.5126	20.6285	20.6800	20.4025	19.8939	21.6583		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.8 VOLTS							
205505	20.4449	20.4974	20.5400	20.2504	19.8576	21.4577	3.517	0.10777
205506	20.4407	20.5109	20.5511	20.2618	19.8104	21.4662	3.500	0.10709
205507	20.4970	20.5709	20.6541	20.3982	19.8762	21.5374	3.480	0.10588
205508	20.5309	20.5863	20.6320	20.3463	19.9320	21.5550	3.490	0.10614
205509	20.5505	20.6132	20.6570	20.3870	19.9624	21.5581	3.500	0.10673
205511	20.4971	20.5620	20.6496	20.3739	19.8668	21.5301	3.495	0.10666

Table A.3 Original Data for Data Set 3--Vacuum Runs at 1032°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205517	22.9755	22.1076	23.0787	22.1921	22.1630	24.0144		
205521	23.0183	22.1492	23.1310	22.9731	22.2047	24.0491		
205522	22.9860	22.1002	23.0809	22.9262	22.1655	24.0165		
205523	22.9900	22.1084	23.0900	22.9533	22.1778	24.0266		
205524	22.9859	22.0997	23.0949	22.9433	22.1753	24.0251		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 3.05 VOLTS							
205532	23.0183	22.0505	23.0857	22.9238	22.1884	23.9835	1.800	0.05615
205533	23.0455	22.0819	23.1360	22.9938	22.2242	23.9994	1.810	0.05628
205534	23.0449	22.0825	23.1184	22.9708	22.2170	23.9921	1.810	0.05651
205536	23.0548	22.0762	23.1244	22.9808	22.2283	24.0051	1.810	0.05606
205540	23.0702	22.1038	23.1741	23.0199	22.2649	24.0045	1.810	0.05624

Table A.4 Original Data for Data Set 4--Nitrogen Runs at 1027°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205541	22.8990	22.9978	23.1288	22.8321	22.2412	24.0749		
205542	22.9099	23.0068	23.0941	22.8137	22.2576	24.0823		
205543	22.9336	23.0335	23.1187	22.8459	22.2824	24.0769		
205544	22.9411	23.0345	23.1107	22.8300	22.2740	24.0942		
205545	22.9355	23.0357	23.1167	22.8407	22.2752	24.0901		
205546	22.9000	22.9943	23.1111	22.8274	22.2087	24.0573		
205547	22.9370	23.0355	23.1251	22.8413	22.2760	24.0949		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.95 VOLTS							
205702	22.9230	22.9702	23.1358	22.8508	22.2508	24.0338	3.605	0.11089
205703	22.9350	22.9824	23.1442	22.8564	22.2858	24.0648	3.580	0.11976
205704	22.9147	22.9655	23.1204	22.8332	22.2653	24.0445	3.600	0.11067

Table A.5 Original Data for Data Set 5--Vacuum Runs at 1117°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205710	25.1948	24.4017	25.2847	25.1441	24.3508	26.2737		
205712	25.0308	24.2373	25.0876	24.9258	24.1796	26.1206		
205713	25.0014	24.1717	25.0665	24.9563	24.1597	26.0553		
205715	25.0540	24.2708	25.1255	24.9687	24.1959	26.1220		
205716	24.9398	24.1225	24.9910	24.8820	24.0837	26.0315		
205717	24.9824	24.1707	25.0653	24.9459	24.1349	26.0850		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 3.15 VOLTS							
205718	25.0489	24.1718	25.1237	25.0282	24.1978	26.0719	1.860	0.05760
205719	25.0510	24.1824	25.1364	25.0308	24.2061	26.0658	1.870	0.05785
205720	25.0535	24.1770	25.1419	25.0311	24.2143	26.0820	1.860	0.05755
205721	25.0483	24.1630	25.1338	25.0288	24.2081	26.0752	1.860	0.05753
205722	25.0642	24.1981	25.1702	25.0318	24.2163	26.1118	1.815	0.05636
205723	25.0775	24.2150	25.1784	25.0527	24.2405	26.1240	1.830	0.05685

Table A.6 Original Data for Data Set 6--Nitrogen Runs at 1113°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205724	24.9095	24.9797	25.1239	24.8252	24.2194	26.1156		
205725	24.9528	25.0340	25.1718	24.8852	24.2673	26.1514		
205726	24.9038	24.9795	25.1215	24.8340	24.2098	26.0938		
205727	24.9242	24.9973	25.1542	24.8722	24.2204	26.1100		
205728	24.9217	24.9955	25.1419	24.8547	24.2228	26.1142		
205729	24.9605	25.0328	25.1756	24.8908	24.2520	26.1515		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.95 VOLTS							
205732	24.9587	24.9911	25.1788	24.8866	24.2814	26.1170	3.570	0.10967
205733	24.9464	24.9737	25.1645	24.8722	24.2427	26.1048	3.590	0.11021
205734	24.9334	24.9622	25.1479	24.8559	24.2330	26.0921	3.590	0.10981

Table A.7 Original Data for Data Set 7--Vacuum Runs at 1213°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205735	27.2570	26.6156	27.3619	27.2032	26.4027	28.3616		
205736	27.2594	26.6152	27.3644	27.2119	26.4023	28.3581		
205737	27.2190	26.5633	27.3183	27.1694	26.3581	28.3321		
205739	27.2738	26.6184	27.3794	27.2257	26.4123	28.3854		
205741	27.2336	26.5859	27.3510	27.1990	26.3569	28.3530		
205743	27.2956	26.6518	27.4277	27.2665	26.4228	28.4161		
205744	27.3045	26.6562	27.4372	27.2771	26.4362	28.4255		
205745	27.2313	26.5625	27.3286	27.1809	26.3473	28.3618		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 4.6 VOLTS							
205600	27.3431	26.6168	27.4783	27.3286	26.4789	28.3839	2.470	0.07584
205601	27.3564	26.6308	27.5005	27.3444	26.4712	28.4147	2.385	0.07324
205602	27.3656	26.6522	27.5142	27.3492	26.4849	28.4177	2.395	0.07365
205605	27.3303	26.6277	27.4443	27.2651	26.4228	28.3815	2.410	0.07431
205606	27.3158	26.5899	27.4430	27.2604	26.4020	28.3709	2.413	0.07447
205607	27.2634	26.5457	27.3516	27.1419	26.3508	28.3339	2.420	0.07461

Table A.8 Original Data for Data Set 8--Nitrogen Runs at 1213°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205608	27.1575	27.1987	27.3242	27.0632	26.3990	28.3922		
205609	27.2425	27.2782	27.4044	27.1284	26.4995	28.4825		
205610	27.2658	27.3029	27.4265	27.1513	26.5213	28.4947		
205611	27.1894	27.2284	27.3329	27.0580	26.4520	28.4113		
205612	27.1986	27.2358	27.3761	27.1091	26.4386	28.4381		
205613	27.2039	27.2383	27.4086	27.1554	26.4129	28.4363		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.8 VOLTS							
205614	27.3300	27.3301	27.4996	27.2315	26.5713	28.4847	3.510	0.10781
205615	27.2833	27.2862	27.4539	27.1849	26.5320	28.4437	3.540	0.10875
205616	27.3365	27.3367	27.4985	27.2318	26.5748	28.4866	3.505	0.10737
205617	27.3482	27.3461	27.5046	27.2349	26.5913	28.4981	3.505	0.10779
205619	27.2848	27.2823	27.4119	27.1337	26.5354	28.4251	3.500	0.10721
205620	27.2467	27.2442	27.3889	27.1176	26.4836	28.4050	3.510	0.10768
205621	27.2735	27.2717	27.4250	27.1690	26.4922	28.4337	3.510	0.10793
205622	27.2635	27.2587	27.4007	27.1252	26.4882	28.4160	3.510	0.10750

Table A.9 Original Data for Data Set 9--Vacuum Runs at 1008°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205626	22.4422	22.2485	22.1940	22.0796	21.5189	22.6509		
205627	22.3734	22.1731	22.1142	22.0180	21.4500	22.5418		
205628	22.3421	22.1386	22.0932	21.9941	21.4363	22.5156		
205629	22.3138	22.1101	22.0639	21.9614	21.3948	22.5051		
205630	22.3948	22.1962	22.1471	22.0423	21.4783	22.5818		
205631	22.4013	22.2010	22.1514	22.0506	21.4866	22.5759		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 4.0 VOLTS							
205638	22.4758	22.1878	22.2261	22.1297	21.5732	22.5796	1.800	0.05507
205639	22.5114	22.2245	22.2549	22.1607	21.5888	22.6070	1.800	0.05500
205640	22.5388	22.2561	22.2868	22.1901	21.6169	22.6384	1.800	0.05497
205641	22.4377	22.1519	22.1957	22.0946	21.5373	22.5440	1.800	0.05514
205642	22.3914	22.1065	22.1401	22.0446	21.4687	22.4883	1.800	0.05519

Table A.10 Original Data for Data Set 10--Vacuum Runs at 1113°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205644	24.7385	24.6095	24.4005	24.2666	23.7197	24.6645		
205645	24.7933	24.6676	24.4615	24.3291	23.7686	24.7202		
205646	24.8700	24.7472	24.5416	24.4093	23.8622	24.8015		
205647	24.9350	24.8102	24.5973	24.4741	23.9149	24.8495		
205648	24.9121	24.7939	24.5842	24.4536	23.8957	24.8226		
205649	24.8820	24.7644	24.5438	24.4179	23.8532	24.7808		
205550	24.7870	24.6706	24.4666	24.3450	23.7658	24.6870		
205551	24.7889	24.6719	24.4560	24.3253	23.7637	24.7054		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 3.9 VOLTS							
205556	24.9378	24.7625	24.6409	24.5097	23.9269	24.7781	1.900	0.05779
205557	24.8968	24.7219	24.6087	24.4806	23.8856	24.7361	1.900	0.05780
205558	24.8514	24.6698	24.5464	24.4458	23.8209	24.6731	1.900	0.05782
205559	24.9200	24.7536	24.6314	24.4919	23.9191	24.7906	1.900	0.05782
205560	25.0221	24.8431	24.7358	24.6075	24.0093	24.8576	1.900	0.05771
205561	25.0431	24.8691	24.7438	24.6198	24.0291	24.8713	1.900	0.05770
205562	24.9635	24.7885	24.6722	24.5446	23.9582	24.8147	1.900	0.05773

Table A.11 Original Data for Data Set 11--Vacuum Runs at 1205°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205564	27.0069	26.9530	26.7191	26.5797	25.9271	26.8754		
205565	27.0567	27.0033	26.7688	26.6244	25.9826	26.9218		
205566	27.0922	27 0407	26.8032	26.6563	26.0240	26.9616		
205567	27.0798	27.0205	26.7894	26.6458	26.0013	26.9203		
205568	26.9974	26.9318	26.6891	26.5496	25.9181	26.8267		
205569	26.9687	26.9139	26.6625	26.5191	25.8982	26.8304		
205570	26.9255	26.8626	26.6240	26.4885	25.8508	26.7706		
	HEATED TOP PLATE - GUARD VOLTAGE = 4.5 VOLTS							
205571	27.0071	26.8640	26.7167	26.6135	25.9024	26.7803	2.30	0.06965
205572	27.1400	27.0034	26.8618	26.7145	26.0621	26.9030	2.30	0.06954
	HEATED TOP PLATE - GUARD VOLTAGE = 5.0 VOLTS							
205573	27.1400	27.0034	26.8618	26.7145	26.0621	26.9030	2.30	0.06954
205574	27.1776	27.0409	26.8972	26.7617	26.0926	26.9210	2.30	0.06951
205575	27.1676	27.0284	26.8818	26.7502	26.0875	26.9080	2.30	0.06953
205576	27.1769	27.0422	26.8969	26.7559	26.1160	26.9252	2.30	0.06953
205577	27.2550	27.1258	26.9437	26.8192	26.1503	26.9881	2.30	0.06971
205578	27.1862	27.0467	26.8698	26.7384	26.0921	26.9245	2.30	0.06972
205579	27.1992	27.0635	26.8862	26.7459	26.1185	26.9555	2.30	0.06971
205580	27.1972	27.0773	26.9006	26.7613	26.1124	26.9812	2.30	0.06975
205581	27.1920	27.0538	26.8626	26.7321	26.0988	26.9334	2.30	0.06974

Table A.12 Original Data for Data Set 12--Vacuum Runs at 1305°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205582	29.1300	29.1149	28.8170	28.6874	28.0108	28.9498		
205585	39.3198	29.3022	28.9780	28.8594	28.1848	29.0904		
205586	29.2962	29.2811	28.9572	28.8372	28.1657	29.0726		
205587	29.3112	29.3022	28.9833	28.8484	28.1884	29.0955		
205588	29.3108	29.2949	28.9673	28.8340	28.1797	29.0812		
205589	29.4244	29.4153	29.0869	28.9590	28.2775	29.1996		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.0 VOLTS							
205590	29.4831	29.4130	29.1720	29.0367	28.3310	29.2003	2.30	0.06925
205591	29.5542	29.4887	29.2260	29.0878	28.3980	29.2572	2.30	0.06935
205592	29.5455	29.4853	29.2487	29.1041	28.3870	29.2562	2.30	0.06937
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.25 VOLTS							
205593	29.4393	29.3520	29.1254	29.0053	28.3060	29.1364	2.30	0.06916
205594	29.4058	29.3152	29.0925	28.9652	28.2757	29.1031	2.30	0.06913
205595	29.4016	29.3161	29.0820	28.9415	28.2706	29.1067	2.30	0.06916
205596	29.4480	29.3582	29.1150	28.9849	28.3070	29.1227	2.30	0.06912
205597	29.4170	29.3323	29.0972	28.9636	28.2849	29.1109	2.30	0.06913
205598	29.4244	29.3521	29.1039	28.9623	28.2780	29.1302	2.30	0.06916
205599	29.4188	29.3426	29.0942	28.9529	28.2788	29.1090	2.30	0.06916

Table A.13 Original Data for Data Set 13--Potassium Runs at 1010°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206004	22.3240	22.5324	22.0849	21.9963	21.3558	22.2892	17.6139		
206005	22.3542	22.5616	22.1129	22.0302	21.3966	22.3100	17.6224		
206006	22.3858	22.5957	22.1463	22.0626	21.4284	22.3458	17.6803		
206007	22.3688	22.5791	22.1206	22.0441	21.4002	22.2996	17.6956		
206008	22.3798	22.5925	22.1384	22.0576	21.4157	22.3219	17.7321		
206009	22.3256	22.5391	22.0814	22.0058	21.3652	22.2629	17.6721		
	HEATED TOP PLATE - GUARD VOLTAGE = 8.2 VOLTS								
206010	22.5925	22.6322	22.3620	22.2725	21.6436	22.3363	17.6212	3.60	0.11064
206011	22.5837	22.6225	22.3535	22.2635	21.6338	22.3285	17.6043	3.60	0.11066
	HEATED TOP PLATE - GUARD VOLTAGE = 7.6 VOLTS								
206013	22.5155	22.5683	22.2774	22.1915	21.5515	22.2911	17.5834	3.60	0.11031
206014	22.5689	22.6237	22.3310	22.2458	21.6136	22.3408	17.6438	3.60	0.11023
206015	22.5898	22.6449	22.3514	22.2698	21.6334	22.3571	17.6647	3.60	0.11022
206016	22.5897	22.6434	22.3493	22.2700	21.6378	22.3447	17.6648	3.60	0.11015
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.3 VOLTS								
206017	22.5198	22.5828	22.2804	22.2019	21.5720	22.2948	17.6336	3.60	0.10990
206018	22.5010	22.5654	22.2621	22.1844	21.5579	22.2796	17.6218	3.60	0.10994
206019	22.5976	22.6638	22.3592	22.2807	21.6484	22.3796	17.7340	3.60	0.10994
	HEATED TOP PLATE - GUARD VOLTAGE = 6.9 VOLTS								
206020	22.5483	22.6247	22.2978	22.2254	21.5891	22.3285	17.6909	3.60	0.10997
206021	22.5438	22.6185	22.2956	22.2251	21.5888	22.3253	17.6911	3.60	0.10998
206022	22.5380	22.6145	22.2907	22.2167	21.5812	22.3227	17.6890	3.60	0.11001
206023	22.5424	22.6204	22.2964	22.2217	21.5820	22.3281	17.6938	3.60	0.11001
206024	22.5412	22.6167	22.2936	22.2198	21.5831	22.3279	17.6742	3.60	0.11001

Table A.14 Original Data for Data Set 14--Potassium Runs at 1018°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	VOLTS	AMPS
	ISOTHERMAL								
206025	22.4604	22.9492	22.1235	22.1289	21.4245	22.0232	20.5790		
206026	22.4984	22.9876	22.1637	22.1702	21.4749	22.0691	20.6024		
206027	22.4931	22.9817	22.1538	22.1620	21.4556	22.0488	20.5786		
206028	22.4903	22.9806	22.1529	22.1611	21.4518	22.0527	20.5983		
206029	22.5032	22.9947	22.1657	22.1711	21.4543	22.0642	20.6135		
206030	22.4921	22.9831	22.1529	22.1597	21.4329	22.0427	20.6034		
206031	22.6291	23.1306	22.2890	22.2974	21.5903	22.1888	20.7585		
206032	22.6262	23.1181	22.2832	22.2945	21.5844	22.1697	20.7104		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE= 16.9 VOLTS								
206035	22.6622	23.0159	22.3215	22.3332	21.6318	22.0781	20.5318	3.60	0.11046
206036	22.6887	23.0425	22.3448	22.3604	21.6666	22.0948	20.5496	3.60	0.11038
206037	22.6784	23.0301	22.3337	22.3508	21.6553	22.0807	20.5317	3.60	0.11037
206038	22.6793	23.0319	22.3334	22.3509	21.6631	22.0823	20.5372	3.60	0.11035
206039	22.6820	23.0345	22.3366	22.3528	21.6647	22.0864	20.5449	3.60	0.11040
206040	22.6674	23.0169	22.3217	22.3391	21.6501	22.0711	20.5198	3.60	0.11040
206041	22.8010	23.1702	22.4483	22.4651	21.7573	22.2216	20.6910	3.60	0.11046
206042	22.7976	23.1659	22.4445	22.4650	21.7522	22.2108	20.6705	3.60	0.11052
206043	22.7906	23.1606	22.4449	22.4647	21.7555	22.2140	20.6908	3.60	0.11017
206044	22.7971	23.1617	22.4496	22.4715	21.7644	22.2178	20.6829	3.60	0.11016
206045	22.8051	23.1748	22.4626	22.4811	21.7739	22.2345	20.7129	3.60	0.11017

