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Alkali Metals Evaluation Program

THE DETERMINATION OF THE LATENT HEAT OF VAPORIZATION
AND VAPOR PRESSURE OF POTASSIUM FROM 1000 TO 1900°F

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Topical Report

Contract AT(04-3)-368, P.A. No. 1

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AEROJET-GENERAL NUCLEONICS

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Report No. AGN-8141
Project Agreement 1
Contract AT(04-3)-368

ALKALI METALS EVALUATION PROGRAM

THE DETERMINATION OF THE LATENT HEAT OF VAPORIZATION
AND VAPOR PRESSURE OF POTASSIUM FROM 1000 TO 1900°F

Topical Report

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THE DETERMINATION OF THE LATENT HEAT
OF VAPORIZATION AND VAPOR PRESSURE OF POTASSIUM
FROM 1000 TO 1900°F*

ABSTRACT

The latent heat of vaporization and vapor pressure of potassium were determined experimentally in the temperature ranges of 1008 to 1907°F and 985 to 1908°F, respectively. The apparatus designed for this measurement was of the flow calorimeter type, comprising a boiler with an internal heater and a guard heater, a condenser, and a volumeter in which the rate of vaporization was measured. The boiling temperature was established by means of an argon overpressure.

For the latent heat of vaporization, a technique of double measurements was developed which permitted the elimination of heat losses between boiler and guard heater.

The following equation was fitted to the latent heat data:

$$h_{fg} \text{ Btu/lb} = 948.5 - 0.1044 T_{\text{°F}}$$

with a standard error of estimate of $\pm 0.8\%$.

For the vapor pressure the equation obtained was

$$\log_{10} P_{\text{psia}} = 5.31574 - \frac{7707.31}{T_{\text{°F}} + 459.7}$$

with a standard error of estimate on the pressure of $\pm 0.65\%$. The normal boiling point calculated with this equation was 1398.1°F.

Analysis of the results of the vapor pressure and latent heat determinations, and comparison with results of other investigators have shown some of the limitations of the calculational method based on the Clapeyron equation to obtain latent heat from the vapor pressure data. This was evidenced by the fact that vapor pressure curves differing by less than 0.6% could have differences in slopes of up to 13%.

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TABLE OF CONTENTS

	<u>Page</u>
I. <u>INTRODUCTION</u>	1
A. BACKGROUND	1
B. PROGRAM SUMMARY	2
C. THEORETICAL CONSIDERATIONS	2
II. <u>APPARATUS</u>	5
A. BOILER	5
1. <u>Pressure Vessel and Internal Heater</u>	5
2. <u>Guard Heater and Radiation Shields</u>	8
3. <u>Support Structure</u>	8
B. HEAT EXCHANGER	10
1. <u>Condenser</u>	10
2. <u>Subcoolers</u>	10
3. <u>Nitrogen Gas Preheater</u>	13
4. <u>Exhaust Gas Heat Exchanger</u>	13
C. VOLUMETER	13
D. PRESSURIZATION AND CONTROL	15
E. INSTRUMENTATION AND CONTROL	15
III. <u>METHODOLOGICAL APPROACH</u>	19
IV. <u>PROCEDURE</u>	25
A. CALIBRATION	25
B. LIQUID METAL LOADING	25
C. CHEMICAL ANALYSIS	26
D. TEST OPERATION	27
V. <u>EXPERIMENTAL RESULTS</u>	31
A. LATENT HEAT OF VAPORIZATION	31
B. VAPOR PRESSURE	51
VI. <u>CONCLUSION AND EVALUATION</u>	61
<u>REFERENCES</u>	63

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Page</u>
1. Schematic Diagram of Latent Heat Apparatus	6
2. Latent Heat Boiler before Welding	7
3. Latent Heat Apparatus - Shield and Boiler Vessel Assembly	9
4. Latent Heat Apparatus - Condenser and Subcooler Components	11
5. Latent Heat Apparatus - Condenser, Subcooler and Heat Exchanger	12
6. Latent Heat of Vaporization Volumeter Assembly	14
7. Latent Heat Apparatus Installed in Vacuum Chamger	16
8. Latent Heat Apparatus - Pneumatic Control Panel	17
9. Latent Heat Determination at 1008.0°F.	38
10. Latent Heat Determination at 1097.3°F	39
11. Latent Heat Determination at 1198.1°F	40
12. Latent Heat Determination at 1297.6°F	41
13. Latent Heat Determination at 1407.2°F	42
14. Latent Heat Determination at 1504.9°F (First Experiment)	43
15. Latent Heat Determination at 1504.9°F (Second Experiment)	44
16. Latent Heat Determination at 1607.7°F	45
17. Latent Heat Determination at 1708.6°F	46
18. Latent Heat Determination at 1804.8°F	47
19. Latent Heat Determination at 1907.3°F (First Experiment)	48
20. Latent Heat Determination at 1907.3°F (Second Experiment)	49
21. Latent Heat of Potassium vs Temperature	52
22. Typical Vapor Pressure Hysteresis Loop	55
23. Linear Plot of Vapor Pressure of Potassium	56
24. Comparison of Vapor Pressure Curves from Various Investigators	58

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Analyses of impurities in Potassium	26
2. Experimental Latent Heat of Vaporization Data	32 - 37
3. Results of Latent Heat Data Reduction	51
4. Vapor Pressure Data	53 & 54
5. Vapor Pressure and Latent Heat of Vaporization of Potassium, as Computed from the Regression Equations	59

NOMENCLATURE

d	=	density, lb/ft ³
h_{fg}	=	latent heat of vaporization, Btu/lb or absolute joules/gram-mole
P	=	pressure, psia or absolute atmospheres as noted
T	=	temperature, °F, °R, or °K as noted
t	=	time, minutes
P	=	power, watts
m	=	masses of condensate, grams/cm ³
q	=	rate of heat loss in or out of boiler, Btu/hr or watts

CONVERSION FACTORS

1 Btu	=	1055.040 abs. joules
1 atm	=	14.696 psi
Degrees Rankine	=	degrees Fahrenheit + 459.67

I. INTRODUCTION

A. BACKGROUND

The work reported in this document is part of a program sponsored by the U. S. Atomic Energy Commission to provide data on the thermodynamic and transport properties of alkali metals at elevated temperatures. These data are needed to evaluate such materials as potential working fluids in turbines for space power systems.

The current Alkali Metals Program has been underway at AGN since early 1960. Since that time, the following thermodynamic and transport properties have been determined experimentally for the fluids of interest (rubidium, cesium, potassium):

- 1) Latent heat of vaporization of rubidium and cesium was determined in a specially designed apparatus in the range of 900 to 1800°F with standard errors of estimate of 0.1% and 0.5%, respectively. The vapor pressures of rubidium and cesium were measured in the same apparatus and in the same temperature range with standard errors of estimate of 1.1% and 0.7%, respectively.
- 2) The liquid enthalpy and specific heat of rubidium and cesium were determined (using a Bunsen ice-calorimeter) from 150 to 1650°F with a standard error of estimate of 1.3%.
- 3) The densities of liquid rubidium and cesium were determined by means of a specially designed pycnometer from the melting point to 1671°F with standard errors of estimate of 0.4% and 0.7%, respectively.

B. PROGRAM SUMMARY

During the current program (FY 65) the following thermodynamic and transport properties are being determined:

- 1) Liquid viscosity of rubidium and cesium from the melting point to 2000°F
- 2) Vapor PVT relationships of rubidium, cesium and potassium to 2200°F
- 3) Vapor thermal conductivity of rubidium and cesium to 2000°F
- 4) Vapor viscosity of rubidium and cesium from 900 to 2000°F
- 5) Vapor specific heat, enthalpy and entropy of rubidium and cesium to 2200°F
- 6) Latent heat of vaporization and vapor pressure of potassium to 2000°F

C. THEORETICAL CONSIDERATIONS

In the past, the latent heat of vaporization of liquid metals has been obtained by calculation, generally using the Clapeyron equation and the vapor pressure data. In these calculations, it is assumed that the vapor follows the ideal gas law, and a calculated value for the equilibrium constant of formation is used to account for the formation of polymers and the resulting increase of the average molecular weight of the saturated vapor with temperature. The errors expected, however, using these calculational procedures, are about $\pm 3\%$ at the lower end of the temperature range (1000°F) and as much as $\pm 6\%$ at the higher temperatures (1900°F). Consequently, it is important to obtain the latent heat of vaporization of liquid metals by direct experimental determination.

Many experimental determinations have been reported for the latent heats of organic liquids, but none for liquid metals at elevated temperatures. The various techniques used to measure latent heat follow one of two approaches: 1) measuring the temperature rise in a given mass of liquid to determine the heat released by the condensation of a given mass of vapor, or 2) directly measuring the heat required to vaporize a given mass of liquid.

For the first method, the heat rise in the coolant, and the flow rate of the coolant are measured. For the second method, it is necessary to measure the power input to the boiler, the mass of material vaporized and the time required to boil it off. This latter method is applicable over a wider range of temperature and yields more accurate results.

In both methods, it should be noted that careful consideration should be given to minimizing the heat losses in or out of the system and that the actual determination of these heat losses would be highly desirable for correcting the results. An analysis of the various methods available (conducted earlier in the program) was directed at the evaluation of each method, using rubidium and cesium (Ref. 1). After evaluating each method, it was decided to base the design of the latent heat apparatus upon the second method mentioned above.

This method uses an internally heated, high pressure boiler surrounded by radiant heat shields and a guard heater to minimize heat losses, and the vapor is gathered into an external system. The vapor is condensed in a condenser and received in a calibrated vessel where the volume of the condensate can be measured accurately at a known temperature (slightly above the melting point). The mass of liquid can then be calculated, using the known density at this temperature. The rate of boiling is obtained by automatically recording the time required to fill the calibrated volume. Pressurized argon cover gas controls the boiling temperature, protects the liquid metal from oxidation, and provides the means of returning the condensate to the boiler. The method developed for this determination involved a technique of double measurements which permitted the cancellation of the unknown heat losses between the boiler and the guard heater.

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II. APPARATUS

The latent heat apparatus previously developed and operated under the rubidium/cesium program was used, after completing minor repairs and modifications to the heat exchanger and volumeter, for determining the latent heat of potassium. This apparatus consisted of five major components: boiler, heat exchanger, volumeter, system pressurization and controls, and electrical instrumentation and controls. The boiler and heat exchanger assemblies were located inside the vacuum chamber, the volumeter and various controls outside the chamber (Figure 1).

A. BOILER

This assembly was composed of a boiler, guard heaters and radiation heat shields, and a support structure.

1. Pressure Vessel and Internal Heater

The boiler was a pressure vessel formed of two hemispherical sections welded together (Figure 2). The internal heater was a single 900-w, 115-v, tubular heater coil encased in Inconel. This coil was positioned in the lower section of the pressure vessel; the end leads penetrated the flat part of the lower section and were externally seal-welded. A vapor outlet tube made from Haynes 25 also passed through the lower section and was externally seal-welded with the entrance baffled to minimize liquid carryover. Temperature of the vapor and bulk liquid metal was sensed by five Inconel-sheathed thermocouples that penetrated the upper head and were installed so that two were immersed in the liquid, two were located in the vapor space above the liquid, and the one remaining was in the entrance to the vapor outlet tube. The thermocouples were seal-welded externally.

FIGURE 1. SCHEMATIC DIAGRAM OF LATENT HEAT APPARATUS

FIGURE 2. LATENT HEAT BOILER BEFORE WELDING

Tantalum-10% tungsten and columbium-1% zirconium were first considered for the pressure vessel sections. The tantalum-tungsten alloy is stronger at elevated temperatures than either columbium-zirconium or Haynes 25; however, to assure welding compatibility, use of this material would require using tantalum-10% tungsten, tantalum, or molybdenum for all components (such as the condenser and subcoolers) located in the high temperature region. Analysis of costs and lead times indicated that Haynes 25 was the most versatile material for operation at temperatures up to 1900°F.

2. Guard Heater and Radiation Shields

Three 115-v heater coils, connected in series, formed an evenly distributed 2000-w guard heater to control the heat losses. The top and bottom heaters were flat spirals and the cylindrical heater was a helical coil. All three heaters were sheathed with Inconel and positioned between the third and fourth radiation shields (Figure 3).

The radiation shield assembly consisted of 14 concentric cylinders, covered top and bottom with a corresponding number of flat disks. Each bottom disk was riveted to a corresponding cylinder and the entire assembly was secured by machine screws. Insulating ceramic washers were used between each shield. The top cover was also made up of 14 flat disks, held together by machine screws and spaced by insulating ceramic washers.

Heat transfer consideration and the cost of several shield arrangements using high temperature insulation and molybdenum sheet were evaluated. The final shield design was as follows: the first 10 shields from the center outward were made from 0.010-in. molybdenum; shields 11, 12 and 13 were made of 0.018-in., rhodium-plated, nickel sheet; and the outermost shield was made of 0.032-in. aluminum sheet. Rhodium plating of the nickel shields reduced the emissivity from 0.107 to 0.043 in the temperature range of interest, 1200 to 1400°F. The radiation shields were used without insulation.

3. Support Structure

The pressure vessel (boiler) and radiation shield assemblies were supported independently of each other by a welded stainless steel support structure. The four legs of the boiler, machined from Haynes 25 bar stock, were inserted through holes in the bottom shield disks and bolted to the support structure. The radiation shield assembly was attached to the support structure by means of four adjustable, stainless steel brackets.

FIGURE 3. LATENT HEAT APPARATUS - SHIELD AND BOILER VESSEL ASSEMBLY

B. HEAT EXCHANGER

Three of the four heat exchangers which comprised this assembly were positioned in tandem; i.e., the condensate flowed through the condenser and then through the upper and lower subcoolers (Figure 1). Nitrogen gas was used as the coolant in the upper subcooler and condenser. The nitrogen flowed through the exhaust gas heat exchanger before exhausting to the atmosphere outside the vacuum chamber.