Table A.15 Original Data for Data Set 15--Potassium Runs at 1106°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206046	24.7299	24.7550	24.5273	24.3803	23.7657	24.8970	17.7576		
206047	24.7405	24.7670	24.5385	24.3954	23.7626	24.9049	17.7988		
206048	24.7357	24.7620	24.5321	24.3880	23.7625	24.8967	17.7869		
206049	24.7357	24.7636	24.5327	23.3883	23.7505	24.8986	17.7959		
206050	24.7515	24.7805	24.5508	24.4037	23.7811	24.9242	17.8176		
206051	24.7612	24.7906	24.5566	24.4110	23.7854	24.9255	17.8255		
206052	24.7469	24.7790	24.5386	24.3979	23.7725	24.9012	17.8257		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.7 VOLTS								
206055	24.8308	24.7379	24.6128	24.4799	23.8586	24.8639	17.7248	3.60	0.11000
206056	24.8436	24.7510	24.6230	24.4928	23.8673	24.8645	17.7483	3.60	0.11004
206057	24.8350	24.7419	24.6127	24.4828	23.8559	24.8537	17.7466	3.60	0.11005
206058	24.8378	24.7472	24.6148	24.4845	23.8527	24.8565	17.7609	3.60	0.11005
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.0 VOLTS								
206061	24.8705	24.7409	24.6637	24.5201	23.8961	24.8612	17.7242	3.60	0.10993
206062	24.8277	24.7007	24.6198	24.4830	23.8540	24.8025	17.7225	3.60	0.10985
206063	24.8442	24.7159	24.6360	24.4980	23.8801	24.8173	17.7538	3.60	0.10983
206064	24.7990	24.6719	24.5877	24.4496	23.8365	24.7691	17.7297	3.60	0.10985
206065	24.8591	24.7330	24.6487	24.5093	23.8930	24.8319	17.7943	3.60	0.10985
206066	24.8489	24.7241	24.6387	24.4967	23.8760	24.8324	17.7901	3.60	0.10988

Table A.16 Original Data for Data Set 16--Potassium Runs at 1108°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206070	24.6069	24.8482	24.3383	24.2593	23.5770	24.5372	20.1165		
206071	24.6059	24.8497	24.3358	24.2532	23.5686	24.5427	20.1089		
206072	24.7889	25.0328	24.5147	24.4349	23.7498	24.7144	20.2823		
206073	24.7794	25.0246	24.5073	24.4289	23.7538	24.7044	20.2782		
206074	24.7686	25.0138	24.4967	24.4172	23.7278	24.6907	20.2673		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.0 VOLTS								
206075	24.8704	24.9536	24.5969	24.5162	23.7960	24.6355	20.0679	3.60	0.11003
206076	24.8957	24.9779	24.6177	24.5412	23.8264	24.6596	20.0946	3.60	0.10998
206077	24.8890	24.9718	24.6131	24.5356	23.8199	24.6561	20.0960	3.60	0.10996
206078	24.8869	24.9701	24.6122	24.5339	23.8258	24.6574	20.1021	3.60	0.10995
206079	24.9012	24.9845	24.6268	24.5492	23.8397	24.6694	20.1152	3.60	0.10995
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 9.0 VOLTS								
206080	24.9013	24.9568	24.6375	24.5494	23.8591	24.6375	20.0671	3.60	0.11009
206081	24.9778	25.0384	24.7124	24.6271	23.9382	24.7024	20.1501	3.60	0.11014
206082	24.9530	25.0141	24.6927	24.6027	23.9226	24.6953	20.1469	3.60	0.11014
206083	24.9913	25.0563	24.7314	24.6381	23.9668	24.7393	20.1953	3.60	0.11016
206084	24.9206	24.9749	24.6565	24.5641	23.8707	24.6634	20.0779	3.60	0.11022
206085	24.9238	24.9751	24.6571	24.5680	23.8773	24.6603	20.0766	3.60	0.11019
206086	24.9288	24.9829	24.6708	24.5807	23.8792	24.6706	20.0922	3.60	0.11017
206087	24.9486	25.0045	24.6890	24.5982	23.8988	24.6915	20.1207	3.60	0.11015
206088	24.9279	24.9846	24.6625	24.5753	23.9029	24.6642	20.1111	3.60	0.11007
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.5 VOLTS								
206089	24.8767	25.0236	24.5809	24.5235	23.8156	24.7076	20.2317	3.60	0.10975
206090	24.8955	25.0407	24.6024	24.5443	23.8189	24.7264	20.2484	3.60	0.10973

Table A.17 Original Data for Data Set 17--Potassium Runs at 1113°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206091	24.7412	25.1934	24.3939	24.3810	23.6203	24.4466	22.3385		
206092	24.7326	25.1895	23.3960	24.3771	23.6328	24.4576	22.3857		
206093	24.7714	25.2324	24.4340	24.4185	23.6770	24.4899	22.4432		
206094	24.8557	25.3179	24.5073	24.4993	23.7599	24.5489	22.5128		
206095	24.8399	25.3070	24.5020	24.4875	23.7670	24.5537	22.5411		
206096	24.8531	25.3152	24.5059	24.4958	23.7628	24.5459	22.5158		
206097	24.8450	25.3089	24.5000	24.4901	23.7585	24.5451	22.5213		
206098	24.8742	25.3334	24.5236	24.5132	23.7773	24.5716	22.5244		
206099	24.8494	25.3121	24.5042	24.4936	23.7507	24.5538	22.5169		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.0 VOLTS								
206101	25.0096	25.3173	24.6786	24.6549	23.9399	24.5804	22.3854	3.11	0.09504
206102	25.0201	25.3323	24.6847	24.6617	23.9562	24.5863	22.4090	3.11	0.09501
206103	25.0035	25.3479	24.6983	24.6745	23.9570	24.6039	22.4380	3.11	0.09497
206104	25.0994	25.4241	24.7665	24.7451	24.0270	24.6618	22.5212	3.11	0.09477
206105	25.0285	25.3462	24.6967	24.6749	23.9602	24.5980	22.4600	3.11	0.09488
206106	25.0443	25.3674	24.7090	24.6876	23.9654	24.6036	22.4650	3.11	0.09494
206107	25.0321	25.3509	24.6954	24.6763	23.9533	24.5850	22.4420	3.11	0.09496
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206108	24.8887	25.2225	24.5458	24.5275	23.7696	24.4922	22.3092	3.11	0.09521
206109	24.8999	25.2338	24.5526	24.5389	23.7776	24.4921	22.3123	3.11	0.09515
206110	24.9032	25.2404	24.5680	24.5496	23.7878	24.5093	22.3588	3.11	0.09513
206111	24.9473	25.2836	24.6071	24.5920	23.8462	24.5454	22.4047	3.11	0.09502
206112	24.9518	25.2910	24.6133	24.6015	23.8498	24.5452	22.4154	3.11	0.09503
206113	24.9612	25.3013	24.6194	24.6022	23.8681	24.5544	22.4220	3.11	0.09510
206114	24.9452	25.2823	24.6075	24.5916	23.8386	24.5404	22.4046	3.11	0.09518

Table A.18 Original Data for Data Set 18--Potassium Runs at 1190°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206139	26.6482	26.7204	26.4067	26.2752	25.6135	26.7572	19.9829		
206140	26.6516	26.7264	26.4152	26.2813	25.6242	26.7699	19.9020		
206141	26.6567	26.7346	26.4162	26.2822	25.6194	26.7686	19.9261		
206142	26.6379	26.7135	26.3958	26.2633	25.6071	26.7450	19.8976		
206143	26.6529	26.7265	26.4166	26.2817	25.6301	26.7746	19.9049		
206144	26.7078	26.7791	26.4641	26.3354	25.6729	26.8072	19.9505		
206145	26.7046	26.7730	26.4667	26.3358	25.6905	26.8186	19.9595		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206147	26.7607	26.7297	26.5222	26.3941	25.7440	26.7523	19.8708	3.10	0.09447
206148	26.7422	26.7134	26.5038	26.3769	25.7149	26.7386	19.8563	3.10	0.09448
206149	26.7527	26.7245	26.5111	26.3844	25.7274	26.7458	19.8676	3.10	0.09444
206150	26.7485	26.7197	26.5079	26.3818	25.7281	26.7402	19.8626	3.10	0.09449
206151	26.7653	26.7345	26.5291	26.4016	25.7377	26.7549	19.8856	3.10	0.09446
206152	26.7634	26.7310	26.5265	26.3999	25.7397	26.7529	19.8816	3.10	0.09452

Table A.19 Original Data for Data Set 19--Potassium Runs at 1192°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206153	26.6216	26.9338	26.3179	26.2572	25.5410	26.5018	22.3087		
206154	26.6772	26.9894	26.3713	26.3082	25.5834	26.5544	22.3595		
206155	26.6564	26.9691	26.3495	26.2881	25.5550	26.5309	22.3338		
206156	26.6687	26.9712	26.3685	26.3115	25.5755	26.5437	22.3389		
206157	26.7129	27.0167	26.4141	26.3560	25.6251	26.5879	22.3677		
206158	26.7345	27.0273	26.4326	26.3786	25.6555	26.5945	22.3688		
206159	26.7006	27.0116	26.4058	26.3401	25.6245	26.5877	22.3543		
206160	26.6794	26.9801	26.3807	26.3205	25.5998	26.5542	22.3138		
206161	26.6790	26.9812	26.3842	26.3206	25.5868	26.5581	22.3226		
206162	26.6287	26.9284	26.3387	26.2768	25.5563	26.5175	22.2563		
206163	26.6603	26.9552	26.3687	26.3061	25.5897	26.5456	22.2873		
206164	26.6681	26.9698	26.3713	20.3033	25.5967	26.5554	22.3108		
206165	26.7225	27.0324	26.4235	26.3577	25.6511	26.6027	22.3787		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206166	26.7968	26.9989	26.4872	26.4275	25.7186	26.5523	22.2837	3.10	0.09474
206167	26.8400	27.0446	26.5279	26.4676	25.7486	26.5951	22.3199	3.10	0.09473
206168	26.8558	27.0612	26.5465	26.4850	25.7812	26.6148	22.3380	3.10	0.09469
206169	26.8775	27.0864	26.5675	26.5069	25.7933	26.6328	22.3564	3.10	0.09464
206170	26.8909	27.1003	26.5814	26.5224	25.8100	26.6434	22.3676	3.10	0.09464
206171	26.8861	27.0923	26.5759	26.5141	25.8009	26.6402	22.3702	3.10	0.09466
206172	26.8592	27.0653	26.5462	26.4876	25.7672	26.6056	22.3296	3.10	0.09467
206173	26.8354	27.0428	26.5236	26.4652	25.7532	26.5826	22.3136	3.10	0.09475
206174	26.8324	27.0360	26.5235	26.4635	25.7519	26.5834	22.3054	3.10	0.09472

Table A.20 Original Data for Data Set 20--Potassium Runs at 1201°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206175	26.9335	27.5105	26.5330	26.5629	25.7653	26.4904	24.8181		
206176	26.9169	27.4900	26.5204	26.5490	25.7390	26.4819	24.7907		
206177	26.8633	27.4431	26.4656	26.4901	25.6944	26.4365	24.7654		
206178	26.8682	27.4415	26.4766	26.5041	25.7089	26.4393	24.7806		
206179	26.8756	27.4624	26.4736	26.4967	25.7194	26.4518	24.7855		
206180	26.8543	27.4356	26.4516	26.4758	25.6929	26.4228	24.7403		
206181	26.8337	27.4163	26.4330	26.4537	25.6749	26.4123	24.7371		
206182	26.8507	27.4373	26.4511	26.4696	25.6814	26.4329	24.7607		
206183	26.8918	27.4854	26.4963	26.5126	25.7319	26.4840	24.8386		
206184	26.8936	27.4764	26.4918	26.5110	25.7201	26.4663	24.7898		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206185	27.0308	27.5126	26.6328	26.6469	25.8599	26.5108	24.7720	3.10	0.09526
206186	27.0470	27.5229	26.6445	26.6634	25.8768	26.5122	24.7551	3.10	0.09519
206187	27.0750	27.5587	26.6771	26.6911	25.9022	26.5519	24.8229	3.10	0.09519
206188	27.0717	27.5541	26.6732	26.6883	25.9071	26.5461	24.8135	3.10	0.09521
206189	27.0891	27.5708	26.6897	26.7069	25.9131	26.5544	24.8179	3.10	0.09520
206190	27.0753	27.5500	26.6685	26.6892	25.8991	26.5317	24.7738	3.10	0.09519
206191	27.0286	27.5029	26.6293	26.6468	25.8598	26.4979	24.7234	3.10	0.09531
206192	27.0388	27.5144	26.6395	26.6566	25.8675	26.5063	24.7297	3.10	0.09532

Table A.21 Original Data for Data Set 21--Potassium Runs at 1004°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206197	22.2269	22.4259	22.0447	21.9753	21.2422	22.1537	17.5533		
206198	22.2125	22.4098	22.0265	21.9601	21.2251	22.1237	17.5276		
206199	22.2048	22.4037	22.0287	21.9611	21.2297	22.1377	17.5504		
206200	22.2190	22.4176	22.0389	21.9722	21.2395	22.1422	17.5558		
206201	22.2168	22.4164	22.0392	21.9700	21.2409	22.1517	17.5671		
206202	22.2431	22.4412	22.0644	22.0043	21.2639	22.1616	17.5804		
206203	22.2412	22.4415	22.0641	21.9950	21.2637	22.1699	17.5854		
206204	22.2579	22.4562	22.0696	22.0045	21.2634	22.1817	17.5754		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.2 VOLTS								
206205	22.3987	22.4672	22.2067	22.1431	21.4011	22.1846	17.5071	3.10	0.09497
206206	22.3861	22.4563	22.1974	22.1332	21.3900	22.1722	17.4947	3.10	0.09498
206207	22.3558	22.4252	22.1690	22.1035	21.3624	22.1460	17.4641	3.10	0.09496
206208	22.3576	22.4273	22.1734	22.1052	21.3678	22.1536	17.4721	3.10	0.09492
206209	22.4040	22.4745	22.2144	22.1518	21.4106	22.1899	17.4931	3.10	0.09481
206210	22.3936	22.4628	22.2078	22.1452	21.4020	22.1836	17.4751	3.10	0.09479
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206211	22.4659	22.5109	22.2854	22.2200	21.4799	22.2234	17.4741	3.10	0.09452
206212	22.4443	22.4887	22.2688	22.2003	21.4622	22.2132	17.4600	3.10	0.09557
206213	22.4720	22.5170	22.3012	22.2297	21.4944	22.2504	17.4876	3.10	0.09445
206214	22.4890	22.5342	22.3120	22.2424	21.5018	22.4890	17.4847	3.10	0.09458
206215	22.4148	22.4593	22.2321	22.1646	21.4253	22.1665	17.4716	3.10	0.09461
206216	22.4057	22.4511	22.2259	22.1571	21.4213	22.1612	17.4713	3.10	0.09459
206217	22.3906	22.4384	22.2158	22.1412	21.4115	22.1637	17.4701	3.10	0.09454
206218	22.4334	22.4801	22.2575	22.1841	21.4536	22.2058	17.4904	3.10	0.09447

Table A.22 Original Data for Data Set 22--Vacuum Runs at 998°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
206219	22.1524	22.2375	21.9829	21.8926	21.1969	22.1804		
206220	22.2175	22.3152	22.0574	21.9579	21.2658	22.2700		
206221	22.2315	22.3192	22.0658	21.9897	21.2752	22.2092		
206222	22.2150	22.3004	22.0501	21.9656	21.2645	22.2254		
206223	22.2098	22.2952	22.0498	21.9648	21.2615	22.2212		
206224	22.2105	22.2987	22.0429	21.9568	21.2550	22.2194		
206225	22.0978	22.1818	21.9368	21.8496	21.1553	22.1142		
206226	22.0831	22.1674	21.9212	21.8401	21.1397	22.0883		
206227	22.1180	22.2076	21.9706	21.8774	21.1896	22.1675		
206228	22.2018	22.2893	22.0543	21.9618	21.2704	22.2475		
206229	22.2382	22.3274	22.0765	21.9863	21.2901	22.2678		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.0 VOLTS							
206230	22.2001	22.1944	22.0294	21.9515	21.2491	22.1017	2.20	0.06672
206231	22.1810	22.1764	22.0177	21.9339	21.2337	22.0939	2.20	0.06670
206232	22.2406	22.2433	22.0749	21.9873	21.2930	22.1638	2.20	0.06649
206233	22.2747	22.2782	22.1021	22.0207	21.3230	22.1819	2.20	0.06646
206234	22.2475	22.2480	22.0734	21.9998	21.2910	22.1321	2.20	0.06644
206235	22.2180	22.2161	22.0547	21.9737	21.2769	22.1355	2.20	0.06641
206236	22.1998	22.2003	22.0375	21.9571	21.2580	22.1194	2.20	0.06644
206237	22.3206	22.3227	22.1671	22.0773	21.3867	22.2746	2.20	0.06646
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.0 VOLTS							
206238	22.2602	22.2169	22.0969	22.0109	21.3157	22.1391	2.20	0.06672
206239	22.1897	22.1573	22.0376	21.9441	21.2528	22.0804	2.20	0.06672
206240	22.1972	22.1661	22.0425	21.9493	21.2608	22.0937	2.20	0.06671
206241	22.2113	22.1845	22.0525	21.9537	21.2708	22.1062	2.20	0.06660
206242	22.2248	22.2034	22.0697	21.9715	21.2874	22.1253	2.20	0.06664
206243	22.2276	22.2020	22.0677	21.9761	21.2871	22.1126	2.20	0.06664
206244	22.3929	22.3811	22.2318	22.1415	21.4440	22.2804	2.20	0.06673
206245	22.3822	22.3629	22.2202	22.1311	21.4340	22.2662	2.20	0.06672
206246	22.3716	22.3536	22.2065	22.1145	21.4152	22.2530	2.20	0.06674

Table A.23 Original Data for Data Set 23--Vacuum Runs at 1000°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
205654	22.0218	21.9638	21.8981	21.7880	21.1034	22.1568		
205655	22.0108	21.9574	21.8914	21.7767	21.1004	22.1566		
205656	22.0307	21.9779	21.9096	21.7967	21.1137	22.1664		
205657	22.1799	22.1323	22.0615	21.9452	21.2720	22.3235		
205658	22.1531	22.1040	22.0362	21.9147	21.2446	22.2962		
205659	22.1362	22.0891	22.0163	21.8950	21.2192	22.2783		
205660	22.1115	22.0542	21.9911	21.8684	21.1945	22.2587		
205661	22.1167	22.0644	22.0135	21.8923	21.2106	22.2895		
205662	22.1617	22.1146	22.0428	21.9175	21.2466	22.3212		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.5 VOLTS							
205663	22.3686	22.1859	22.2462	22.1274	21.4511	22.3568	2.60	0.07894
205664	22.3380	22.1553	22.2152	22.0989	21.4198	22.3259	2.60	0.07902
205665	22.3389	22.1555	22.2140	22.0955	21.4182	22.3245	2.60	0.07903
205666	22.3237	22.1326	22.2009	22.0881	21.4052	22.3040	2.60	0.07898
205667	22.2989	22.1051	22.1775	22.0642	21.3759	22.2821	2.60	0.07903
205668	22.3096	22.1221	22.1846	22.0703	21.3849	22.2926	2.60	0.07909
205669	22.3288	22.1456	22.2088	22.0865	21.4046	22.3221	2.60	0.07909
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.2 VOLTS							
205670	22.3733	22.1641	22.2533	22.1276	21.4521	22.3317	2.60	0.07911
205671	22.3843	22.1771	22.2694	22.1409	21.4649	22.3540	2.60	0.07911
205672	22.2901	22.0742	22.1745	22.0495	21.3694	22.3568	2.60	0.07911
205673	22.3015	22.0871	22.1828	22.0547	21.3815	22.2711	2.60	0.07911
205674	22.3134	22.0982	22.1950	22.0685	21.3942	22.2816	2.60	0.07908
205675	22.3111	22.0966	22.2024	22.0825	21.4021	22.2807	2.60	0.07899
205676	22.2126	21.9952	22.0977	21.9771	21.3064	22.1660	2.60	0.07899
205677	22.2095	21.9949	22.0949	21.9667	21.3046	22.1740	2.60	0.07899
205678	22.3551	22.1469	22.2352	22.1140	21.4367	22.3038	2.60	0.07903
205679	22.3385	22.1334	22.2149	22.0874	21.4158	22.2952	2.60	0.07905

Table A.24 Original Data for Data Set 24--Vacuum Runs at 1002°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
206763	22.1354	21.8328	21.9345	21.8251	21.3077	22.2501		
206764	22.1247	21.8248	21.9299	21.8159	21.3025	22.2589		
206765	22.1419	21.8401	21.9482	21.8335	21.3331	22.2782		
206766	22.0913	21.7849	21.8914	21.7838	21.2764	22.2060		
206767	22.0616	21.7589	21.8647	21.7542	21.2467	22.1859		
206768	22.2328	21.9398	22.0408	21.9325	21.4191	22.3640		
206769	22.2402	21.9466	22.0478	21.9401	21.4268	22.3802		
206770	22.3457	22.0527	22.1492	22.0476	21.5234	22.4740		
206771	22.3515	22.0617	22.1599	22.0537	21.5316	22.4933		
206772	22.3678	22.0729	22.1764	22.0724	21.5528	22.5192		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.6 VOLTS							
206757	22.3451	21.8741	22.1589	22.0449	21.5209	22.3252	1.40	0.04274
206758	22.3804	21.8955	22.1865	22.0680	21.5563	22.3579	1.40	0.04271
206759	22.4082	21.9270	22.2121	22.0972	21.5751	22.3813	1.40	0.04267
206760	22.4264	21.9515	22.2359	22.1118	21.6005	22.4173	1.40	0.04267
206761	22.3503	21.8704	22.1555	22.0409	21.5262	22.3235	1.40	0.04265
206762	22.3701	21.8953	22.1798	22.0601	21.5427	22.3591	1.40	0.04269

Table A.25 Original Data for Data Set 25--Vacuum Runs at 1191°F.

RUN	THERMOCOUPLES						HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Volts	Amps
	ISOTHERMAL							
206773	26.7324	26.4876	26.5227	26.3974	25.8196	26.8491		
206774	26.6229	26.3761	26.3973	26.2756	25.7043	26.7074		
206775	26.6438	26.4089	26.4288	26.3019	25.7360	26.7569		
206776	26.6204	26.3799	26.3972	26.2679	25.7111	26.7142		
206777	26.6222	26.3835	26.4098	26.2815	25.7228	26.7469		
206778	26.6864	26.4466	26.4708	26.3363	25.7786	26.7979		
206779	26.7032	26.4679	26.4872	26.3464	25.7961	26.8167		
206780	26.7257	26.4821	26.5020	26.3805	25.8185	26.8197		
206781	26.6964	26.4554	26.4781	26.3409	25.7777	26.7985		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.6 VOLTS							
206782	26.7519	26.4055	26.5403	26.4037	25.8504	26.7701	1.40	0.04270
206783	26.8198	26.4710	26.6120	26.4841	25.9226	26.8436	1.40	0.04265
206784	26.8174	26.4620	26.5998	26.4628	25.8965	26.8091	1.40	0.04263
206785	26.8122	26.4629	26.6009	26.4598	25.9049	26.8238	1.40	0.04263
206786	26.7909	26.4478	26.5828	26.4442	25.8916	26.8144	1.40	0.04263
206787	26.8701	26.5255	26.6562	26.5313	25.9669	26.8752	1.40	0.04264
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.1 VOLTS							
206788	26.7922	26.4629	26.5807	26.4703	25.9018	26.8257	1.40	0.04270
206789	26.7911	26.4573	26.5805	26.4609	25.8938	26.8242	1.40	0.04270
206790	26.7913	26.4582	26.5765	26.4434	25.8833	26.8159	1.40	0.04270
206791	26.8619	26.5320	26.6481	26.5269	25.9592	26.8939	1.40	0.04266
206792	26.8795	26.5489	26.6577	26.5320	25.9613	26.8860	1.40	0.04267
206793	26.8323	26.5000	26.6152	26.4980	25.9218	26.8544	1.40	0.04267
206794	26.8382	26.5093	26.6190	26.5066	25.9302	26.8514	1.40	0.04268
206795	26.8670	26.5353	26.6517	26.5482	25.9753	26.8875	1.40	0.04267

Table A.26 Original Data for Data Set 26--Potassium Runs at 1016°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206801	22.5130	22.9536	22.1742	22.1746	21.5812	22.2188	20.0355		
206802	22.4730	22.9022	22.1252	22.1310	21.5095	22.2148	19.9267		
206803	22.4594	22.8888	22.1081	22.1164	21.4987	22.1073	19.9050		
206804	22.6057	23.0348	22.2397	22.2504	21.6320	22.2589	20.0325		
206805	22.6014	23.0396	22.2427	22.2491	21.6352	22.2621	20.0694		
206806	22.5914	23.0234	22.2257	22.2346	21.6215	22.2494	20.0403		
206807	22.5367	22.9471	22.1983	22.2028	21.5616	22.2145	19.9074		
206808	22.4713	22.9053	22.1183	22.1209	21.5142	22.1400	19.9602		
206809	22.5535	22.9880	22.1978	22.2121	21.5852	22.1799	20.0281		
206810	22.5378	22.9751	22.1803	22.1917	21.5770	22.1840	20.0420		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.95 VOLTS								
206811	22.7856	23.0516	22.4353	22.4414	21.8221	22.2807	19.8425	3.11	0.09588
206812	22.6767	22.9655	22.3434	22.3448	21.7124	22.1706	19.8587	3.11	0.09583
206813	22.6624	22.9540	22.3274	22.3315	21.6917	22.1486	19.8551	3.11	0.09584
206814	22.7043	22.9743	22.3771	22.3711	21.7257	22.2297	19.7802	3.11	0.09595
206815	22.6785	22.9459	22.3443	22.3417	21.7197	22.1929	19.7517	3.11	0.09595
206816	22.6579	22.9288	22.3320	22.3233	21.6922	22.1791	19.7605	3.11	0.09592
206818	22.6530	22.9285	22.3283	22.3211	21.6873	22.1759	19.7734	3.11	0.09593
206819	22.7544	22.0380	22.4271	22.4164	21.8005	22.2884	19.9181	3.11	0.09593

Table A.27 Original Data for Data Set 27--Potassium Runs at 1016°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206821	22.4498	22.8553	22.1103	22.1040	21.4985	22.1461	20.0156		
206822	22.4802	22.8992	22.1293	22.1322	21.5249	22.1466	20.0986		
206823	22.5069	22.9354	22.1565	22.1626	21.5436	22.1569	20.1103		
206824	22.5191	22.9130	22.1756	22.1726	21.5645	22.2202	19.9818		
206825	22.4987	22.8845	22.1556	22.1553	21.5534	22.1996	19.9053		
206826	22.4874	22.8738	22.1448	22.1429	21.5431	22.1992	19.9118		
206827	22.5050	22.9109	22.1562	22.1533	21.5497	22.1876	20.0435		
206828	22.5291	22.9334	22.1767	22.1765	21.5704	22.2086	20.0550		
206829	22.5741	22.9785	22.2266	22.2314	21.6315	22.2574	20.0942		
206830	22.5423	22.9358	22.1986	22.2000	21.6087	22.2442	20.0379		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.60 VOLTS								
206831	22.7123	22.9811	22.3646	22.3603	21.7710	22.2742	19.9612	3.10	0.09572
206832	22.7064	22.9743	22.3570	22.3543	21.7489	22.2401	19.9418	3.11	0.09551
206833	22.7204	22.9937	22.3675	22.3648	21.7731	22.2589	20.0156	3.11	0.09558
206834	22.6235	22.9262	22.2970	22.2971	21.6721	22.1470	20.0464	3.11	0.09547
206835	22.6919	23.0081	22.3504	22.3448	21.7352	22.1759	20.1552	3.11	0.09542
206836	22.6524	22.9647	22.3011	22.2985	21.6852	22.1188	20.0843	3.11	0.09550
206837	22.6306	22.9485	22.2822	22.2766	21.6655	22.1129	20.1004	3.11	0.09551

Table A.28 Original Data for Data Set 28--Potassium Runs at 1095°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206838	24.3909	24.4230	24.1954	24.0615	23.4330	24.5959	17.5543		
206839	24.3903	24.4220	24.1941	24.0631	23.4328	24.5900	17.5484		
206840	24.3590	24.3925	24.1617	24.0332	23.3959	24.5712	17.5299		
206841	24.4025	24.4314	24.2029	24.0715	23.4579	24.6119	17.5774		
206842	24.4270	24.4597	24.2361	24.1012	23.4790	24.6439	17.6010		
206843	24.4490	24.4782	24.2441	24.1187	23.4825	24.6421	17.6065		
206844	24.3467	24.3752	24.1420	24.0006	23.3688	24.5515	17.4673		
206845	24.3130	24.3412	24.1110	23.9732	23.3468	24.5215	17.4590		
206846	24.3114	24.3351	24.1116	23.9796	23.3557	24.4978	17.4576		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.8 VOLTS								
206847	24.5808	24.4894	24.3751	24.2503	23.6085	24.6330	17.5365	3.09	0.09474
206848	24.5868	24.4944	24.3872	24.2607	23.6227	24.6416	17.5543	3.10	0.09477
206849	24.5481	24.4532	24.3476	24.2187	23.5796	24.5998	17.4943	3.10	0.09486
206850	24.5422	24.4456	24.3410	24.2128	23.5709	24.5880	17.4923	3.10	0.09480
206851									
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.6 VOLTS								
206852	24.5661	24.4472	24.3690	24.2242	23.6291	24.5953	17.4765	3.10	0.09482
206853	24.5684	24.4441	24.3719	24.2316	23.6227	24.5835	17.4641	3.10	0.09483
206855	24.4795	24.3514	24.2850	24.1486	23.5053	24.5074	17.3235	3.10	0.09495
206856	24.5347	24.4101	24.3470	24.2075	23.5732	24.5733	17.3911	3.10	0.09493
206857	24.5576	24.4359	24.3711	24.2316	23.5937	24.5977	17.4265	3.10	0.09490
206858	24.5793	24.4588	24.3984	24.2571	23.6180	24.6157	17.4545	3.10	0.09491
206859	24.5831	24.4630	24.3905	24.2537	23.6130	24.6183	17.4630	3.10	0.09489
206860	23.5434	24.4216	24.3554	24.2238	23.6229	24.5839	17.4264	3.10	0.09492
206861	24.5286	24.4023	24.3376	24.2061	23.6101	24.5619	17.4037	3.10	0.09497

Table A.29 Original Data for Data Set 29--Potassium Runs at 1097°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206862	24.4918	24.7113	24.2208	24.1547	23.5116	24.4629	19.6441		
206863	24.5079	24.7338	24.2361	24.1636	23.5203	24.4859	19.6814		
206864	24.5717	24.7935	24.2959	24.2335	23.6036	24.5308	19.7561		
206865	24.5186	24.7356	24.2424	24.1807	23.5503	24.4766	19.6829		
206866	24.4888	24.7092	24.2207	24.1515	23.5257	24.4719	19.6911		
206867	24.4989	24.7196	24.2223	24.1557	23.5136	24.4696	19.6848		
206868	24.4986	24.7193	24.2278	24.1633	23.5258	24.4710	19.7121		
206869	24.4777	24.7010	24.2075	24.1404	23.5000	24.4556	19.6895		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.42 VOLTS								
206870	24.6643	24.7329	24.4075	24.3361	23.6941	24.4783	19.5801	3.12	0.09560
206871	24.6084	24.6822	24.3617	24.2820	23.6158	24.4223	19.5368	3.11	0.09560
206872	24.6189	24.6959	24.3758	24.2935	23.6261	24.4417	19.5616	3.12	0.09559
206873	24.5377	24.6111	24.2917	24.2095	23.5527	24.3590	19.4849	3.12	0.09559
206874	24.5946	24.6753	24.3541	24.2649	23.6253	24.4398	19.5642	3.12	0.09559
206875	24.6774	24.7499	24.4289	24.3497	23.6874	24.5027	19.5981	3.12	0.09560
206876	24.6950	24.7693	24.4447	24.3655	23.6983	24.5225	19.6178	3.12	0.09560
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206877	24.6257	24.7044	24.3661	24.2970	23.6491	24.4587	19.5263	3.12	0.09570
206878	24.6063	24.6881	24.3530	24.2749	23.6116	24.4425	19.5175	3.12	0.09570
206879	24.5752	24.6570	24.3240	24.2459	23.5818	24.4189	19.4994	3.12	0.09570
206880	24.5880	24.6706	24.3369	24.2589	23.5976	24.4321	19.5156	3.12	0.09569
206881	24.5974	24.6813	24.3474	24.2679	23.6013	24.4393	19.5267	3.12	0.09569
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.6 VOLTS								
206882	24.5573	24.6487	24.3078	24.2320	23.5515	24.4189	19.4977	3.11	0.09546
206883	24.5656	24.6541	24.3099	24.2392	23.5560	24.4082	19.4857	3.11	0.09546
206884	24.6627	24.7516	24.4023	24.3329	23.6707	24.5167	19.5735	3.11	0.09547
206885	24.6228	24.7119	24.3699	24.2918	23.6207	24.4812	19.5364	3.11	0.09549