1. Condenser

The condenser, shown before assembly in Figure 4, was a small pressure vessel with a condenser coil mounted inside. The vessel shell was machined from Haynes 25 bar stock and the cooling coil was made from Inconel tubing. The vapor tube connected the condenser to the boiler. A baffle at the exit from the vapor tube prevented vapor from bypassing the condenser coil. The assembled apparatus is shown in Figure 5.

2. Subcoolers

The upper subcooler consisted of a Haynes 25 inner tube with helical fins covered by a close fitting, concentric Inconel cylinder (Figure 4). A bellows at the lower end where the Inconel outer cylinder joined the Haynes 25 inner tube accommodated the difference in thermal growth between the two materials. Counterflow cooling was achieved by cooling the upper subcooler with preheated nitrogen gas which entered at the bottom, flowed vertically upward in the space between the helical fins, emerged at the top, and then flowed from the subcooler through the condenser coil. The gas was moved serially through the subcooler and condenser to prevent thermal stress in the condenser shell or at the welded joints between the condenser outlet and the subcooler inlet.

The subcooler was a straight tube, water-jacketed heat exchanger. A bellows at the lower end, at the junction of the inner and outer tubes, accommodated the difference in thermal growth (Figure 4). Both tubes were made of stainless steel. Counterflow cooling was achieved by making the condensate flow downward in the inner tube and the water flow upward in the annulus created by the concentric cylinders. Thermocouples were installed in the liquid metal line at the outlet from both the upper and lower subcoolers. The assembled condenser, heat exchanger, and subcoolers are shown in Figure 5.

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FIGURE 4. LATENT HEAT APPARATUS - CONDENSER AND SUBCOOLER COMPONENTS

EXHAUST GAS
HEAT EXCHANGER

CONDENSER

NITROGEN
SUBCOOLER
(UPPER)

OUT

WATER SUBCOOLER (LOWER)

IN

FIGURE 5. LATENT HEAT APPARATUS - CONDENSER,
SUBCOOLER, AND HEAT EXCHANGER

3. Nitrogen Gas Preheater

The preheater was made of Inconel wire inserted through ceramic insulators mounted inside a stainless steel tube. During operation, the nitrogen gas passed over the electrically heated Inconel wire, controlled by a variable transformer, at a controlled flow rate which would provide the desired gas inlet temperature. The addition of this preheater, combined with the controlled nitrogen flow, provided a more constant condenser temperature.

4. Exhaust Gas Heat Exchanger

The nitrogen gas coming out of the condenser was cooled in the exhaust gas heat exchanger by a separate supply of nitrogen to prevent damage to the rubber O-rings which were used to seal the bulkhead plate on the vacuum box (Figure 5).

C. VOLUMETER

There were problems with the volumeter used in the cesium/rubidium apparatus due to electrical shorting in the long flexible probes contained in a tube. For the potassium experiment, a modified volumeter was designed with a reduced over-all height and a larger center section, thus permitting the use of much shorter, larger diameter probes. Small diameter tubular cavities were maintained in the areas of contact for both the upper and lower probes to minimize the calibration errors (Figure 6).

The primary function of the volumeter was to collect known volumes of liquid metal condensate during experimental runs. The assembly consisted of two vessels placed one above the other. One vessel was a calibrated, vertical, volumeter cavity, which included the fill line in its calibrated volume; the other was a storage vessel. The two vessels were separated by a pneumatically operated (normally open) valve. Two electrical probes, mounted in the top of the vertical volumeter cavity, terminated at different depths inside the tube. The condensate entered below the volumeter tube, flowed through the pneumatic valve to the storage vessel, and remained there until steady-state conditions were reached. Then the pneumatic valve was closed and the condensate level rose in the volumeter tube. When the level of condensate contacted the lower probe, an electrical timer was activated. The condensate level continued to rise until the upper probe was contacted,

FIGURE 6
LATENT HEAT OF VAPORIZATION VOLUMETER ASSEMBLY

stopping the timer and reopening the pneumatic valve via relay, after a time interval to prevent flooding of the base of the probes. The volumeter was wrapped with a flexible tape heater, controlled by a variable transformer, to maintain the temperature between 220 to 240°F, the approximate temperature of the condensate as it emerged from the second subcooler.

All the liquid metal lines were also covered with tape heaters and insulation to keep the metal in liquid form. Figure 7 shows the latent heat apparatus installed in the vacuum box and the volumeter covered with the insulation.

D. PRESSURIZATION AND CONTROL

Pressure of the argon cover gas was controlled by high and low pressure regulators. Vapor pressure and the temperature at which boiling commenced were thus controlled by the cover gas pressure. Argon gas pressure was also used for charging initially and subsequently refilling the vapor generator with liquid metal. A liquid metal trap between the argon and liquid metal system prevented liquid metal from returning into the argon lines. The pressure control panel is shown in Figure 8.

E. INSTRUMENTATION AND CONTROL

The electrical instrumentation for the latent heat experiment consisted primarily of temperature-sensing and temperature-controlling instruments. Chromel-alumel calibrated thermocouples, monitored by Leeds & Northrup and Honeywell portable potentiometers, were used for temperature sensing. The information from the thermocouples, recorded on a strip chart recorder, generated control signals to saturable reactor power supplies connected to the heaters which controlled the system temperature.

The boiler contained five thermocouples and a heater. One of these thermocouples, connected to a Leeds and Northrup automatic controller, was used in the control of the boiler temperature during the heating period preparatory to an experiment. For a test run, the controller was switched to manual operation and the power input to the boiler was set at a fixed value by means of an adjustable transformer.

The guard heater between the third and fourth shields was controlled by signals from a differential thermocouple, one junction of which

FIGURE 7. LATENT HEAT APPARATUS INSTALLED IN VACUUM CHAMBER

FIGURE 8. LATENT HEAT APPARATUS - PNEUMATIC CONTROL PANEL

was located on the outer surface of the boiler vessel, the other against the first shield outside the guard heater. A Leeds and Northrup automatic differential controller was used with this thermocouple.

Two electrical level probes, terminating at different depths in the volumeter, were connected to a timer which recorded the time for the liquid metal to rise and contact the first and second probes. The pneumatic valve between the volumeter and the storage vessel was also connected to the second probe. When the liquid metal reached the second probe, the valve reopened automatically after a controlled time interval to prevent the metal from wetting the upper part of the volumeter and creating a short circuit between the probes and the volumeter tube.

Thermocouples were located at various other points in the apparatus, including the condenser, exit for the lower subcooler, exit for nitrogen gas preheater, volumeter, and boiler return line and were monitored during each run.

III. METHODOLOGICAL APPROACH

In the test runs, a temperature equilibrium was established between the boiling liquid and the guard heater at successive temperatures between 1000 and 1900°F. Liquid metal saturation temperature, vapor pressure, power input, mass of condensate, and time required to collect the condensate were recorded at each equilibrium datum point.

There are two methods of controlling boiler temperature. In the first method, the desired temperature can be obtained by operating the boiler without cover gas, using an automatic temperature controller to adjust the power input to the boiler. At the same time, a separate controller would maintain a null temperature differential between the boiler and the shield heater. Though this method would be capable of maintaining temperature very accurately, corrections introduced by the controller would create small oscillations in power input, thus making it necessary to integrate the power input over the time range of the measurement, resulting in additional errors.