Table A.30 Original Data for Data Set 30--Potassium Runs at 1191°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206886	26.7352	26.6134	26.5578	26.3660	25.7754	27.1105	17.9247		
206887	26.6590	26.5387	26.4832	26.2990	25.7010	27.0238	17.8945		
206888	26.6190	26.4979	26.4377	26.2567	25.6630	26.9745	17.8684		
206889	26.6532	26.5325	26.4679	26.2911	25.6907	27.0026	17.9582		
206890	26.6277	26.5121	26.4428	26.2650	25.6660	26.9815	17.9408		
206891	26.6148	26.4936	26.4304	26.2556	25.6629	26.9648	17.9043		
206892	26.6269	26.5100	26.4428	26.2671	25.6767	26.9851	17.9116		
206893	26.6266	26.5086	26.4458	26.2736	25.6813	26.9860	17.9106		
206894	26.6559	26.5336	26.4693	26.3003	25.7167	27.0084	17.9339		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.8 VOLTS								
206895	26.8034	26.5699	26.6350	26.4627	25.8351	27.0336	17.9439	3.11	0.09519
206896	26.7999	26.5655	26.6286	26.4553	25.8241	27.0322	17.9339	3.11	0.09521
206897	26.7999	26.5747	26.6278	26.4550	25.8280	27.0222	17.9299	3.11	0.09522
206898	26.7932	26.5697	26.6230	26.4492	25.8265	27.0244	17.9273	3.11	0.09522
206899	26.8716	26.6444	26.6789	26.5038	25.9092	27.1071	17.9764	3.12	0.09522
206900	26.8411	26.6146	26.6433	26.4709	25.8728	27.0680	17.9525	3.12	0.09527
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.75 VOLTS								
206901	26.8702	26.6309	26.7095	26.5259	25.9076	27.0902	17.9505	3.11	0.09512
206902	26.7877	26.5497	26.6269	26.4487	26.8164	26.9977	17.9076	3.11	0.09510
206903	26.9077	26.6637	26.7455	26.5640	25.9393	27.1198	17.9990	3.11	0.09509
206904	26.8948	26.6566	26.7326	26.5507	25.9288	27.1057	17.9930	3.11	0.09510
206906	26.8276	26.5881	26.6640	26.4869	25.8608	27.0345	17.9571	3.11	0.09506
206907	26.8297	26.5908	26.6650	26.4869	25.8627	27.0378	17.9602	3.11	0.09506
206908	26.8320	26.5902	26.6620	26.4849	25.8609	27.0306	17.9894	3.11	0.09507
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.5 VOLTS								
206909	26.8246	26.5534	26.6696	26.4784	25.8783	27.0081	17.8587	3.11	0.09512
206910	26.8470	26.5789	26.6949	26.5042	25.8840	27.0356	17.8792	3.11	0.09510
206911	26.8217	26.5552	26.6648	26.4784	25.8598	27.0041	17.8719	3.11	0.09501
206912	26.8553	26.5872	26.7050	26.5165	25.8945	27.0315	17.8994	3.11	0.09504
206913	26.8508	26.5810	26.6991	26.5073	25.8985	27.0270	17.8986	3.11	0.09506
206914	26.8174	26.5460	26.6649	26.4716	25.8678	27.0005	17.8351	3.11	0.09515
206915	26.8396	26.5705	26.6846	26.4988	25.8738	27.0135	17.8833	3.11	0.09507
206916	26.8277	26.5596	26.6764	26.4875	25.8650	27.0076	17.8932	3.11	0.09507

Table A.31 Original Data for Data Set 31--Potassium Runs at 1191°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206917	26.6417	26.6203	26.4194	26.2725	25.6665	26.8907	19.4194		
206918	26.7140	26.6921	26.4916	26.3430	25.7322	26.9595	19.4763		
206919	26.7096	26.6857	26.4705	26.3277	25.7212	26.9441	19.4825		
206920	26.6675	26.6456	26.4396	26.2966	25.6908	26.9034	19.4551		
206921	26.7060	26.6851	26.4977	26.3522	25.7251	26.9544	19.4893		
206922	26.6454	26.6284	26.4209	26.2788	25.6626	26.8753	19.4568		
206923	26.6395	26.6270	26.4209	26.2749	25.6707	26.8793	19.4697		
206924	26.5797	26.5690	26.3572	26.2134	25.6123	26.8131	19.4374		
206925	26.6648	26.6497	26.4255	26.2835	25.6780	26.8991	19.4980		
206926	26.6978	26.6848	26.4614	26.3193	25.7167	26.9403	19.5303		
206927	26.7070	26.6925	26.4773	26.3328	25.7341	26.9506	19.5333		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.5 VOLTS								
206929	26.8682	26.6989	26.6605	26.5057	25.9188	26.9315	19.4515	3.11	0.09542
206930	26.7813	26.6152	26.5834	26.4278	25.8240	26.8289	19.4092	3.11	0.09540
206931	26.7795	26.6183	26.5815	26.4266	25.8209	26.8286	19.4154	3.11	0.09539
206932	26.7941	26.6351	26.5975	26.4435	25.8357	26.8515	19.4379	3.11	0.09539
206933	26.7842	26.6238	26.5882	26.4387	25.8159	26.8244	19.4262	3.12	0.09539
206934	26.9358	26.7745	26.7377	26.5788	25.9768	26.9988	19.5484	3.12	0.09540
206935	26.9231	26.7594	26.7191	26.5624	25.9676	26.9872	19.5355	3.12	0.09542
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.55 VOLTS								
206936	26.8484	26.7080	26.6424	26.4938	25.8838	26.9443	19.4939	3.12	0.09542
206937	26.7403	26.6072	26.5386	26.3940	25.7649	26.8311	19.4289	3.12	0.09539
206938	26.7514	26.6183	26.5472	26.4045	25.7760	26.8356	19.4398	3.12	0.09538
206939	26.7508	26.6167	26.5478	26.4051	25.7796	26.8354	19.4409	3.12	0.09538
206940	26.7376	26.5994	26.5221	26.3832	25.7428	26.8186	19.4226	3.12	0.09538
206941	26.8356	26.6980	26.6306	26.4834	25.8546	26.9234	19.4864	3.12	0.09544
206942	26.8304	26.6920	26.6275	26.4799	25.8605	26.9197	19.4802	3.12	0.09544
206943	26.8260	26.6893	26.6218	26.4762	25.8551	26.9090	19.4843	3.12	0.09543
206944	26.8313	26.6929	26.6241	26.4771	25.8664	26.9209	19.4849	3.12	0.09546

Table A.32 Original Data for Data Set 32--Potassium Runs at 1099°F.

RUN	THERMOCOUPLES							HEATER	
	3 mv	4 mv	5 mv	6 mv	7 mv	8 mv	Boiler mv	Volts	Amps
	ISOTHERMAL								
206948	24.4932	24.4927	24.2861	24.1529	23.5545	24.7147	17.5966		
206949	24.4745	24.4781	24.2771	24.1434	23.5332	24.6997	17.5478		
206950	24.4955	24.4975	24.2935	24.1632	23.5702	24.7235	17.5665		
206951	24.4915	24.4967	24.2944	24.1604	23.5584	24.7225	17.5553		
206952	24.5075	24.5103	24.3110	24.1773	23.5714	24.7304	17.5790		
206953	24.4960	24.5025	24.3006	24.1658	23.5572	24.7226	17.5805		
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.15 VOLTS								
206954	24.6583	24.5242	24.4711	24.3299	23.7269	24.7313	17.4859	3.11	0.09571
206955	24.6740	24.5418	24.4865	24.3433	23.7417	24.7475	17.5003	3.10	0.09568
206956	24.6811	24.5466	24.4919	24.3497	23.7493	24.7469	17.5035	3.11	0.09568
206957	24.6634	24.5258	24.4700	24.3403	23.7446	24.7288	17.5040	3.11	0.09569
206958	24.6575	24.5209	24.4638	24.3335	23.7426	24.7181	17.4956	3.11	0.09570
206959	24.6539	24.5188	24.4605	24.3298	23.7431	24.7217	17.4933	3.11	0.09570
206960	24.6424	24.5071	24.4559	24.3164	23.7096	24.7163	17.4714	3.11	0.09571
206961	24.6682	24.5349	24.4796	24.3399	23.7288	24.7396	17.4933	3.11	0.09567
206962	24.6775	24.5428	24.4863	24.3471	23.7376	24.7443	17.5053	3.11	0.09566
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.55 VOLTS								
206963	24.7006	24.5887	24.5092	24.3765	23.7568	24.7852	17.6024	3.11	0.09563
206964	24.7096	24.5969	24.5201	24.3870	23.7631	24.7901	17.6096	3.11	0.09562
206965	24.6489	24.5376	24.4561	24.3276	23.6949	24.7219	17.5622	3.11	0.09560
206966	24.6818	24.5692	24.4908	24.3626	23.7353	24.7633	17.5950	3.11	0.09559
206967	24.6571	24.5419	24.4600	24.3351	23.7090	24.7257	17.5700	3.11	0.09559
206968	24.6451	24.5302	24.4476	24.3236	23.7020	24.7186	17.5645	3.11	0.09560

APPENDIX B

PRELIMINARY PROCESSED DATA

Table B.1 Preliminary Processed Data for Data Set 1--Vacuum Runs at 943°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3	4-3	5-3	6-3	7-3	8-3		
	°F	°F	°F	°F	°F	°F	°F	mm Hg
	ISOTHERMAL							
199465	928.7	-26.747	3.802	-3.907	-32.211	46.430	24.502	0.004
199466	935.2	-26.532	3.034	-4.278	-34.067	40.641	26.755	0.004
199467	936.5	-27.595	3.004	-3.932	-33.763	42.248	26.827	0.004
199468	927.2	-27.295	2.878	-4.616	-32.747	46.130	25.253	0.004
199469	934.7	-27.553	4.645	-3.713	-33.426	47.772	25.068	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 4.0 VOLTS							
199472	950.0	-37.253	3.607	-2.979	-31.793	40.801	25.207	0.002
199474	954.6	-37.160	2.612	-4.169	-32.498	37.209	25.717	0.002
199475	939.9	-36.186	3.194	-2.810	-32.338	35.434	26.334	0.002

Table B.2 Preliminary Processed Data for Data Set 2--Nitrogen Runs at 925°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
199488	923.9	4.519	3.017	-8.485	-25.586	44.278	14.084	1210.
199489	941.4	5.312	4.376	-7.675	-27.333	47.544	15.282	1210.
199490	938.7	4.093	2.384	-11.181	-25.608	50.051	12.043	1210.
199491	928.5	5.266	4.789	-7.139	-26.245	47.152	14.317	1210.
199494	913.3	4.494	3.810	-7.700	-26.970	46.573	15.460	1210.
199495	913.1	4.194	3.679	-8.321	-25.835	46.962	13.835	1210.
199497	916.2	4.574	3.882	-8.072	-25.232	46.447	13.278	1210.
199498	917.0	4.684	5.321	-6.266	-25.215	47.228	13.628	1210.
199499	926.6	4.890	7.063	-4.646	-26.105	48.342	14.396	1210.
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.8 VOLTS							
205505	923.7	2.215	4.013	-8.207	-24.781	42.734	12.561	1180.
205506	923.5	2.962	4.658	-7.548	-26.594	43.270	14.388	1180.
205507	926.0	3.118	6.628	-4.169	-26.194	43.898	15.397	1190.
205508	927.5	2.338	4.265	-7.789	-25.270	43.120	13.216	1190.
205509	928.3	2.646	4.493	-6.898	-24.814	42.514	13.423	1200.
205511	926.1	2.738	6.434	-5.198	-26.594	43.586	14.962	1200.

Table B.3 Preliminary Processed Data for Data Set 3--Vacuum Runs at 1032°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205517	1030.6	-36.775	4.372	-2.686	-34.427	44.021	27.369	0.002
205521	1032.4	-36.826	4.775	-1.915	-34.474	43.677	27.784	0.002
205522	1031.1	-37.533	4.021	-2.533	-34.766	43.665	28.212	0.002
205523	1031.2	-37.355	4.237	-1.555	-34.415	43.924	28.623	0.002
205524	1031.1	-37.550	4.618	-1.805	-34.347	44.033	27.924	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 3.05 VOLTS							
205532	1032.4	-41.008	2.855	-4.004	-35.165	40.898	28.306	0.001
205533	1033.6	-40.830	3.834	-2.190	-34.788	40.419	28.764	0.001
205534	1033.5	-40.779	3.114	-3.139	-35.080	40.135	28.827	0.002
205536	1034.0	-41.466	2.949	-3.135	-35.021	40.266	28.937	0.002
205540	1034.5	-40.949	4.406	-2.131	-34.122	39.588	27.585	0.002

Table B.4 Preliminary Processed Data for Data Set 4--Nitrogen Runs at 1027°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205541	1027.5	4.186	9.737	-2.834	-27.872	49.826	15.301	1270.
205542	1027.9	4.105	7.805	-4.076	-27.639	49.677	15.758	1285.
205543	1028.9	4.233	7.843	-3.716	-27.593	48.444	16.034	1310.
205544	1029.2	3.957	7.186	-4.707	-28.266	48.860	16.373	1310.
205545	1029.0	4.245	7.677	-4.016	-27.978	48.923	16.285	1310.
205546	1027.5	3.995	8.944	-3.076	-29.292	49.038	17.272	1300.
205547	1029.1	4.173	7.970	-4.055	-28.008	49.063	15.983	1310.
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.95 VOLTS							
205702	1028.4	2.000	9.016	-3.059	-28.483	47.067	16.408	1310.
205703	1029.0	2.008	8.864	-3.330	-27.508	47.872	15.314	1305.
205704	1028.1	2.152	8.716	-3.453	-27.516	47.872	15.347	1300.

Table B.5 Preliminary Processed Data for Data Set 5--Vacuum Runs at 1117°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205710	1124.4	-33.748	3.825	-2.157	-35.914	45.910	29.932	0.003
205712	1117.6	-33.765	2.417	-4.468	-36.221	46.374	29.336	0.002
205713	1116.3	-35.306	2.770	-1.919	-35.817	44.846	31.128	0.002
205715	1118.5	-33.327	3.042	-3.629	-36.514	45.446	29.843	0.002
205716	1113.2	-34.778	2.178	-2.459	-36.429	46.455	31.792	0.001
205717	1115.5	-34.540	3.527	-1.553	-36.063	46.919	30.983	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 3.15 VOLTS							
205718	1118.2	-37.323	3.182	-0.880	-36.217	43.531	32.155	0.002
205719	1118.4	-36.961	3.634	-0.859	-35.953	43.182	31.460	0.001
205720	1118.5	-37.297	3.761	-0.953	-35.710	43.765	30.996	0.001
205721	1118.2	-37.672	3.638	-0.829	-35.753	43.697	31.286	0.002
205722	1118.9	-36.855	4.510	-1.378	-36.080	44.578	30.192	0.001
205723	1119.5	-36.702	4.293	-1.055	-35.617	44.531	30.269	0.001

Table B.6 Preliminary Processed Data for Data Set 6--Nitrogen Runs at 1113°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205724	1112.5	2.987	9.123	-3.587	-29.365	51.323	16.655	1350.
205725	1114.2	3.455	9.319	-2.876	-29.170	51.004	16.975	1360.
205726	1112.2	3.221	9.263	-2.970	-29.531	50.638	17.298	1360.
205727	1113.0	3.110	9.787	-2.212	-29.948	50.459	17.949	1370.
205728	1112.9	3.140	9.370	-2.851	-29.740	50.744	17.519	1370.
205729	1114.6	3.076	9.153	-2.965	-30.148	50.680	18.030	1370.
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.95 VOLTS							
205732	1114.5	1.417	9.676	-2.859	-30.170	49.097	17.635	1360.
205733	1114.0	1.153	9.195	-3.268	-29.446	49.378	16.983	1360.
205734	1113.5	1.378	9.365	-3.068	-28.821	49.289	16.388	1360.

Table B.7 Preliminary Processed Data for Data Set 7--Vacuum Runs at 1213°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205735	1211.9	-27.293	4.463	-2.289	-36.353	47.004	29.601	0.001
205736	1212.0	-27.412	4.468	-2.021	-36.472	46.753	29.983	0.001
205737	1210.1	-27.902	4.225	-2.110	-36.634	47.365	30.299	0.001
205739	1212.5	-27.889	4.493	-2.046	-36.659	47.302	30.120	0.001
205741	1210.8	-27.561	4.995	-1.472	-37.306	47.634	30.839	0.001
205743	1213.5	-27.395	5.621	-1.238	-37.140	47.680	30.281	0.001
205744	1213.9	-27.587	5.646	-1.165	-36.948	47.702	30.137	0.002
205745	1210.7	-28.459	4.140	-2.144	-37.617	48.106	31.333	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 4.6 VOLTS							
205600	1215.5	-30.906	5.753	-0.617	-36.774	44.289	30.404	0.002
205601	1216.1	-30.876	6.131	-0.510	-37.668	45.034	31.027	0.001
205602	1216.6	-30.357	6.323	-0.697	-37.476	44.770	30.456	0.002
205605	1214.9	-29.897	4.851	-2.774	-38.617	44.731	30.992	0.002
205606	1214.4	-30.889	5.412	-2.357	-38.885	44.897	31.116	0.002
205607	1212.1	-30.540	3.753	-5.170	-38.834	45.553	29.911	0.002

Table B.8 Preliminary Processed Data for Data Set 8--Nitrogen Runs at 1213°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205608	1207.5	1.761	7.903	-4.012	-32.276	52.540	21.171	1355.
205609	1211.2	1.519	6.889	-4.855	-32.617	52.765	19.873	1360.
205610	1212.2	1.578	6.838	-4.872	-31.680	52.293	19.970	1365.
205611	1208.9	1.659	6.106	-5.591	-31.378	51.995	19.681	1365.
205612	1209.3	1.582	7.553	-3.808	-32.340	52.744	20.979	1365.
205613	1209.6	1.463	8.710	-2.063	-33.659	52.446	22.886	1365.
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.8 VOLTS							
205614	1215.0	0.004	7.217	-4.191	-32.285	49.136	20.877	1380.
205615	1213.0	0.123	7.259	-4.187	-31.970	49.378	20.524	1380.
205616	1215.2	0.008	6.893	-4.455	-32.412	48.940	21.064	1380.
205617	1215.7	-0.089	6.655	-4.821	-32.208	48.931	20.732	1380.
205619	1215.8	-0.106	5.408	-6.429	-31.889	48.523	20.052	1380.
205620	1213.1	-0.106	6.051	-5.493	-32.471	49.289	20.928	1380.
205621	1212.5	-0.076	6.446	-4.446	-33.246	49.370	22.354	1380.
205622	1212.1	-0.204	5.838	-5.885	-32.991	49.042	21.268	1380.

Table B.9 Preliminary Processed Data for Data Set 9--Vacuum Runs at 1008°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205626	1008.1	-8.172	-10.472	-15.299	-38.957	8.805	34.130	0.002
205627	1005.3	-8.451	-10.936	-14.995	-38.962	7.105	34.903	0.002
205628	1003.9	-8.586	-10.502	-14.683	-38.219	7.302	34.038	0.002
205629	1002.7	-8.594	-10.544	-14.869	-38.776	8.071	34.451	0.002
205630	1003.8	-8.379	-10.451	-14.873	-38.670	7.890	34.248	0.002
205631	1006.5	-8.451	-10.544	-14.797	-38.594	7.367	34.341	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 4.0 VOLTS							
205638	1009.5	-12.151	-10.535	-14.603	-38.084	4.379	34.016	0.002
205639	1011.2	-12.105	-10.822	-14.797	-38.928	4.003	34.953	0.002
205640	1012.2	-11.928	-10.632	-14.713	-38.898	4.202	34.817	0.002
205641	1007.9	-12.059	-10.210	-14.476	-37.991	4.485	33.725	0.002
205642	1006.0	-12.021	-10.603	-14.632	-38.932	4.088	34.903	0.002

Table B.10 Preliminary Processed Data for Data Set 10--Vacuum Runs at 1113°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205644	1104.9	-5.466	-14.322	-19.995	-43.169	-3.135	37.496	0.002
205645	1107.2	-5.326	-14.059	-19.669	-43.419	-3.097	37.809	0.002
205646	1110.8	-5.203	-13.915	-19.521	-42.703	-2.902	37.097	0.002
205647	1113.5	-5.292	-14.309	-19.529	-43.224	-3.622	38.004	0.002
205648	1112.5	-5.008	-13.894	-19.427	-43.067	-3.792	37.534	0.002
205649	1111.5	-4.983	-14.330	-19.665	-43.593	-4.288	38.258	0.002
205550	1106.9	-4.932	-13.576	-18.728	-43.271	-4.237	38.119	0.002
205551	1107.0	-4.957	-14.105	-19.644	-43.440	-3.538	37.901	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 3.9 VOLTS							
205556	1113.7	-7.427	-12.580	-18.139	-42.834	-6.766	37.275	0.002
205557	1111.9	-7.411	-12.207	-17.635	-42.847	-6.809	37.419	0.002
205558	1110.1	-7.694	-12.923	-17.186	-43.686	-7.555	39.423	0.002
205559	1112.9	-7.050	-12.228	-18.139	-42.411	-5.483	36.500	0.002
205560	1117.2	-7.584	-12.131	-17.567	-42.915	-6.970	37.479	0.002
205561	1118.1	-7.372	-12.682	-17.936	-42.966	-7.279	37.712	0.002
205562	1114.7	-7.415	-12.343	-17.750	-42.597	-6.305	37.190	0.002

Table B.11 Preliminary Processed Data for Data Set 11--Vacuum Runs at 1205°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205564	1201.1	-2.293	-12.246	-18.178	-45.948	-5.595	40.016	0.002
205565	1203.3	-2.272	-12.251	-18.395	-45.706	-5.740	39.562	0.002
205566	1204.8	-2.191	-12.297	-18.548	-45.455	-5.557	39.204	0.002
205567	1204.2	-2.523	-12.357	-18.468	-45.893	-6.787	39.782	0.002
205568	1200.7	-2.791	-13.119	-19.055	-45.927	-7.263	39.991	0.002
205569	1199.2	-2.331	-13.029	-19.131	-45.553	-5.885	39.451	0.002
205570	1197.7	-2.676	-12.829	-18.595	-45.731	-6.591	39.965	0.002
	HEATED TOP PLATE - GUARD VOLTAGE = 4.5 VOLTS							
205571	1201.1	-6.204	-12.502	-15.987	-47.191	-10.042	43.706	0.002
205572	1206.8	-6.089	-12.357	-16.748	-47.008	- 9.651	42.617	0.002
	HEATED TOP PLATE - GUARD VOLTAGE = 5.0 VOLTS							
205573	1206.9	-5.812	-11.838	-18.106	-45.868	-10.085	39.600	0.002
205574	1208.5	-5.817	-11.931	-17.697	-46.170	-10.919	40.404	0.002
205575	1208.0	-5.923	-12.161	-17.761	-45.961	-11.046	40.361	0.002
205576	1208.4	-5.731	-11.914	-17.914	-45.144	-10.710	39.144	0.002
205577	1211.8	-5.497	-13.243	-18.544	-47.008	-11.357	41.710	0.002
205578	1208.8	-5.936	-13.463	-19.055	-46.557	-11.136	40.965	0.002
205579	1209.4	-5.774	-13.319	-19.289	-45.987	-10.370	40.017	0.002
205580	1209.2	-5.102	-12.621	-18.548	-46.161	- 9.191	40.234	0.002
205581	1209.0	-5.880	-14.017	-19.570	-46.519	-11.004	40.966	0.002

Table B.12 Preliminary Processed Data for Data Set 12--Vacuum Runs at 1305°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205582	1291.6	-0.642	-13.319	-18.834	-47.625	-7.668	42.110	0.002
205585	1299.7	-0.748	-14.669	-19.759	-48.712	-9.845	43.622	0.002
205586	1298.5	-0.648	-14.549	-19.699	-48.519	-9.596	43.369	0.002
205587	1299.2	-0.386	-14.072	-19.862	-48.188	-9.257	42.398	0.002
205588	1299.3	-0.682	-14.742	-20.463	-48.545	-9.854	42.824	0.002
205589	1304.0	-0.390	-14.484	-19.974	-49.223	-9.648	43.733	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.0 VOLTS							
205590	1306.6	-3.008	-13.351	-19.158	-49.446	-12.137	43.639	0.002
205591	1309.6	-2.811	-14.085	-20.017	-49.662	-12.746	43.690	0.002
205592	1309.2	-2.583	-12.738	-18.944	-49.721	-12.416	43.515	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.25 VOLTS							
205593	1304.7	-3.746	-13.472	-18.626	-48.639	-13.000	43.485	0.002
205594	1303.3	-3.888	-13.446	-18.909	-48.502	-12.991	43.039	0.002
205595	1303.1	-3.669	-13.716	-19.746	-48.540	-12.656	42.510	0.002
205596	1305.1	-3.854	-14.291	-19.875	-48.969	-13.961	42.385	0.002
205597	1303.8	-3.635	-13.725	-19.459	-48.587	-13.137	42.853	0.002
205598	1304.0	-3.103	-13.755	-19.832	-49.201	-13.626	43.124	0.002
205599	1303.8	-3.270	-13.931	-19.995	-48.927	-13.296	42.863	0.002

Table B.13 Preliminary Processed Data for Data Set 13--Potassium Runs at 1010°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs/sq.in.
	ISOTHERMAL								
206004	1002.9	8.793	-10.088	-13.827	-40.852	-1.468	37.113	804.0	0.163
206005	1004.4	8.751	-10.181	-13.670	-40.405	-1.864	36.916	804.4	0.164
206006	1005.7	8.856	-10.105	-13.637	-40.396	-1.687	36.864	806.8	0.169
206007	1005.0	8.873	-10.472	-13.700	-40.869	-2.919	37.641	807.5	0.170
206008	1005.5	8.974	-10.185	-13.594	-40.679	-2.443	37.270	809.1	0.171
206009	1003.2	9.008	-10.303	-13.493	-40.523	-2.645	37.333	806.5	0.168
	HEATED TOP PLATE - GUARD VOLTAGE = 8.2 VOLTS								
206010	1014.5	1.675	-9.725	-13.502	-40.037	-10.810	36.260	804.4	0.164
206011	1014.1	1.637	-9.713	-13.510	-40.080	-10.767	36.283	803.6	0.162
	HEATED TOP PLATE - GUARD VOLTAGE = 7.6 VOLTS								
206013	1011.3	2.227	-10.046	-13.670	-40.675	-9.468	37.051	802.7	0.162
206014	1013.5	2.312	-10.037	-13.632	-40.308	-9.624	36.713	805.3	0.167
206015	1014.4	2.324	-10.059	-13.502	-40.354	-9.818	36.911	806.2	0.168
206016	1014.4	2.265	-10.143	-13.489	-40.164	-10.337	36.818	806.2	0.168
	HEATED TOP PLATE - GUARD VOLTAGE = 7.3 VOLTS								
206017	1011.4	2.658	-10.101	-13.413	-39.991	-9.493	36.679	804.9	0.165
206018	1010.6	2.717	-10.080	-13.358	-39.793	-9.341	36.515	804.4	0.165
206019	1014.7	2.793	-10.059	-13.371	-40.050	-9.198	36.738	809.1	0.170
	HEATED TOP PLATE - GUARD VOLTAGE = 6.9 VOLTS								
206020	1012.6	3.223	-10.569	-13.624	-40.472	-9.274	37.417	807.4	0.168
206021	1012.4	3.151	-10.472	-13.447	-40.295	-9.219	37.320	807.4	0.168
206022	1012.2	3.227	-10.434	-13.556	-40.371	-9.084	37.249	807.2	0.168
206023	1012.3	3.291	-10.379	-13.531	-40.523	-9.042	37.371	807.5	0.168
206024	1012.3	3.177	-10.455	-13.569	-40.434	-9.008	37.320	806.5	0.167

Table B.14 Preliminary Processed Data for Data Set 14--Potassium Runs at 1018°F.

RUN	THERMOCOUPLES 3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	NULL °F	BOILER °F	PRESSURE lbs./sq.in.
	ISOTHERMAL								
206025	1008.9	20.624	-14.215	-13.987	-43.708	-18.447	43.936	929.6	0.167
206026	1010.5	20.604	-14.122	-13.848	-43.185	-18.113	43.459	931.0	0.625
206027	1010.2	20.616	-14.316	-13.970	-43.776	-18.746	44.122	929.5	0.617
206028	1010.2	20.687	-14.236	-13.890	-43.818	-18.464	44.164	930.2	0.621
206029	1010.7	20.738	-14.240	-14.012	-44.257	-18.523	44.485	930.9	0.625
206030	1010.2	20.717	-14.312	-14.025	-44.691	-18.962	44.978	930.6	0.622
206031	1016.0	21.160	-14.350	-13.995	-43.831	-18.578	44.186	937.1	0.662
206032	1015.9	20.755	-14.472	-13.995	-43.957	-19.261	44.434	935.0	0.651
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.9 VOLTS								
206035	1017.4	14.924	-14.375	-13.881	-43.476	-24.645	43.970	927.6	0.604
206036	1018.6	14.928	-14.510	-13.852	-43.126	-25.059	43.784	928.2	0.610
206037	1018.1	14.839	-14.544	-13.822	-43.168	-25.219	43.890	927.6	0.604
206038	1018.1	14.877	-14.594	-13.856	-42.877	-25.189	43.615	927.8	0.605
206039	1018.3	14.873	-14.573	-13.890	-42.924	-25.130	43.607	928.1	0.609
206040	1017.6	14.746	-14.586	-13.852	-42.924	-25.160	43.658	927.0	0.601
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.5 VOLTS								
206041	1023.4	15.578	-14.881	-14.172	-44.037	-24.447	44.746	934.2	0.646
206042	1023.2	15.540	-14.898	-14.033	-44.109	-24.759	44.974	933.3	0.640
206043	1023.0	15.611	-14.586	-13.751	-43.675	-24.329	44.510	934.2	0.649
206044	1023.2	15.383	-14.662	-13.738	-43.573	-24.443	44.497	933.9	0.643
206045	1023.6	15.599	-14.451	-13.670	-43.510	-24.075	44.291	935.2	0.652

Table B.15 Preliminary Processed Data for Data Set 15--Potassium Runs at 1106°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206046	1104.5	1.063	-8.584	-14.813	-40.855	7.080	34.626	810.1	0.174
206047	1105.0	1.112	-8.559	-14.622	-41.436	6.966	35.373	812.0	0.179
206048	1104.8	1.114	-8.627	-14.733	-41.237	6.822	35.131	815.0	0.185
206049	1104.8	1.182	-8.601	-14.720	-41.745	6.902	35.626	811.9	0.179
206050	1105.5	1.228	-8.504	-14.737	-41.118	7.317	34.885	812.7	0.180
206051	1105.9	1.245	-8.669	-14.838	-41.347	6.961	35.178	813.1	0.181
206052	1105.3	1.360	-8.826	-14.788	-41.288	6.538	35.326	813.1	0.181
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.7 VOLTS								
206055	1108.9	-3.936	-9.237	-14.868	-41.194	1.402	35.563	808.7	0.171
206056	1109.3	-3.923	-9.347	-14.864	-41.368	0.885	35.851	809.7	0.172
206057	1109.0	-3.944	-9.419	-14.923	-41.487	0.792	35.983	809.6	0.172
206058	1109.1	-3.838	-9.449	-14.970	-41.741	0.792	36.220	810.3	0.174
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.0 VOLTS								
206061	1110.6	-5.491	-8.762	-14.847	-41.288	-0.394	35.203	808.7	0.170
206062	1108.6	-5.381	-8.809	-14.605	-41.258	-1.067	35.462	808.7	0.170
206063	1109.3	-5.436	-8.822	-14.669	-40.851	-1.139	35.004	810.0	0.172
206064	1107.5	-5.385	-8.953	-14.805	-40.783	-1.266	34.931	809.0	0.170
206065	1110.0	-5.343	-8.915	-14.822	-40.936	-1.152	35.029	811.7	0.178
206066	1109.5	-5.288	-8.906	-14.923	-41.224	-1.080	35.207	811.6	0.178

Table B.16 Preliminary Processed Data for Data Set 16--Potassium Runs at 1108°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206070	1109.5	10.224	-11.381	-14.728	-43.639	-2.953	40.292	909.7	0.490
206071	1109.4	10.330	-11.444	-14.944	-43.953	-2.677	40.453	909.5	0.490
206072	1106.6	10.334	-11.618	-15.000	-44.029	-3.156	40.647	916.7	0.535
206073	1106.6	10.389	-11.529	-14.851	-43.457	-3.177	40.135	917.0	0.535
206074	1106.2	10.389	-11.521	-14.889	-44.101	-3.300	40.733	916.1	0.533
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.0 VOLTS								
206075	1110.5	3.525	-11.588	-15.008	-45.525	-9.953	42.105	907.7	0.485
206076	1111.6	3.483	-11.779	-15.021	-45.309	-10.004	41.779	909.0	0.495
206077	1110.8	3.508	-11.690	-14.974	-45.300	-9.868	42.016	909.0	0.495
206078	1111.2	3.525	-11.639	-14.957	-44.961	-9.724	41.643	909.3	0.496
206079	1112.2	3.529	-11.627	-14.915	-44.978	-9.822	41.690	909.8	0.499
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 9.0 VOLTS								
206080	1112.1	2.351	-11.177	-14.911	-44.161	-11.177	40.427	907.6	0.490
206081	1115.3	2.567	-11.245	-14.860	-44.050	-11.669	40.435	911.2	0.510
206082	1114.3	2.588	-11.029	-14.843	-43.661	-10.919	39.847	911.0	0.510
206083	1115.9	2.754	-11.012	-14.966	-43.411	-10.677	39.457	913.2	0.520
206084	1112.9	2.300	-11.190	-15.105	-44.487	-10.898	40.572	908.2	0.491
206085	1113.1	2.173	-11.300	-15.076	-44.343	-11.165	40.567	908.1	0.491
206086	1113.2	2.292	-10.932	-14.750	-44.474	-10.940	40.656	908.8	0.495
206087	1114.0	2.369	-11.000	-14.847	-44.483	-10.894	40.636	910.0	0.500
206088	1113.2	2.402	-11.245	-14.940	-43.432	-11.173	39.737	909.6	0.499
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.5 VOLTS								
206089	1110.7	6.224	-12.533	-14.966	-44.961	-7.165	42.528	914.5	0.515
206090	1111.5	6.152	-12.419	-14.881	-45.618	-7.165	43.156	915.3	0.521

Table B.17 Preliminary Processed Data for Data Set 17--Potassium Runs at 1113°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206091	1105.1	19.161	-14.716	-15.262	-47.495	-12.483	46.949	1003.7	1.158
206092	1104.7	19.360	-14.262	-15.063	-46.601	-11.652	45.800	1005.7	1.176
206093	1106.3	19.533	-14.296	-14.953	-46.372	-11.927	45.715	1008.1	1.201
206094	1109.9	19.584	-14.762	-15.101	-46.432	-13.021	46.093	1011.2	1.231
206095	1109.2	19.792	-14.317	-14.932	-45.461	-12.127	44.846	1012.2	1.412
206096	1109.8	19.580	-14.711	-15.139	-46.199	-13.016	45.771	1011.2	1.232
206097	1109.4	19.656	-14.618	-15.038	-46.038	-12.707	45.618	1011.5	1.235
206098	1110.6	19.457	-14.855	-15.296	-46.478	-12.822	46.037	1011.6	1.235
206099	1109.6	19.605	-14.627	-15.076	-46.555	-12.525	46.106	1011.2	1.232
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.0 VOLTS								
206101	1116.2	13.038	-14.025	-15.029	-45.326	-18.186	44.322	1005.7	1.174
206102	1117.1	13.228	-14.211	-15.186	-45.504	-18.381	44.529	1006.7	1.183
206103	1117.6	13.322	-14.203	-15.211	-45.614	-18.203	44.606	1008.0	1.200
206104	1120.3	13.758	-14.105	-15.012	-45.440	-18.542	44.533	1011.5	1.232
206105	1117.4	13.460	-14.059	-14.983	-45.266	-18.241	44.342	1008.9	1.210
206106	1118.0	13.690	-14.207	-15.114	-45.716	-18.673	44.809	1009.1	1.211
206107	1117.6	13.508	-14.266	-15.076	-45.711	-18.944	44.901	1008.1	1.200
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206108	1111.2	14.144	-14.529	-15.305	-47.496	-16.800	46.643	1002.5	1.140
206109	1111.7	14.148	-14.716	-15.296	-47.555	-17.279	46.975	1002.6	1.141
206110	1112.2	14.288	-14.203	-14.983	-47.262	-16.690	46.482	1004.6	1.162
206111	1114.0	14.250	-14.415	-15.055	-46.656	-17.029	46.016	1006.5	1.185
206112	1114.2	14.372	-14.343	-14.843	-46.694	-17.228	46.194	1007.0	1.190
206113	1114.6	14.411	-14.483	-15.211	-46.317	-17.237	45.589	1007.3	1.192
206114	1114.0	14.283	-14.309	-14.983	-46.889	-17.152	46.215	1006.5	1.185