The other method, which was used here, is a modification of that used by Henning for his measurement of the latent heat of vaporization of water (described by Roberts and Miller in Ref. 2, p. 243). The boiler temperature was controlled by using argon as a cover gas to set the boiling pressure, thereby establishing the boiling temperature. The heat input to the boiler could thus be manually set to any given value. This method has the advantage of allowing several measurements to be made at the same temperature, but with different power inputs. While it is extremely difficult to completely eliminate the heat losses, even when elaborate shielding and guard heaters are used, this method provides a means of analytically eliminating the heat

losses from the results. This is important, since a change of a few degrees in the temperature differences between boiler and guard heater results in relatively large heat losses either in or out of the boiler. For example, for the potassium run at 1400°F, the losses amounted to 3.3 w/°F change in temperature difference.

Let us consider two consecutive experiments performed at the same temperature but at different power inputs, P_1 and P_2 . Let q_1 and q_2 be the rates of heat losses in or out of the boiler in each experiment, m_1 and m_2 the masses of condensate collected during times t_1 and t_2 , and h_{fg} the latent heat of vaporization at that temperature. We have the heat balance equations

$$P_1 t_1 = m_1 h_{fg} + q_1 t_1 \quad (1)$$

and

$$P_2 t_2 = m_2 h_{fg} + q_2 t_2 \quad (2)$$

from which:

$$h_{fg} = \frac{P_1 t_1}{m_1} - \frac{q_1 t_1}{m_1} = \frac{P_2 t_2}{m_2} - \frac{q_2 t_2}{m_2} \quad (3)$$

If both experiments are made under identical conditions of temperature and temperature-difference (ΔT) between boiler and guard heater, and if this ΔT is such that the heat losses are small compared to the heat that goes to vaporization, it can be assumed that $q_1 = q_2$ and Eqs. 1 and 2 give:

$$h_{fg} = \frac{\frac{P_1}{t_1} - \frac{P_2}{t_2}}{\frac{1}{m_1} - \frac{1}{m_2}} \quad (4)$$

During the course of the experimental work, however, it was established that this was strictly true only at the value of ΔT for which there were no heat losses.

In the first approach, used earlier for the determination of the latent heat of rubidium, the ΔT for which the quantity Pt/m was independent of the power input to the boiler was first determined and a number of runs were made at this value. Pairs of data, using high and low power values, were then combined according to Eq. 4 to obtain the latent heat of vaporization.

The arithmetic average of the values thus obtained gave the latent heat at that particular boiling temperature. Due to the difficulties of accurately determining the ΔT value resulting in no heat exchange between vessel and guard heater, an alternate technique was then conceived and applied for the cesium latent heat determination and again for the measurement of the latent heat of potassium.

This second, more sensitive method, was based on the more general premise that for a given boiling temperature, the rate of heat losses is a function of ΔT and of the power input to the boiler. The heat balance equation is then written

$$\frac{Pt}{m} = h_{fg} + \frac{qt}{m} = h_{fg} + \frac{t}{m} \times f(\Delta T, P) \quad (5)$$

Consequently, the experimental procedure consisted of making a series of runs at a given temperature and constant power input to the boiler but for different values of ΔT ($\Delta T = T_{\text{vessel}} - T_{\text{guard heater}}$). The value of the quantity Pt/m was then plotted as a function of ΔT , and the experiment was then repeated at a different power input.

The two curves thus obtained are shown on the figure on p. 21 and it is seen that they intersect at a point A at which the values of Pt/m and ΔT are equal. Therefore,

$$\frac{P_1 T_1}{m_1} = \frac{P_2 t_2}{m_2} \quad (6)$$

Hence, from Eq. 3,

$$\frac{q_1 t_1}{m_1} = \frac{q_2 t_2}{m_2} \quad (7)$$

but, since $m_1 = m_2$ by design, and $t_1 \neq t_2$ because $P_1 \neq P_2$, it results that at the point of intersection, A, we must have a $q_1 = q_2 = 0$ in order to satisfy Eq. 7. Therefore, the value of latent heat of vaporization is given by

$$h_{fg} = \left[\frac{Pt}{m} \right]_A \quad (8)$$

Once the latent heat was known, the heat losses were calculated for a few values of P_1 and P_2 and are shown on the figure on p. 21 as lines of constant q . This shows conclusively that for a given ΔT , the rates of heat losses were different at P_1 and P_2 , and consequently Eq. 4 could be used only at the value of ΔT corresponding to zero or very small heat losses.

From the foregoing it is seen that the two possible approaches can be summarized as follows: one consists of first determining the value of ΔT for which the quantity Pt/m is the same at high and low power levels, and then making several more runs at this value of ΔT . Pairs of data which fulfill these conditions can then be combined according to Eq. 4 to obtain h_{fg} . In the second approach (used for cesium and potassium), the variation of the quantity Pt/m is determined over a wide range of ΔT values for both the high and low power levels, thus deliberately creating heat losses between the boiler and guard heater. Equations are then fitted to the two sets of data points and solved for their common value which gives the latent heat.

Two important requisites for the success of the method were an accurate control of the ΔT between boiler and guard heater, and the capability of maintaining the condenser temperature constant during consecutive runs at high and low power input, thus keeping the heat losses by conduction along the vapor tube constant.

This latest approach was used for cesium and again in the present work for the determination of the latent heat of potassium. At each temperature, two series of runs were made at two power levels (about 110 and 300 w).

Each set of Pt/m versus ΔT curves was then fitted to a third degree polynomial equation and the intersection of the two curves gave the value of the latent heat of vaporization at the temperature selected.

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IV. PROCEDURE

A. CALIBRATION

All thermocouples were of the chromel-alumel type. The two thermocouples immersed in the boiling liquid, one in the vapor space and the differential thermocouple used to control the guard heater, were each calibrated at six temperatures covering the range of interest. The thermocouple in the volumeter was calibrated at the boiling point of water.

The volume between the probes of the volumeter was calibrated with water and later with mercury. Calibration values obtained with mercury were used in the measurements because they were more reproducible than those obtained with water. To calibrate the volumeter, it was slowly filled with known weights of mercury until contact with each probe was detected by means of an ohmmeter. The calibrated volume between probes was 48.006 ± 0.007 ml.

The volume of the boiler vessel was calibrated before the two halves were welded together. The amount of liquid metal needed for loading and the quantity that could be boiled off before uncovering the heater coil were thus determined. The latent heat apparatus required 976 g of potassium for the loading.

B. LIQUID METAL LOADING

The liquid metal was first transferred to a gettering tank in which the liquid was boiled in the presence of zirconium-titanium chips at 1100°F for 2 hr. The gettering tank was then connected to the fill line of the latent heat apparatus. A vacuum of 10^{-5} mm Hg was achieved inside the system, and with Valves 3 and 5 open, the liquid metal was transferred

into the boiler at 500°F using about 15 psia of argon in the gettering tank (Figure 1).

C. CHEMICAL ANALYSIS

The pre-test analysis for metallic impurities was performed by the vendor (MSAR), and the post-test analysis by AGN, in both cases by the semiquantitative emission spectroscopy method. Table 1 lists the amounts of impurities which were detected in the potassium before and after the tests.

TABLE 1
ANALYSES OF IMPURITIES IN POTASSIUM

	Pre-Test Analysis*, ppm	Post-Test Analysis,** ppm
Fe	5	-
B	<5	-
Co	<5	-
Na	3	10
Mn	<1	-
Al	3	<10
Mg	<1	<10
Sn	<1	-
Cu	<1	-
Pb	<1	-
Cr	<1	-
Si	10	10
Ti	<5	-
Ni	<1	-
Mo	<5	-
V	<1	-
Ca	4	50
Ba	<3	-
Sr	<1	-
Be	<1	-
Zr	<10	-
Ag	<1	-
O ₂	26	not analyzed
N	<5	not analyzed

* MSA Research Corporation.

** AGN

D. TEST OPERATION

From 29 September 1964 to 16 February 1965, 1067 latent heat runs and 80 vapor pressure runs were completed at saturation temperatures ranging from 1006 to 1915°F for latent heat, and from 977 to 1910°F for vapor pressure. The power levels were between 100 and 400 w for the latent heat measurements. The vacuum in the containment chamber was maintained between 1×10^{-5} and 1×10^{-4} mm Hg throughout the entire experiment.

In a typical latent heat test run, the liquid metal was brought to a selected temperature by manually maintaining the power input to the boiler internal heater at a predetermined value under a sufficiently high overpressure of argon to prevent boiling. The temperature of the lower subcooler was maintained constant by means of an automatically controlled condensate-to-water heat exchanger, and the temperatures of all other components outside the vacuum chamber (i.e., volumeter, storage vessel, liquid metal trap, and connecting lines) were maintained at about 200°F by means of trace heaters controlled by variable transformers.

The nitrogen preheater was set at a constant heat input, and regulated to a specified gas flow which had been determined from initial trial runs that were performed for both the high and low power level runs for each saturation temperature. For the trial runs, the boiler heat input was set at low power level with the preheater set at a constant heat input and a gas flow of 15 ft³/hr. The temperature of the condenser was recorded when it reached equilibrium. The boiler heat input was then set at the high power level with the same preheater heat input. The preheater flow was then adjusted to give a constant condenser temperature that would correspond with the one recorded for the low power level. When the boiler temperature (which was being monitored throughout the startup period) was within 50°F of the selected saturation temperature, the argon overpressure was reduced to a predetermined corresponding pressure, the power to the boiler was reduced to 300 w, and the liquid metal was allowed to reach its saturation temperature.

The liquid metal was permitted to boil at this power level for 10 to 30 minutes, until the apparatus temperature had reached an equilibrium. At the end of this period, the pneumatic valve between the volumeter and storage

vessel was closed, allowing the liquid condensate to fill the volumeter to the first probe and sound a buzzer. This operation provided assurance that the saturation temperature was attained and boiling had commenced. After emptying the volumeter, the boiler was adjusted to the running power level for the first run of the day and permitted to reach an equilibrium temperature. Under these conditions pneumatic Valve 1 (Figure 1) was closed, causing the condensate to flow into the volumeter. The following temperatures were recorded: boiler liquid, boiler vapor, volumeter, condenser, upper subcooler, and lower subcooler. Also recorded were the pressure, power input, and the volumeter filling time.

At the end of a run, the liquid metal in the volumeter was dumped into the storage vessel, which was large enough to contain all the liquid metal that could be safely boiled off without uncovering the internal heater in the boiler. The operator was informed that the storage vessel was full when, with Valve 1 opened, the volumeter would not empty to clear the electrical probes and thus permit the timer to be reset.

The liquid metal was returned to the boiler with Valves 2 and 14 closed, and Valves 1 and 4 opened. Valve 3 was opened after a sufficient over-pressure of argon was applied to the system. The operator was informed that the transfer was complete when a sudden drop of argon pressure was noted on the gauge indicating that argon was bubbling through the fill line in the boiler. The fill line was wrapped with a 340-w heater to preheat the liquid metal before it re-entered the pressure vessel. This preheating prevented thermal stresses which would result from a mass of cold liquid re-entering the hot pressure vessel.

The vapor pressure of potassium was measured in the latent heat apparatus by using a low power input (about 13 w) to avoid the large temperature gradients which would otherwise exist within the bulk of the liquid, and between the liquid and vapor. At each data point, pressure and temperature were recorded at about nine different settings. The pressure was first increased by small increments and then decreased by equally small increments to obtain a hysteresis loop covering a range of approximately 10°F about the datum temperature (see Figure 22). The slight hysteresis was eliminated from the result

by considering both of these curves in the reduction of the data. The temperature difference that produced no heat losses, either in or out of the boiler, for each latent heat data point was the value chosen for use on the corresponding vapor pressure hysteresis loop.

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V. EXPERIMENTAL RESULTS

A. LATENT HEAT OF VAPORIZATION

The experimental data obtained during the latent heat of vaporization measurements are shown in Table 2 and a graphical representation of the experimental data (Pt/m vs ΔT) and of the regression curves are given in Figures 9 through 20 for each datum temperature. The temperature in each case was calculated from the pressure, using the vapor pressure equation, since the pressure could be easily maintained within very close limits, regardless of the input to the boiler, but the local temperature measured within the boiling liquid tended to be affected by the power level; thus, differences of 2 or 3°F could be noted between high and low power runs.

The mass of condensate in the volumeter was calculated for each run, using the calibrated volume value obtained at room temperature, and the density of liquid potassium corrected for temperature by means of the density equation given by C. T. Ewing, et al. (Ref. 3):

$$d = 52.7274 - 7.3539 \times 10^{-3}T - 0.56013 \times 10^{-6}T^2 + 0.03158 \times 10^{-9}T^3$$

where T is temperature in °F.

Recently, a slightly revised equation has been published by J. P. Stone, et al. of the same laboratory (Ref. 4) which would give density values about 0.02% higher than the first equation in the temperature range of interest (220 to 240°F). Since the confidence limit given for the latest density equation is stated as being ± 0.2 to $\pm 0.3\%$ and the standard error of estimate of the latent heat data distribution is $\pm 0.8\%$, recalculation of the results was not deemed necessary.