Table B.18 Preliminary Processed Data for Data Set 18--Potassium Runs at 1190°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206139	1185.9	3.072	-10.276	-15.872	-44.029	4.638	38.433	900.6	0.463
206140	1186.0	3.182	-10.059	-15.757	-43.719	5.034	38.021	901.0	0.467
206141	1186.2	3.314	-10.234	-15.936	-44.140	4.761	38.438	902.1	0.471
206142	1185.5	3.217	-10.302	-15.940	-43.863	4.557	38.225	900.8	0.465
206143	1186.0	3.131	-10.055	-15.795	-43.523	4.178	37.783	901.1	0.467
206144	1188.4	3.034	-10.370	-15.846	-44.038	4.229	38.563	903.2	0.476
206145	1188.2	2.910	-10.123	-15.693	-43.153	4.851	37.583	903.4	0.478
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206147	1190.7	-1.319	-10.148	-15.600	-43.263	-0.357	37.811	899.7	0.459
206148	1189.9	-1.225	-10.144	-15.544	-43.714	-0.153	38.314	899.1	0.457
206149	1190.3	-1.200	-10.280	-15.672	-43.629	-0.293	38.237	899.5	0.459
206150	1190.1	-1.225	-10.238	-15.604	-43.421	-0.353	38.055	899.3	0.458
206151	1190.8	-1.310	-10.051	-15.476	-43.727	-0.442	38.302	900.2	0.461
206152	1190.7	-1.378	-10.080	-15.468	-43.561	-0.446	38.173	900.1	0.460

Table B.19 Preliminary Processed Data for Data Set 19--Potassium Runs at 1192°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3	4-3	5-3	6-3	7-3	8-3			
	°F	°F	°F	°F	°F	°F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206153	1184.7	13.285	-12.923	-15.506	-45.982	-5.097	43.399	1002.4	1.141
206154	1187.1	13.285	-13.017	-15.702	-46.544	-5.225	43.859	1004.6	1.168
206155	1186.2	13.306	-13.059	-15.672	-46.868	-5.340	44.255	1003.5	1.157
206156	1186.7	12.872	-12.774	-15.200	-46.519	-5.319	44.093	1003.7	1.157
206157	1188.7	12.927	-12.714	-15.187	-46.289	-5.319	43.816	1005.0	1.171
206158	1189.5	12.459	-12.846	-15.144	-45.914	-5.957	43.616	1005.1	1.171
206159	1188.1	13.234	-12.544	-15.340	-45.791	-4.804	42.995	1004.4	1.166
206160	1187.6	12.795	-12.710	-15.272	-45.940	-5.327	43.378	1002.9	1.151
206161	1187.6	12.859	-12.544	-15.251	-46.476	-5.144	43.769	1003.1	1.152
206162	1185.0	12.753	-12.340	-14.974	-45.634	-4.731	43.000	1000.3	1.128
206163	1186.4	12.548	-12.408	-15.072	-45.557	-4.880	42.893	1001.6	1.138
206164	1186.7	12.838	-12.629	-15.523	-45.591	-4.795	42.697	1002.6	1.144
206165	1189.2	13.187	-12.723	-15.523	-45.591	-5.097	42.791	1005.4	1.177
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206166	1192.2	8.600	-13.174	-15.714	-45.880	-10.404	43.340	1001.4	1.137
206167	1194.0	8.706	-13.280	-15.846	-46.442	-10.421	43.876	1002.9	1.151
206168	1194.7	8.740	-13.161	-15.778	-45.727	-10.255	43.110	1003.7	1.158
206169	1195.6	8.889	-13.191	-15.770	-46.136	-10.412	43.557	1004.5	1.164
206170	1196.2	8.914	-13.165	-15.676	-45.991	-10.527	43.480	1005.0	1.171
206171	1195.9	8.774	-13.200	-15.829	-46.178	-10.463	43.549	1005.2	1.172
206172	1194.8	8.770	-13.319	-15.812	-46.468	-10.791	43.975	1003.2	1.150
206173	1193.8	8.825	-13.268	-15.753	-46.051	-10.757	43.566	1002.6	1.148
206174	1193.7	8.663	-13.144	-15.697	-45.978	-10.595	43.425	1002.4	1.147

Table B.20 Preliminary Processed Data for Data Set 20--Potassium Runs at 1201°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206175	1197.9	24.553	-17.042	-15.770	-49.710	-18.855	50.982	1108.3	1.205
206176	1197.2	24.387	-16.872	-15.655	-50.123	-18.510	51.340	1107.2	1.190
206177	1195.0	24.672	-16.923	-15.880	-49.740	-18.161	50.783	1106.0	1.181
206178	1195.2	24.395	-16.663	-15.493	-49.331	-18.251	50.501	1106.7	1.189
206179	1195.5	24.970	-17.106	-16.123	-49.200	-18.034	50.183	1106.9	1.190
206180	1194.6	24.736	-17.136	-16.106	-49.421	-18.361	50.451	1105.1	1.171
206181	1193.8	24.791	-17.051	-16.170	-49.310	-17.931	50.191	1104.9	1.170
206182	1194.5	24.961	-17.004	-16.217	-49.757	-17.778	50.544	1105.8	1.179
206183	1196.2	25.259	-16.829	-16.136	-49.357	-17.353	50.050	1109.2	1.210
206184	1196.2	24.800	-17.097	-16.280	-49.936	-18.182	50.753	1107.1	1.190
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206185	1202.0	20.502	-16.936	-16.336	-49.825	-22.127	50.425	1106.3	1.185
206186	1202.7	20.251	-17.125	-16.323	-49.795	-22.757	50.597	1105.6	1.173
206187	1203.9	20.582	-16.931	-16.336	-49.906	-22.259	50.501	1108.5	1.203
206188	1203.8	20.527	-16.957	-16.314	-49.557	-22.365	50.200	1108.1	1.201
206189	1204.5	20.497	-16.995	-16.263	-50.042	-22.753	50.774	1108.2	1.201
206190	1203.9	20.200	-17.310	-16.429	-50.051	-23.131	50.932	1106.4	1.182
206191	1202.0	20.182	-16.991	-16.246	-49.736	-22.582	50.481	1104.3	1.161
206192	1202.4	20.238	-16.991	-16.263	-49.842	-22.659	50.570	1104.5	1.162

Table B.21 Preliminary Processed Data for Data Set 21--Potassium Runs at 1004°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206197	999.0	8.396	-7.687	-10.616	-41.548	-3.088	38.619	801.4	0.160
206198	998.4	8.324	-7.848	-10.649	-41.662	-3.746	38.861	800.2	0.158
206199	998.2	8.392	-7.430	-10.282	-41.143	-2.831	38.291	801.3	0.160
206200	997.5	8.379	-7.599	-10.413	-41.329	-3.240	38.515	801.6	0.161
206201	996.6	8.421	-7.493	-10.413	-41.177	-2.746	38.257	802.0	0.162
206202	999.8	8.358	-7.540	-10.075	-41.316	-3.438	38.781	802.6	0.163
206203	999.6	8.451	-7.472	-10.388	-41.244	-3.008	38.328	802.7	0.163
206204	1000.3	8.367	-7.945	-10.691	-41.962	-3.215	39.216	802.3	0.162
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.2 VOLTS								
206205	1006.3	2.890	-8.101	-10.784	-42.092	-9.003	39.409	799.4	0.156
206206	1005.7	2.965	-7.962	-10.670	-42.029	-9.025	39.321	798.9	0.155
206207	1004.5	2.928	-7.881	-10.645	-41.915	-8.852	39.151	797.6	0.153
206208	1004.6	2.940	-7.772	-10.649	-41.763	-8.607	38.886	798.0	0.154
206209	1006.5	2.974	-8.000	-10.641	-41.915	-9.033	39.274	798.8	0.155
206210	1006.1	2.919	-7.839	-10.481	-41.839	-8.860	39.197	798.0	0.154
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206211	1009.1	1.898	-7.616	-10.375	-41.603	-10.232	38.844	798.0	0.155
206212	1008.2	1.873	-7.405	-10.295	-41.438	-9.751	38.548	797.4	0.152
206213	1009.3	1.898	-7.206	-10.223	-41.248	-9.350	38.231	798.6	0.156
206214	1010.1	1.907	-7.468	-10.405	-41.653	-9.776	38.717	798.5	0.156
206215	1007.0	1.877	-7.708	-10.556	-47.751	-10.476	38.903	797.9	0.155
206216	1006.7	1.915	-7.586	-10.489	-41.535	-10.316	38.632	797.9	0.155
206217	1005.9	2.016	-7.375	-10.523	-41.312	-9.573	38.164	797.9	0.155
206218	1007.7	1.970	-7.421	-10.518	-41.341	-9.603	38.244	798.3	0.156

Table B.22 Preliminary Processed Data for Data Set 22--Vacuum Runs at 998°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
206219	995.8	3.590	-7.151	-10.962	-40.316	1.181	36.505	0.003
206220	998.6	4.122	-6.755	-10.953	-40.156	2.215	35.958	0.003
206221	999.2	3.700	-6.991	-10.202	-14.350	-0.940	37.139	0.003
206222	998.5	3.603	-6.957	-10.523	-40.105	0.438	36.539	0.003
206223	998.3	3.603	-6.751	-10.337	-40.012	0.481	36.426	0.003
206224	998.4	3.721	-7.071	-10.704	-40.316	0.375	36.683	0.003
206225	993.6	3.544	-6.793	-10.472	-39.767	0.691	36.088	0.003
206226	993.0	3.556	-6.831	-10.253	-39.805	0.219	36.383	0.003
206227	994.5	3.780	-6.219	-10.151	-39.172	2.088	35.240	0.003
206228	998.0	3.691	-6.223	-10.126	-39.299	1.928	35.396	0.003
206229	999.5	3.763	-6.822	-10.628	-40.004	1.248	36.198	0.003
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.0 VOLTS							
206230	997.9	-0.240	-7.202	-10.489	-40.126	-4.151	36.839	0.003
206231	997.1	-0.194	-6.890	-10.426	-39.970	-3.675	36.434	0.003
206232	999.6	0.113	-6.991	-10.687	-39.983	-3.240	36.287	0.003
206233	1001.0	0.147	-7.282	-10.717	-40.156	-3.915	36.721	0.003
206234	999.9	0.021	-7.345	-10.451	-40.358	-4.869	37.252	0.003
206235	998.6	-0.080	-6.890	-10.308	-39.708	-3.481	36.290	0.003
206236	997.8	0.021	-6.848	-10.240	-39.738	-3.392	36.346	0.003
206237	1003.0	0.088	-6.476	-10.265	-39.405	-1.940	35.616	0.003
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.0 VOLTS							
206238	1000.4	-1.827	-6.890	-10.519	-39.852	-5.109	36.223	0.003
206239	997.3	-1.367	-6.417	-10.362	-39.531	-4.611	35.586	0.003
206240	997.7	-1.312	-6.527	-10.459	-39.570	-4.367	35.578	0.003
206241	998.4	-1.130	-6.700	-10.869	-39.683	-4.434	35.514	0.003
206242	998.9	-0.902	-6.544	-10.687	-39.552	-4.198	35.409	0.003
206243	1001.0	-1.080	-6.746	-10.611	-39.683	-4.852	35.818	0.003
206244	1006.0	-0.498	-6.797	-10.608	-40.380	-4.747	36.227	0.003
206245	1005.5	-0.814	-6.835	-10.594	-40.008	-4.894	36.249	0.003
206246	1005.2	-0.759	-6.966	-10.848	-40.354	-5.004	36.472	0.003

Table B.23 Preliminary Processed Data for Data Set 23--Vacuum Runs at 1000°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
205654	990.5	-2.447	-5.219	-9.864	-38.751	5.696	34.106	0.002
205655	990.0	-2.253	-5.037	-9.877	-38.413	6.151	33.573	0.002
205656	990.8	-2.227	-5.109	-9.873	-38.691	5.725	33.927	0.002
205657	997.0	-2.008	-4.995	-9.902	-38.308	6.059	33.401	0.002
205658	995.9	-2.071	-4.932	-10.059	-38.333	6.037	33.206	0.002
205659	995.2	-1.987	-5.059	-10.177	-38.691	5.995	33.573	0.002
205660	994.2	-2.417	-5.080	-10.257	-38.691	6.621	33.514	0.002
205661	994.9	-2.206	-4.354	-9.468	-38.232	7.291	33.118	0.002
205662	996.3	-1.987	-5.016	-10.303	-38.611	6.729	33.324	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.5 VOLTS							
205663	1004.9	-7.708	-5.164	-10.177	-38.713	0.497	33.700	0.003
205664	1003.7	-7.708	-5.181	-10.088	-38.742	0.510	33.835	0.003
205665	1003.8	-7.738	-5.270	-10.270	-38.848	0.607	33.848	0.002
205666	1003.1	-8.063	-5.181	-9.940	-38.755	0.831	33.996	0.002
205667	1002.0	-8.177	-5.122	-9.902	-38.945	0.708	34.165	0.002
205668	1002.5	-7.911	-5.274	-10.097	-39.016	0.717	34.193	0.002
205669	1003.3	-7.729	-5.063	-10.223	-38.995	0.282	33.835	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.2 VOLTS							
205670	1005.2	-8.827	-5.063	-10.367	-38.869	1.755	33.565	0.003
205671	1005.6	-8.742	-4.848	-10.270	-38.793	1.278	33.371	0.003
205672	1001.7	-9.109	-4.877	-10.151	-38.848	1.405	33.574	0.002
205673	1002.2	-9.046	-5.008	-10.413	-38.818	1.282	33.397	0.002
205674	1002.6	-9.080	-4.995	-10.333	-38.784	-1.341	33.446	0.002
205675	1002.6	-9.050	-4.586	-9.645	-38.354	-1.282	33.295	0.002
205676	998.7	-9.172	-4.848	-9.936	-38.236	-1.966	33.148	0.002
205677	998.3	-9.054	-4.835	-10.244	-38.181	-1.497	32.772	0.002
205678	1004.4	-8.784	-5.059	-10.172	-38.751	-2.164	33.638	0.002
205679	1003.7	-8.654	-5.215	-10.594	-38.932	-1.827	33.553	0.002

Table B.24 Preliminary Processed Data for Data Set 24--Vacuum Runs at 1002°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
206763	995.2	-12.767	-8.476	-13.092	-34.924	4.839	30.308	0.002
206764	994.7	-12.654	-8.219	-13.029	-34.691	5.662	29.881	0.002
206765	995.5	-12.734	-8.172	-13.012	-34.126	5.751	29.286	0.002
206766	993.3	-12.928	-8.434	-12.974	-34.383	4.839	29.843	0.002
206767	992.1	-12.772	-8.308	-12.970	-34.383	5.244	29.721	0.002
206768	999.3	-12.362	-8.101	-12.670	-34.333	5.535	29.764	0.002
206769	999.7	-12.388	-8.118	-12.662	-34.320	5.907	29.776	0.002
206770	1004.1	-12.362	-8.291	-12.578	-34.696	5.413	30.409	0.002
206771	1004.3	-12.227	-8.084	-12.565	-34.594	5.983	30.113	0.002
206772	1005.0	-12.177	-8.075	-12.464	-34.388	6.383	29.999	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.6 VOLTS							
206757	1004.0	-19.873	-7.856	-12.666	-34.776	-0.839	29.966	0.001
206758	1005.6	-20.459	-8.181	-13.181	-34.772	-0.949	29.772	0.001
206759	1007.2	-20.303	-8.274	-13.122	-35.151	-1.135	30.303	0.001
206760	1007.5	-20.037	-8.037	-13.274	-34.848	-0.383	29.611	0.001
206761	1004.3	-20.248	-8.219	-13.054	-34.772	-1.130	29.937	0.001
206762	1005.1	-20.033	-8.029	-13.080	-34.911	-0.464	29.860	0.001

Table B.25 Preliminary Processed Data for Data Set 25--Vacuum Runs at 1191°F.