Table 2

EXPERIMENTAL LATENT HEAT OF VAPORIZATION DATA

Temperature, °F	ΔT , °F	P, watts	t, minutes	m, grams	25.8 $\frac{pt}{lb}$, Btu/lb
1008.0	+22.05	126.00	12.76	39.18	1058.7
	+22.05	126.00	12.65	39.18	1049.6
	+14.67	125.00	11.69	39.17	962.4
	+14.50	125.00	11.76	39.18	968.0
	+14.42	125.00	11.71	39.19	963.7
	+ 6.02	124.25	10.99	39.19	899.0
	+ 5.85	124.50	10.80	39.19	885.3
	+ 5.93	124.50	10.81	39.19	886.1
	- 1.87	124.50	10.03	39.17	822.4
	- 1.95	124.50	10.09	39.17	827.3
	- 2.03	124.50	10.08	39.19	826.3
	-11.36	126.00	9.16	39.28	758.1
	-11.36	125.00	9.26	39.25	760.8
	-11.36	124.50	9.24	39.23	756.6
	+19.92	300.50	4.63	39.16	916.6
	+19.77	300.50	4.63	39.16	916.7
	+19.60	300.50	4.56	39.15	903.0
	+ 8.48	300.50	4.36	39.15	863.4
	+ 8.05	300.00	4.33	39.18	855.4
	+ 7.89	300.00	4.33	39.19	855.1
	- 3.79	300.00	4.25	39.18	839.6
	- 3.79	300.00	4.19	39.18	827.7
	- 3.79	300.00	4.18	39.18	825.7
	-11.88	299.50	4.13	39.17	814.6
	-11.88	300.00	4.09	39.17	808.2
	-11.88	300.00	4.09	39.17	808.2
	-12.05	300.00	4.08	39.17	806.2
1097.3	+22.30	124.00	12.67	39.18	1034.5
	+22.12	124.00	12.60	39.18	1028.8
	+21.92	124.00	12.49	39.17	1020.1
	+11.88	124.00	11.00	39.20	897.6
	+11.88	123.75	10.95	39.20	891.9
	+11.95	123.75	10.95	39.20	891.9
	+ 4.24	124.00	9.98	39.20	814.7
	+ 4.24	124.00	10.02	39.23	817.1
	- 4.41	124.00	9.03	39.23	736.3
	- 5.09	123.50	9.04	39.25	734.0
	-14.42	122.50	8.30	39.25	668.4
	-13.48	123.00	8.29	39.25	670.3
	-13.57	123.50	8.25	39.25	669.8
	+21.45	297.75	4.61	39.28	901.6
	+21.45	297.00	4.57	39.26	891.9
	+21.35	297.00	4.61	39.23	900.5
	+12.55	297.50	4.40	39.16	862.3
	+12.47	297.50	4.38	39.16	858.6
	- 7.63	300.00	3.94	39.19	778.2
	- 7.63	300.00	3.96	39.19	782.2
	-14.60	299.50	3.79	39.20	747.0
	-15.00	300.00	3.86	39.21	762.0
	-15.00	300.00	3.80	39.22	750.0
	-15.00	300.00	3.86	39.21	762.0

Note: ΔT = Vessel temperature-shield temperaturePositive ΔT , vessel hotter than shieldNegative ΔT , shield hotter than vessel

Table 2 (cont'd)

EXPERIMENTAL LATENT HEAT OF VAPORIZATION DATA

Temperature °F	ΔT , °F	P, watts	t, minutes	m, grams	25.8 $\frac{pt}{lb}$, Btu/lb ^m
1198.1	+22.70	112.50	16.75	39.39	1234.4
	+22.80	112.50	16.58	39.41	1221.1
	+22.90	112.25	16.52	39.43	1213.5
	+13.40	112.25	13.32	39.43	978.3
	+13.40	112.00	13.36	39.43	979.0
	+13.40	112.00	13.45	39.43	985.6
	+ 5.59	112.00	11.68	39.43	856.1
	+ 5.59	112.00	11.58	39.42	848.8
	+ 5.42	112.00	11.57	39.42	848.1
	+ 5.26	111.00	11.90	39.35	866.1
	- 4.32	111.00	10.10	39.36	734.8
	- 4.32	111.00	9.98	39.37	726.0
	- 4.32	111.00	10.06	39.37	731.8
	- 5.17	112.00	9.83	39.41	720.7
	-12.29	110.50	9.09	39.37	658.3
	-12.29	110.50	8.99	39.37	651.0
	+21.20	347.00	3.93	39.32	894.8
	+21.11	347.00	4.07	39.32	926.8
	+21.11	347.00	4.06	39.31	924.7
	+16.96	344.00	3.93	39.26	888.4
	+16.96	344.00	3.95	39.29	892.4
	+17.22	343.00	4.00	39.33	900.0
	+13.15	346.00	3.87	39.30	879.1
	+12.89	346.00	3.87	39.30	879.1
	+ 8.40	344.00	3.77	39.27	851.9
	+ 8.31	344.00	3.77	39.29	851.6
	+ 8.23	344.00	3.77	39.30	851.3
	- 5.68	344.00	3.46	39.30	781.4
	- 6.36	344.00	3.43	39.32	774.2
	- 6.44	344.00	3.42	39.32	771.9
	-11.36	345.00	3.39	39.27	768.3
	-11.87	345.00	3.37	39.29	763.4
	-14.33	345.00	3.29	39.32	744.8
	-14.42	345.00	3.28	39.32	742.6
	-19.90	345.00	3.24	39.27	734.3
	-20.00	345.00	3.23	39.27	732.0
1297.6	+21.87	113.00	15.76	39.36	1167.5
	+22.30	112.00	15.65	39.40	1147.7
	+13.57	111.00	13.02	39.27	949.5
	+13.50	112.00	12.96	39.25	954.1
	+13.42	112.00	12.85	39.28	945.3
	+13.40	110.50	13.19	39.30	956.9
	+13.33	112.00	12.78	39.30	939.6
	+ 5.94	112.00	11.14	39.32	818.8
	+ 5.85	112.00	11.00	39.33	808.2
	+ 5.68	112.00	11.07	39.33	813.4
	- 4.24	111.50	9.06	39.28	663.5
	- 4.41	111.50	9.30	39.29	681.0
	- 4.41	111.50	9.21	39.27	674.6
	- 4.41	111.50	9.07	39.27	664.3
	-11.45	110.00	8.32	39.26	601.4
	-11.70	109.50	8.16	39.26	587.1
	-11.95	109.50	8.31	39.26	598.0
	-20.43	113.00	7.21	39.22	536.0
	-20.43	113.00	7.18	39.22	533.7
	-20.60	113.00	7.09	39.22	527.1
	-20.50	113.00	7.18	39.22	533.7
	+13.57	226.50	6.07	39.29	902.8
	+13.48	226.50	6.04	39.27	898.7
	+13.48	226.50	6.04	39.27	898.8
	+ 5.76	228.00	5.44	39.25	815.3
	+ 5.00	224.00	5.48	39.20	807.9
	+ 4.41	224.00	5.46	39.21	804.8
	- 3.48	224.00	5.09	39.23	749.8
	- 3.73	224.50	5.04	39.23	744.1
	- 3.98	224.50	5.11	39.25	754.2
	-11.52	224.50	4.76	39.22	702.9
	-11.70	224.50	4.82	39.24	711.5
	-11.52	222.00	4.83	39.23	705.1
	-11.61	222.00	4.91	39.26	716.4
	-11.70	222.00	4.82	39.25	703.3

Table 2 (cont'd)

EXPERIMENTAL LATENT HEAT OF VAPORIZATION DATA

<u>Temperature,</u> <u>°F</u>	<u>$\Delta T,$</u> <u>°F</u>	<u>P,</u> <u>watts</u>	<u>t,</u> <u>minutes</u>	<u>m,</u> <u>grams</u>	<u>25.8 $\frac{pt}{m},$</u> <u>Btu/lb</u>
1297.6	+21.75	353.00	3.95	39.18	918.2
	+21.75	353.00	3.90	39.20	906.1
	+13.81	350.00	3.68	39.18	848.1
	+ 5.94	349.00	3.55	39.14	816.7
	+ 5.85	349.50	3.56	39.17	819.6
	+ 5.76	349.00	3.58	39.16	823.1
	+ 5.09	350.00	3.51	39.17	809.1
	+ 5.09	350.25	3.53	39.17	814.3
	+ 5.17	350.25	3.51	39.17	809.7
	- 4.07	346.00	3.40	39.15	775.2
	- 4.41	350.00	3.29	39.16	758.6
	- 4.41	350.00	3.32	39.16	765.5
	- 4.41	351.00	3.34	39.17	772.2
	-11.70	346.00	3.19	39.14	727.6
	-11.96	350.00	3.20	39.17	737.7
	-20.60	349.50	2.99	39.16	688.5
	-20.70	349.50	3.03	39.16	697.7
	-20.70	349.50	2.99	39.16	688.5
1407.2	+21.70	113.00	15.28	39.32	1133.1
	+21.70	112.75	15.30	39.32	1132.1
	+21.62	112.75	15.59	39.33	1153.2
	+21.80	112.00	15.63	39.27	1150.0
	+13.57	112.00	12.36	39.27	909.4
	+13.48	112.00	12.26	39.27	902.0
	+13.35	111.50	12.29	39.28	900.1
	+ 5.59	113.00	9.94	39.26	738.1
	+ 5.59	112.50	9.89	39.26	731.1
	+ 5.34	110.00	10.36	39.27	748.6
	- 4.24	111.75	8.38	39.23	615.8
	- 4.41	113.50	8.23	39.23	614.3
	- 4.57	113.50	8.18	39.22	610.7
	-12.12	113.50	7.14	39.20	533.4
	-12.30	113.00	7.19	39.20	534.8
	-20.10	110.50	6.46	39.18	470.0
	-20.25	113.00	6.40	39.17	476.3
	-20.33	113.00	6.23	39.17	463.6
	+16.27	300.00	4.37	39.22	862.4
	+16.27	300.00	4.35	39.22	858.4
	+16.10	300.00	4.34	39.22	856.6
	+ 7.72	301.50	4.02	39.20	797.6
	+ 7.46	300.25	4.01	39.20	792.3
	+ 7.12	300.00	4.00	39.19	790.1
	- 5.68	298.00	3.60	39.17	706.5
	- 5.93	297.00	3.67	39.18	717.7
	- 5.93	301.00	3.58	39.17	709.8
	- 6.10	300.00	3.55	39.16	701.7
	-13.82	297.00	3.42	39.15	669.4
	-13.91	296.00	3.44	39.15	671.0
	-14.16	296.00	3.47	39.16	676.8

Table 2 (cont'd)

EXPERIMENTAL LATENT HEAT OF VAPORIZATION DATA

Temperature, °F	ΔT , °F	P, watts	t, minutes	m, grams	25.8 $\frac{\text{pt}}{\text{lb}^m}$, Btu/lb ^m
1504.9	+17.47	110.50	13.81	39.32	1001.4
	+17.30	110.50	13.92	39.22	1012.0
(First	+17.30	110.00	13.84	39.22	1001.6
Experiment)	+12.72	110.50	12.03	39.23	874.3
	+12.63	110.00	12.04	39.20	871.7
	+12.55	109.50	11.82	39.17	852.4
	+12.55	109.25	11.77	39.19	846.5
	+ 7.29	110.75	9.90	39.21	721.4
	+ 7.20	110.50	9.83	39.22	714.5
	+ 7.29	110.50	9.86	39.25	716.2
	- 5.09	110.25	7.42	39.25	537.7
	- 5.17	110.00	7.40	39.23	535.3
	- 5.26	110.00	7.39	39.22	534.7
	- 5.26	110.00	7.43	39.22	537.7
	+22.88	299.00	4.72	39.30	926.5
	+22.88	299.50	4.77	39.21	940.0
	+22.80	299.00	4.70	39.20	924.8
	+17.97	299.50	4.40	39.14	868.7
	+17.80	299.50	4.38	39.21	863.2
	+18.15	300.00	4.38	39.26	863.4
	+17.81	300.00	4.38	39.25	863.7
	+12.47	300.00	4.13	39.13	816.8
	+ 8.05	299.00	3.89	39.28	764.0
	+ 7.97	299.00	3.85	39.22	757.2
	+ 7.72	299.00	3.90	39.18	767.9
	+ 8.74	298.50	3.97	39.27	778.5
	+ 8.48	298.50	3.90	39.26	765.1
	+ 2.80	301.00	3.65	39.22	722.7
	+ 2.71	301.00	3.61	39.22	714.9
	+ 2.63	301.00	3.58	39.21	709.0
	- 5.68	298.50	3.45	39.19	678.0
	- 5.34	297.50	3.44	39.21	673.4
	- 5.51	297.50	3.44	39.22	673.3
	- 5.42	299.00	3.47	39.14	683.9
	- 5.51	300.25	3.45	39.16	682.4
1504.9	+21.70	112.00	13.46	39.25	990.9
	+21.50	111.50	13.42	39.26	983.4
(Second	+18.15	114.00	11.50	39.24	862.0
Experiment)	+17.80	113.50	11.38	39.25	849.0
	+17.73	113.00	11.55	39.25	857.9
	+12.55	112.25	9.99	39.25	737.1
	+12.46	112.00	9.85	39.25	725.1
	+12.46	112.00	9.78	39.25	720.1
	+12.38	112.00	9.72	39.25	715.6
	+ 5.76	113.00	8.24	39.24	612.2
	+ 5.34	112.50	8.20	39.24	606.6
	+ 5.09	112.00	8.18	39.24	602.4
	+22.05	301.50	4.38	39.26	867.8
	+21.87	301.50	4.36	39.28	863.4
	+22.05	292.50	4.46	39.30	856.3
	+22.05	299.50	4.41	39.27	867.7
	+18.58	298.50	4.16	39.30	815.1
	+18.25	298.50	4.20	39.28	823.5
	+17.96	298.00	4.13	39.25	810.3
	+13.73	299.00	3.92	39.22	771.0
	+13.57	297.00	3.93	39.22	767.8
	+13.57	297.00	3.91	39.22	763.9
	+ 6.19	297.00	3.70	39.21	723.1
	+ 5.94	297.00	3.65	39.21	713.3
	+ 6.27	298.50	3.67	39.21	720.8
	+ 6.19	298.00	3.65	39.21	715.7

Table 2 (cont'd)