RUN	THERMOCOUPLES						NULL	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	mm Hg
	ISOTHERMAL							
206773	1189.6	-10.329	-8.923	-14.255	-38.842	4.965	33.510	0.003
206774	1185.0	-10.502	-9.600	-14.778	-39.089	3.595	33.911	0.003
206775	1185.8	- 9.995	-9.148	-14.548	-38.629	4.812	33.229	0.002
206776	1184.8	-10.234	-9.497	-15.000	-38.693	3.991	33.190	0.002
206777	1184.9	-10.157	-9.038	-14.497	-38.272	5.306	32.813	0.002
206778	1187.6	-10.204	-9.174	-14.897	-38.629	4.744	32.905	0.002
206779	1188.4	-10.012	-9.191	-15.182	-38.600	4.829	32.609	0.002
206780	1189.4	-10.365	-9.519	-14.689	-38.604	4.000	33.434	0.002
206781	1188.1	-10.255	-9.289	-15.127	-39.093	4.344	33.255	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.6 VOLTS							
206782	1190.5	-14.740	-9.004	-14.817	-38.361	0.774	32.548	0.002
206783	1193.5	-14.842	-8.842	-14.285	-38.178	-1.012	32.735	0.002
206784	1193.3	-15.123	-9.259	-15.089	-39.187	-0.350	33.357	0.002
206785	1193.2	-14.863	-8.991	-14.995	-38.608	0.493	32.604	0.002
206786	1192.2	-14.600	-8.855	-14.753	-38.268	1.000	32.370	0.002
206787	1195.4	-14.663	-9.102	-14.417	-38.434	0.217	33.119	0.002
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 5.1 VOLTS							
206788	1192.2	-14.012	-9.000	-13.697	-37.889	1.425	33.192	0.002
206789	1192.2	-14.204	-8.961	-14.051	-38.182	1.408	33.092	0.002
206790	1192.2	-14.174	-9.140	-14.804	-38.638	1.046	32.974	0.002
206791	1195.0	-14.038	-9.097	-14.255	-48.412	1.361	33.254	0.002
206792	1195.7	-14.068	-9.438	-14.787	-39.072	0.276	33.723	0.002
206793	1193.7	-14.140	-9.238	-14.225	-38.744	0.940	33.757	0.002
206794	1194.3	-13.995	-9.327	-14.110	-38.638	0.565	33.855	0.002
206795	1195.2	-14.114	-9.161	-13.565	-37.944	0.872	33.540	0.002

Table B.26 Preliminary Processed Data for Data Set 26--Potassium Runs at 1016°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206801	1011.1	18.590	-14.295	-14.278	-39.316	-12.413	39.333	905.1	0.482
206802	1009.5	18.109	-14.675	-14.430	-40.654	-14.691	40.899	902.1	0.470
206803	1008.8	18.118	-14.822	-14.472	-40.535	-14.856	40.885	901.1	0.466
206804	1015.0	18.105	-15.443	-14.991	-41.084	-14.632	41.536	906.4	0.492
206805	1014.9	18.489	-15.135	-14.864	-40.767	-14.316	41.038	907.7	0.498
206806	1014.4	18.227	-15.430	-15.054	-40.924	-14.430	41.300	906.6	0.492
206807	1012.1	17.316	-14.278	-14.088	-41.143	-13.594	41.333	901.2	0.466
206808	1009.3	18.312	-14.894	-14.784	-40.383	-13.978	40.493	903.5	0.478
206809	1012.7	18.333	-15.008	-14.405	-40.856	-15.763	41.457	906.0	0.490
206810	1012.1	18.451	-15.084	-14.603	-40.540	-14.928	41.021	906.6	0.492
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.95 VOLTS								
206811	1022.8	11.223	-14.780	-14.523	-40.654	-21.303	40.911	898.5	0.453
206812	1018.0	12.185	-14.063	-14.004	-40.687	-21.354	40.746	899.1	0.460
206812	1017.4	12.303	-14.135	-13.962	-40.957	-21.679	41.130	899.0	0.460
206814	1019.7	11.392	-13.805	-14.059	-41.291	-20.025	41.037	895.9	0.441
206815	1018.1	11.282	-14.101	-14.210	-40.455	-20.489	40.346	894.7	0.440
206816	1017.2	11.430	-13.751	-14.118	-40.746	-20.202	40.379	895.1	0.440
206818	1017.0	11.624	-13.700	-14.004	-40.746	-20.130	40.442	895.5	0.441
206819	1021.4	11.966	-13.810	-14.261	-40.248	-19.662	39.797	901.7	0.468

Table B.27 Preliminary Processed Data for Data Set 27--Potassium Runs at 1016°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206821	1008.4	17.109	-14.324	-14.590	-40.139	-12.814	39.873	905.5	0.486
206822	1009.7	17.679	-14.805	-14.683	-40.308	-14.075	40.430	909.0	0.502
206823	1010.8	18.080	-14.784	-14.527	-40.645	-14.767	40.902	909.7	0.505
206824	1011.4	16.620	-14.493	-14.620	-40.278	-12.611	40.151	904.4	0.480
206825	1010.5	16.278	-14.476	-14.489	-39.886	-12.620	39.873	901.1	0.467
206826	1010.0	16.303	-14.455	-14.535	-39.843	-12.160	39.763	901.4	0.468
206827	1010.7	17.126	-14.717	-14.839	-40.308	-13.392	40.186	906.7	0.492
206828	1011.8	17.059	-14.869	-14.877	-40.451	-13.523	40.443	907.2	0.493
206829	1013.2	17.063	-14.662	-14.459	-39.772	-13.362	39.975	908.9	0.502
206830	1012.3	16.603	-14.508	-14.443	-39.392	-12.578	39.457	906.4	0.491
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.0 VOLTS								
206831	1019.8	11.341	-14.670	-14.852	-39.717	-18.485	39.535	903.5	0.477
206832	1019.4	11.303	-14.742	-14.856	-40.400	-19.675	40.286	902.9	0.474
206833	1020.1	11.531	-14.890	-15.004	-39.970	-19.472	39.856	905.5	0.487
206834	1015.8	12.772	-13.776	-13.772	-40.143	-20.276	40.147	906.7	0.494
206835	1018.7	13.341	-14.409	-14.645	-40.367	-21.772	40.131	911.5	0.513
206836	1017.0	13.177	-14.822	-14.932	-40.810	-22.514	40.700	908.5	0.500
206837	1016.1	13.413	-14.700	-14.936	-40.721	-21.843	40.485	909.1	0.502

Table B.28 Preliminary Processed Data for Data Set 28--Potassium Runs at 1095°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206838	1090.5	1.360	-8.283	-13.957	-40.588	8.686	34.914	801.4	0.161
206839	1090.5	1.343	-8.313	-13.864	-40.572	8.461	35.021	801.2	0.161
206840	1089.1	1.419	-8.360	-13.805	-40.809	8.991	35.364	800.4	0.159
206841	1091.0	1.224	-8.457	-14.025	-40.025	8.872	34.457	802.5	0.163
206842	1092.1	1.385	-8.088	-13.805	-40.169	9.190	34.452	803.5	0.165
206843	1092.9	1.237	-8.682	-13.995	-40.953	8.182	35.640	803.7	0.165
206844	1088.7	1.207	-8.673	-14.665	-40.436	8.677	35.444	797.7	0.153
206845	1087.2	1.194	-8.559	-14.398	-40.940	8.834	35.101	797.4	0.152
206846	1088.1	1.004	-8.466	-14.059	-40.495	7.898	34.902	797.3	0.152
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.8 VOLTS								
206847	1098.4	-3.872	-8.716	-14.004	-41.199	2.211	35.911	800.7	0.160
206848	1098.6	-3.915	-8.457	-13.817	-40.851	2.322	35.491	801.4	0.161
206849	1097.0	-4.021	-8.495	-13.957	-41.038	2.190	35.576	798.9	0.156
206850	1096.8	-4.093	-8.525	-13.957	-41.156	1.940	35.724	798.8	0.156
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.6 VOLTS								
206852	1097.7	-5.038	-8.351	-14.487	-39.703	1.237	33.567	798.1	0.155
206853	1097.8	-5.266	-8.326	-14.271	-40.072	0.639	34.127	797.5	0.153
206855	1094.1	-5.427	-8.241	-14.021	-41.279	1.182	35.499	791.4	0.142
206856	1096.5	-5.279	-7.953	-13.864	-40.741	1.635	34.830	794.5	0.148
206857	1097.4	-5.156	-7.902	-13.813	-40.843	1.699	34.932	796.0	0.151
206858	1098.2	-5.105	-7.665	-13.652	-40.733	1.542	34.746	797.2	0.152
206859	1098.5	-5.088	-8.161	-13.957	-41.105	1.491	35.309	797.5	0.153
206860	1096.8	-5.161	-7.966	-13.542	-39.004	1.716	33.428	796.0	0.150
206861	1096.2	-5.351	-8.093	-13.665	-38.919	1.411	33.347	795.0	0.149

Table B.29 Preliminary Processed Data for Data Set 29--Potassium Runs at 1097°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206862	1094.7	9.300	-11.483	-14.283	-41.533	-1.224	38.733	890.1	0.423
206863	1095.4	9.572	-11.516	-14.588	-41.847	-0.932	38.775	891.7	0.429
206864	1098.0	9.398	-11.686	-14.330	-41.021	-1.733	38.377	894.9	0.440
206865	1095.8	9.194	-11.703	-14.317	-41.029	-1.779	38.415	891.7	0.429
206866	1094.5	9.338	-11.360	-14.292	-40.809	-0.716	37.877	892.1	0.430
206867	1095.0	9.351	-11.720	-14.542	-41.750	-1.241	38.928	891.7	0.429
206868	1094.9	9.351	-11.474	-14.207	-41.220	-1.169	38.487	893.0	0.433
206869	1094.1	9.461	-11.449	-14.292	-41.427	-0.936	38.584	892.0	0.430
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.42 VOLTS								
206870	1101.8	2.906	-10.881	-13.906	-41.110	-7.881	38.805	887.3	0.413
206871	1099.5	3.127	-10.453	-13.830	-42.059	-7.885	38.682	885.4	0.405
206872	1100.0	3.262	-10.300	-13.788	-42.067	-7.508	38.579	886.5	0.411
206873	1096.6	3.110	-10.423	-13.906	-41.737	-7.572	38.254	883.4	0.400
206874	1098.9	3.419	-10.190	-13.970	-41.072	-6.559	37.292	886.6	0.411
206875	1102.3	3.072	-10.529	-13.885	-41.949	-7.402	38.593	888.1	0.418
206876	1103.1	3.148	-10.605	-13.961	-42.233	-7.309	38.877	889.0	0.420
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.0 VOLTS								
206877	1100.2	3.334	-11.000	-13.927	-41.381	-7.076	38.454	885.1	0.405
206878	1099.5	3.466	-10.733	-14.042	-42.148	-6.940	38.839	884.7	0.402
206879	1098.1	3.466	-10.644	-13.953	-42.093	-6.622	38.784	883.8	0.400
206880	1098.7	3.500	-10.639	-13.944	-41.966	-6.605	38.661	884.6	0.402
206881	1099.1	3.555	-10.593	-13.961	-42.207	-6.699	38.839	885.1	0.406
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.6 VOLTS								
206882	1097.4	3.872	-10.572	-13.783	-42.618	-5.864	39.407	883.8	0.400
206883	1097.7	3.750	-10.834	-13.830	-42.779	-6.669	39.783	883.2	0.399
206884	1101.9	3.766	-11.033	-13.974	-42.033	-6.186	39.092	887.0	0.413
206885	1100.2	3.775	-10.716	-14.025	-42.461	-6.000	39.152	885.4	0.407

Table B.30 Preliminary Processed Data for Data Set 30--Potassium Runs at 1191°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206886	1189.6	-5.182	-7.548	-15.710	-40.842	15.970	32.680	817.3	0.191
206887	1186.3	-5.119	-7.480	-15.319	-40.765	15.523	32.926	816.1	0.189
206888	1184.6	-5.153	-7.714	-15.417	-40.680	15.127	32.977	814.7	0.187
206889	1186.1	-5.136	-7.885	-15.408	-40.957	14.868	33.434	818.2	0.193
206890	1185.0	-4.919	-7.868	-15.434	-40.923	15.055	33.357	818.0	0.193
206891	1184.4	-5.157	-7.846	-15.285	-40.506	14.893	33.067	816.4	0.189
206892	1185.0	-4.974	-7.834	-15.310	-40.459	15.242	32.983	816.7	0.190
206893	1185.0	-5.021	-7.693	-15.021	-40.225	15.293	32.897	816.7	0.190
206894	1186.3	-5.204	-7.940	-15.131	-39.965	15.000	32.774	812.7	0.183
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.8 VOLTS								
206895	1192.4	-9.936	-7.165	-14.497	-41.204	9.795	33.827	818.1	0.193
206896	1191.5	-9.974	-7.289	-14.663	-41.523	9.885	34.149	817.7	0.191
206897	1191.5	-9.582	-7.323	-14.676	-41.357	9.459	34.004	817.5	0.191
206898	1192.0	-9.510	-7.242	-14.638	-41.136	9.838	33.740	817.4	0.191
206899	1195.3	-9.668	-8.200	-15.651	-40.953	10.021	33.502	819.5	0.194
206900	1194.1	-9.638	-8.417	-15.753	-41.204	9.655	33.868	818.5	0.193
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.75 VOLTS								
206901	1195.3	-10.182	-6.838	-14.651	-40.961	9.361	33.150	818.4	0.194
206902	1191.8	-10.127	-6.842	-14.425	-41.331	8.936	33.748	816.6	0.190
206903	1196.8	-10.382	-6.902	-14.625	-41.208	9.025	33.485	820.5	0.197
206904	1196.3	-10.136	-6.902	-14.642	-41.106	8.974	33.366	820.2	0.197
206906	1193.5	-10.191	-6.961	-14.497	-41.140	8.804	33.604	818.7	0.194
206907	1193.6	-10.165	-7.008	-14.587	-41.148	8.855	33.569	818.9	0.195
206908	1193.7	-10.289	-7.234	-14.770	-41.323	8.451	33.787	819.8	0.195
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.5 VOLTS								
206909	1193.3	-11.540	-6.595	-14.731	-40.268	7.808	32.132	814.5	0.186
206910	1194.3	-11.408	-6.472	-14.587	-40.978	8.025	32.863	815.3	0.187
206911	1193.2	-11.340	-6.676	-14.608	-40.931	7.761	32.999	815.1	0.187
206912	1194.7	-11.408	-6.395	-14.417	-40.885	7.497	32.863	816.2	0.189
206913	1194.5	-11.480	-6.455	-14.617	-40.523	7.497	32.361	816.2	0.189
206914	1192.5	-11.548	-6.484	-14.714	-40.408	7.791	32.183	813.5	0.184
206915	1193.9	-11.451	-6.595	-14.502	-41.097	7.400	33.190	815.7	0.188
206916	1193.5	-11.408	-6.438	-14.476	-40.965	7.655	32.927	816.0	0.189

Table B.31 Preliminary Processed Data for Data Set 31--Potassium Runs at 1191°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206917	1185.7	-0.910	-9.459	-15.710	-41.497	10.595	35.246	880.4	0.389
206918	1188.9	-0.931	-9.463	-15.787	-41.778	10.446	35.454	882.9	0.397
206919	1188.6	-1.017	-10.174	-16.251	-42.059	9.978	35.982	883.2	0.399
206920	1186.8	-0.931	-9.967	-15.782	-41.561	9.697	35.476	882.0	0.394
206921	1188.5	-0.889	-8.863	-15.055	-41.740	10.570	35.548	883.4	0.399
206922	1185.9	-0.723	-9.553	-15.600	-41.821	9.782	35.774	882.1	0.394
206923	1183.6	-0.531	-9.302	-15.514	-41.225	10.204	35.013	882.6	0.395
206924	1183.1	-0.455	-9.468	-15.587	-41.165	9.931	35.046	881.3	0.391
206925	1186.7	-0.642	-10.182	-16.225	-41.991	9.970	35.948	883.8	0.400
206926	1199.9	-0.553	-10.059	-16.106	-41.748	10.319	35.701	885.2	0.404
206927	1201.1	-0.617	-9.774	-15.923	-41.400	10.365	35.251	885.3	0.404
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 8.5 VOLTS								
206929	1195.2	-7.204	-8.838	-15.425	-40.400	2.693	33.813	881.8	0.393
206930	1191.8	-7.068	-8.421	-15.042	-40.736	2.025	34.115	880.0	0.385
206931	1191.7	-6.859	-8.425	-15.017	-40.791	2.089	34.199	880.2	0.386
206932	1192.3	-6.765	-8.365	-14.919	-40.782	2.442	34.228	881.2	0.390
206933	1191.9	-6.825	-8.340	-14.702	-41.204	1.710	34.842	880.7	0.389
206934	1198.1	-6.863	-8.429	-15.191	-40.808	2.680	34.046	885.9	0.409
206935	1197.5	-6.965	-8.680	-15.348	-40.659	2.536	33.991	885.5	0.408
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.55 VOLTS								
206936	1194.7	-5.974	-8.765	-15.089	-41.046	4.080	34.722	883.6	0.399
206937	1190.1	-5.663	-8.582	-14.736	-41.506	3.863	35.352	880.8	0.390
206938	1190.5	-5.663	-8.689	-14.761	-41.506	3.582	35.434	881.3	0.391
206939	1190.5	-5.706	-8.638	-14.710	-41.327	3.600	35.255	881.4	0.391
206940	1189.9	-5.880	-9.170	-15.080	-42.331	3.446	36.421	880.5	0.389
206941	1194.2	-5.855	-8.723	-14.987	-41.319	3.736	35.055	883.3	0.399
206942	1194.0	-5.889	-8.634	-14.914	-41.272	3.800	34.992	883.1	0.399
206943	1193.7	-5.817	-8.689	-14.885	-41.314	3.531	35.118	883.2	0.399
206944	1194.0	-5.889	-8.817	-15.072	-41.059	3.808	34.804	883.2	0.399

Table B.32 Preliminary Processed Data for Data Set 32--Potassium Runs at 1099°F.

RUN	THERMOCOUPLES						NULL	BOILER	PRESSURE
	3 °F	4-3 °F	5-3 °F	6-3 °F	7-3 °F	8-3 °F	°F	°F	lbs./sq.in.
	ISOTHERMAL								
206948	1094.8	0.241	-8.775	-14.419	-39.775	9.385	34.131	803.3	0.164
206949	1093.4	0.152	-8.364	-14.029	-39.885	9.542	34.220	801.2	0.160
206950	1094.9	0.084	-8.559	-14.080	-39.207	9.661	33.686	802.0	0.162
206951	1094.7	0.220	-8.351	-14.029	-39.538	9.788	33.860	801.5	0.161
206952	1095.3	0.118	-8.326	-13.991	-39.665	9.444	34.000	802.5	0.163
206953	1094.9	0.275	-8.279	-13.991	-39.779	9.601	34.067	802.6	0.163
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 7.15 VOLTS								
206954	1101.5	-5.682	-7.932	-13.915	-39.466	3.090	33.483	798.6	0.155
206955	1102.2	-5.608	-7.944	-14.012	-39.504	3.114	33.436	799.2	0.156
206956	1102.5	-5.699	-8.016	-14.042	-39.483	2.788	33.457	799.2	0.156
206957	1101.8	-5.830	-8.194	-13.690	-38.932	2.771	33.436	799.3	0.156
206958	1101.5	-5.788	-8.207	-13.728	-38.766	2.567	33.245	799.0	0.156
206959	1101.4	-5.724	-8.194	-13.733	-38.593	2.872	33.054	798.8	0.156
206960	1100.9	-5.733	-7.902	-13.813	-38.527	3.131	33.614	798.0	0.155
206961	1101.9	-5.648	-7.991	-13.911	-39.805	3.025	33.885	798.9	0.155
206962	1102.4	-5.707	-8.101	-14.000	-39.826	2.830	33.927	799.2	0.156
	HEATED TOP PLATE - GUARD HEATER VOLTAGE = 6.55 VOLTS								
206963	1103.3	-4.741	-8.110	-13.733	-39.991	3.584	34.368	803.5	0.165
206964	1103.6	-4.775	-8.029	-13.669	-40.105	3.411	34.465	803.9	0.166
206965	1101.1	-4.716	-8.169	-13.614	-40.423	3.093	34.978	801.8	0.161
206966	1102.5	-4.771	-8.093	-13.525	-40.105	3.453	34.673	803.2	0.164
206967	1101.5	-4.881	-8.351	-13.644	-40.173	2.906	34.880	802.2	0.162
206968	1101.1	-4.868	-8.368	-13.622	-39.961	3.114	34.707	801.9	0.161

APPENDIX C

COMPUTER PROGRAM

FORTRAN II COMPUTER PROGRAM FOR COMPUTING MEAN TEMPERATURE DIFFERENCES

```
STAT        10:44    SAT.---10/28/67

10 DIMENSION DTI(15), DTH(15), ANULLI(15), ANULLH(15)
19 READ, NI, (DTI(I), I = 1, NI)
20 READ, NI, (ANULLI(I), I = 1, NI)
24 READ, NH, (DTH(I), I = 1, NH)
25 READ, NH, (ANULLH(I), I = 1, NH)
30 SUM = 0.
35 DO 20 I = 1, NI
40 20: SUM = SUM + ANULLI(I)
45 ANI = SUM/NI
50 SUM = 0.
55 DO 30 I = 1, NH
60 30: SUM = SUM + ANULLH(I)
65 ANH = SUM/NH
70 SUM = 0.
75 DO 40 I = 1, NI
80 40: SUM = SUM + DTI (I)
85 ADTI = SUM/NI
90 SUM = 0.
95 DO 50 I = 1, NH
100 50: SUM = SUM + DTH(I)
105 ADTH = SUM/NH
110 SUMA = 0.
115 DO 60 I = 1, NI
120 60: SUMA = SUMA + DTI(I)*(ANULLI(I) - ANI)
125 SUMB = 0.
130 DO 70 I = 1, NH
135 70: SUMB = SUMB + DTH(I)*(ANULLH(I) - ANH)
140 SUMC = 0.
145 DO 80 I = 1, NI
150 80: SUMC = SUMC + (ANULLI(I) - ANI)**2
155 SUMD = 0.
160 DO 90 I =1, NH
170 90: SUMD = SUMD + (ANULLH(I) - ANH)**2
180 SXY = SUMA + SUMB
190 SXSQ = SUMC + SUMD
200 SLOPE = SXY/SXSQ
205 SUME = 0.
210 DO 100 I = 1, NI
215 100: SUME = SUME + (DTI(I) - ADTI)**2
220 SUMF = 0.
225 DO 110 I = 1, NH
230 110: SUMF = SUMF + (DTH(I) - ADTH)**2
235 SSD = SUME + SUMF - (SUMC + SUMD)*SLOPE**2
240 SIGMSQ = SSD/(NI + NH + 3)
245 DTIA = ADTI - SLOPE*ANI
250 DTHA = ADTH - SLOPE*ANH
255 DELT = ABS(DTIA - DTHA)
260 STDEV = SQRT(SIGMSQ)
265 PRINT, DELT, SLOPE, STDEV, SIGMSQ
270 PRINT, DTIA, DTHA, DELT
275 PRINT, ANI, ANH, ADTI, ADTH
280 END
285 $DATA
```

```
261 PRINT "POTASSIUM - 1100/900 F, FIRST RUN 206862"
291 8, 9.300, 9.572, 9.398, 9.194, 9.338, 9.351, 9.351, 9.461
292 8, 38.733, 38.775, 38.377, 38.415, 37.877, 38.928, 38.487, 38.584

262 PRINT "GUARD HEATER VOLTAGE = 7.42 VOLTS"
293 7, 2.906, 3.127, 3.262, 3.110, 3.419, 3.072, 3.148
294 7, 38.805, 38.682, 38.579, 38.254, 37.292, 38.593, 38.877
```

```
STAT      11:03   SAT.---10/28/67


POTASSIUM - 1100/900 F, FIRST RUN 206862
GUARD HEATER VOLTAGE = 7.42 VOLTS
        6.232         -.1289         .105         .011
       14.3362         8.1042       6.232
       38.522         38.4403       9.3706       3.1491
```

NOTATION

NI	NUMBER OF ISOTHERMAL RUNS
DTI	TEMPERATURE DIFFERENCE BETWEEN PLATES - ISOTHERMAL, F.
ANULLI	AVERAGE NULL - ISOTHERMAL, F.
NH	NUMBER OF HEATED RUNS
DTH	TEMPERATURE DIFFERENCE BETWEEN PLATES - HEATED, F.
ANULLH	AVERAGE NULL - HEATED, F.
ANI	AVERAGE NULL FOR DATA SET - ISOTHERMAL, F.
ANH	AVERAGE NULL FOR DATA SET - HEATED, F.
SLOPE	SLOPE OF LEAST SQUARED DEVIATION LINE.
DELT	TEMPERATURE DIFFERENCE, DELTA T, F.
STDEV	STANDARD DEVIATION FROM LEAST SQUARED DEVIATION LINES, F.

APPENDIX D

MISCELLANEOUS FIGURES

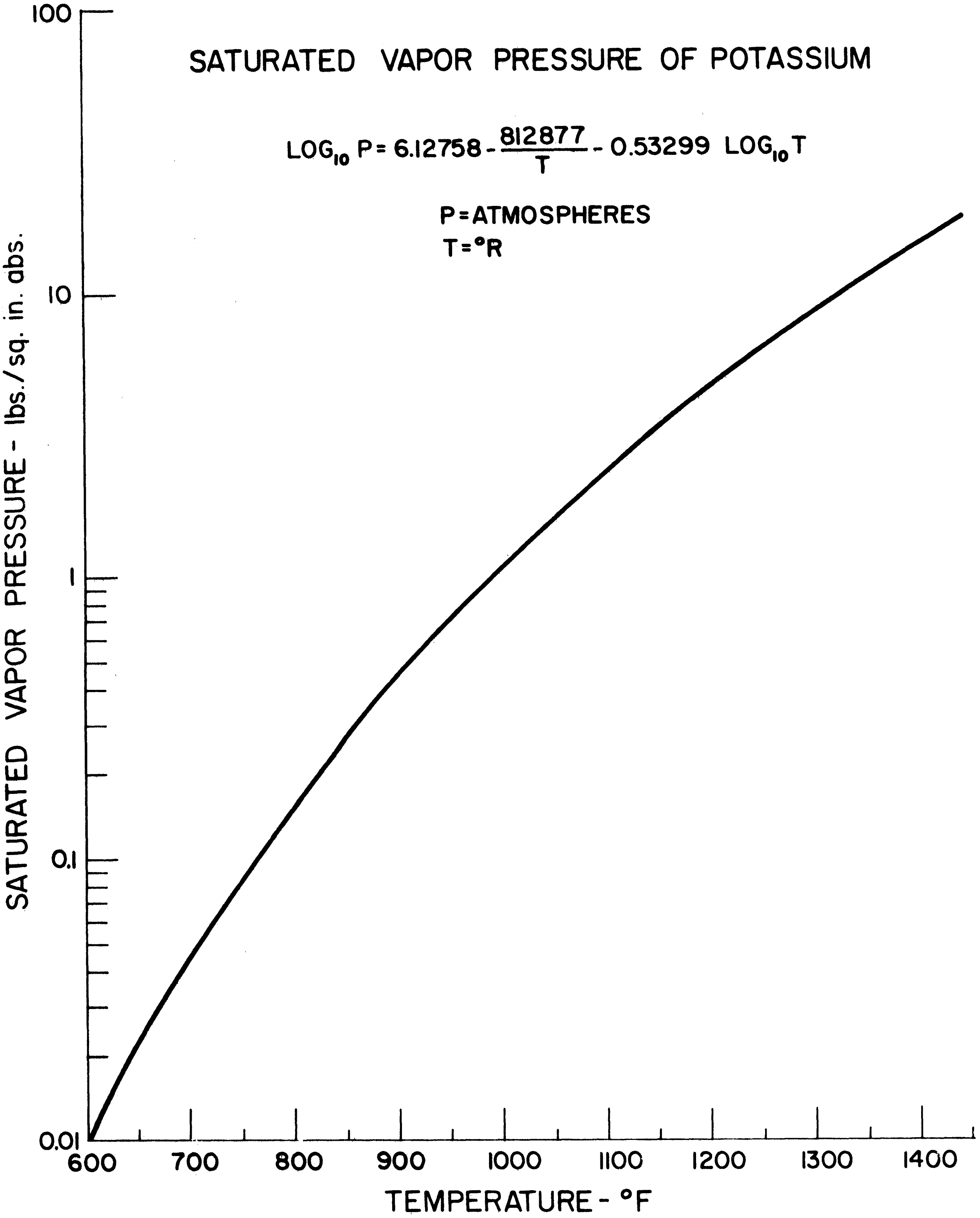


Figure D.1. Vapor Pressure of Potassium (33)

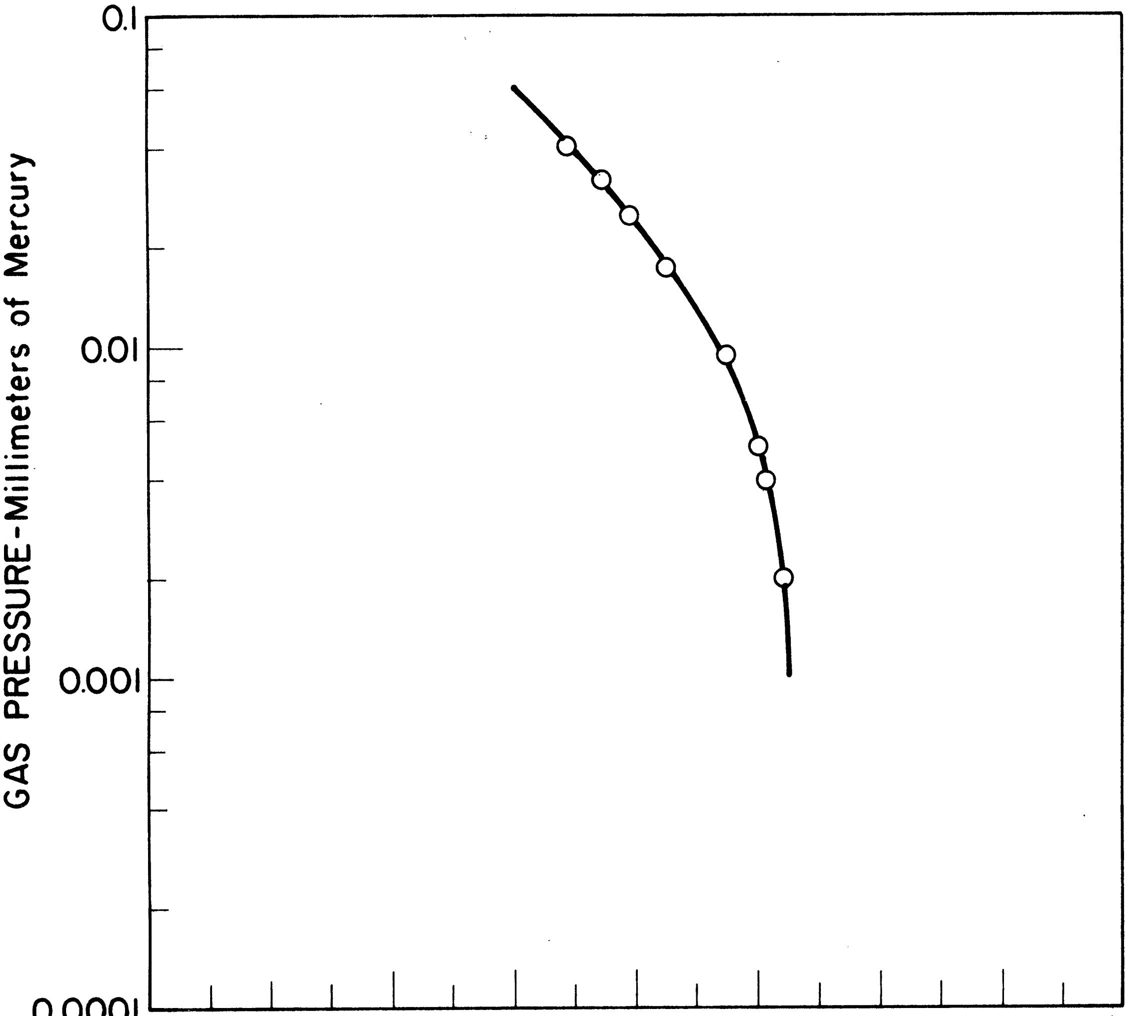


Figure D.2. Calibration for RCA 1946 Thermocouple Vacuum Gauge

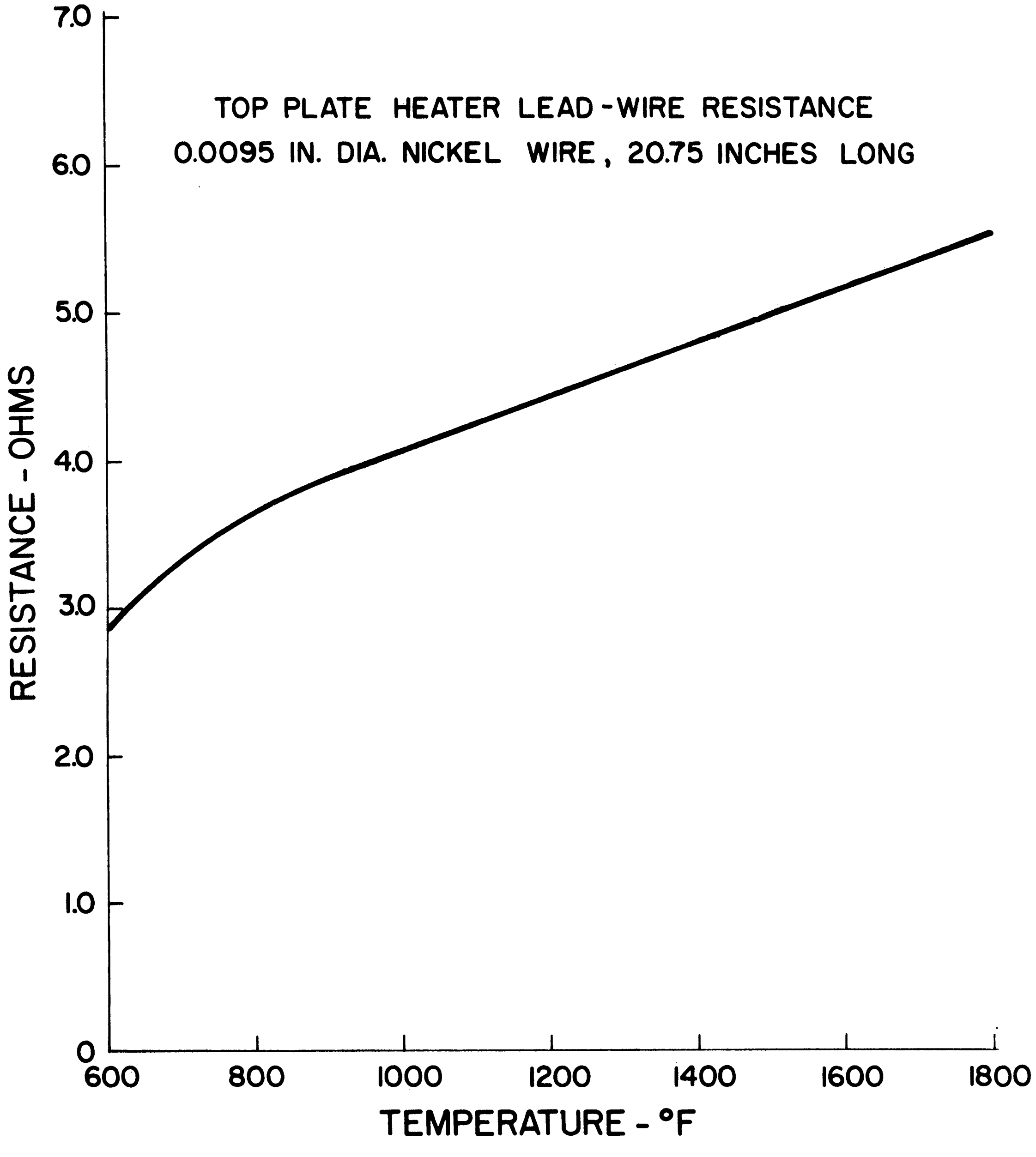


Figure D.3. Lead Wire Resistance of Top Plate Heater

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