EXPERIMENTAL LATENT HEAT OF VAPORIZATION DATA

<u>Temperature, °F</u>	<u>$\Delta T,$ °F</u>	<u>P, watts</u>	<u>t, minutes</u>	<u>m, grams</u>	<u>$25.8 \frac{Pt}{m},$ Btu/lb^m</u>
1607.7	+23.40	119.00	13.29	39.30	1038.2
	+23.06	117.50	13.07	39.29	1008.4
	+23.30	118.00	13.03	39.33	1008.7
	+17.90	119.00	10.87	39.30	849.2
	+17.80	117.00	10.77	39.27	827.8
	+14.17	119.00	9.47	39.35	738.9
	+13.73	118.00	9.51	39.30	736.6
	+11.88	117.00	9.12	39.25	701.4
	+11.96	121.00	8.82	39.26	701.3
	+ 6.87	121.00	7.56	39.26	601.1
	+ 7.29	119.50	7.77	39.26	610.1
	+21.62	297.50	4.24	39.25	829.3
	+21.44	297.50	4.26	39.22	833.8
	+21.35	297.50	4.25	39.21	832.0
	+17.90	300.00	4.03	39.16	796.5
	+17.46	299.50	4.07	39.17	802.8
	+17.37	299.50	3.99	39.17	787.0
	+17.20	299.50	3.98	39.17	785.0
	+14.25	297.50	3.95	39.16	774.2
	+14.00	297.50	3.88	39.16	759.3
	+14.08	298.00	3.91	39.17	767.5
	+ 8.56	300.00	3.65	39.16	721.4
	+ 8.39	300.00	3.65	39.16	721.4
	+ 4.33	299.50	3.52	39.15	694.7
	+ 4.24	299.50	3.47	39.14	685.1
	- 3.05	300.00	3.26	39.13	644.8
	- 3.39	300.00	3.20	39.13	632.9
	- 3.56	299.50	3.23	39.13	637.8
1708.6	+23.12	117.00	12.58	39.28	966.8
	+22.65	116.50	12.19	39.28	932.8
	+22.30	116.50	12.19	39.28	932.8
	+22.10	116.50	12.12	39.28	927.4
	+18.40	119.50	9.64	39.29	756.4
	+18.23	119.50	9.56	39.27	750.6
	+18.06	120.00	9.39	39.26	740.5
	+13.90	119.50	8.26	39.25	648.8
	+14.42	120.00	7.98	39.27	629.2
	+14.25	120.00	7.87	39.26	620.6
	+14.42	120.00	7.97	39.26	628.5
	+ 8.22	120.00	6.71	39.25	529.3
	+ 8.05	120.00	6.61	39.25	521.4
	+33.75	298.00	5.08	39.20	996.3
	+34.60	302.00	5.01	39.20	995.9
	+34.35	302.50	5.01	39.20	997.5
	+33.85	303.50	4.96	39.19	991.0
	+27.80	302.00	4.58	39.20	910.4
	+27.45	302.50	4.38	39.20	872.1
	+27.30	303.50	4.42	39.20	882.8
	+27.20	304.00	4.43	39.20	886.3
	+22.73	302.00	4.08	39.21	810.8
	+22.62	303.00	4.09	39.20	815.6
	+17.20	302.00	3.85	39.20	765.2
	+16.70	302.00	3.77	39.20	749.4
	+16.28	302.00	3.71	39.19	737.6

Table 2 (cont'd)

EXPERIMENTAL LATENT HEAT OF VAPORIZATION DATA

Temperature, °F	ΔT , °F	P, watts	t, minutes	m, grams	25.8 $\frac{Pt}{lb^n}$, Btu/lb ⁿ
1804.8	+30.45	125.25	11.98	39.25	986.4
	+30.30	122.00	12.27	39.20	985.1
	+30.30	122.00	12.30	39.22	987.1
	+25.95	124.50	9.64	39.22	789.5
	+25.87	124.50	9.63	39.22	788.7
	+25.87	124.50	9.59	39.20	785.7
	+22.05	125.75	7.56	39.20	625.7
	+21.93	125.50	7.82	39.20	646.0
	+21.80	125.50	7.78	39.20	642.7
	+14.92	125.50	6.15	39.18	508.2
	+14.92	125.50	6.12	39.18	503.7
	+33.20	256.00	5.37	39.22	904.4
	+32.90	256.00	5.43	39.23	914.3
	+32.80	256.00	5.39	39.23	907.5
	+27.96	256.00	4.75	39.20	800.4
	+27.96	256.00	4.76	39.18	802.4
	+27.96	256.00	4.84	39.18	815.9
	+27.90	256.00	4.83	39.18	814.2
	+22.46	255.00	4.33	39.16	727.4
	+22.13	255.00	4.33	39.16	727.5
	+14.25	255.00	3.89	39.16	653.6
	+13.40	261.00	3.72	39.16	639.6
	+13.57	261.00	3.79	39.17	651.6
1907.3 (First Experiment)	+35.50	111.00	12.05	39.21	880.1
	+33.85	111.75	11.16	39.26	819.6
	+33.85	112.00	11.45	39.26	842.8
	+33.65	112.50	10.78	39.26	797.0
	+37.22	244.0	5.35	39.24	858.3
	+36.45	243.00	5.31	39.26	848.0
	+36.21	242.50	5.35	39.25	852.8
	+36.21	242.50	5.29	39.25	843.3
	+35.50	245.00	5.13	39.18	827.6
	+33.75	241.50	4.88	39.22	775.3
	+33.75	245.00	4.87	39.22	785.0
	+32.25	243.00	4.76	39.21	761.1
	+31.20	243.00	4.59	39.21	733.9
	+31.10	242.50	4.55	39.21	726.0
	+30.70	242.50	4.58	39.24	730.3
	+26.46	242.00	4.09	39.20	651.5
	+26.30	242.00	4.09	39.19	651.6
	+26.20	242.00	4.02	39.19	640.5
	+26.10	242.00	4.04	39.17	643.9
	+22.80	242.00	3.77	39.16	601.0
	+22.73	242.00	3.74	39.16	596.3
	+22.65	242.00	3.72	39.16	593.2
1907.3 (Second Experiment)	+40.20	112.00	13.03	39.23	959.7
	+39.85	115.00	12.59	39.23	952.1
	+39.85	119.75	11.95	39.23	941.0
	+39.70	113.00	12.83	39.26	952.8
	+39.70	118.50	12.05	39.23	939.0
	+35.00	120.00	9.01	39.29	709.9
	+34.10	120.00	8.85	39.26	698.0
	+32.80	112.00	8.90	39.26	655.1
	+40.10	241.00	5.39	39.20	855.0
	+39.90	245.00	5.41	39.20	872.3
	+39.80	246.00	5.36	39.22	867.5
	+39.70	232.00	5.71	39.22	871.5
	+35.50	240.50	4.60	39.16	728.8
	+33.50	251.00	4.40	39.22	726.6

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FIGURE 9. LATENT HEAT DETERMINATION AT 1008°F

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FIGURE 10. LATENT HEAT DETERMINATION AT 1097.3°F

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FIGURE 11. LATENT HEAT DETERMINATION AT 1198.1°F

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FIGURE 16. LATENT HEAT DETERMINATION AT 1607.7°F

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FIGURE 17. LATENT HEAT DETERMINATION AT 1708.6°F

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13.10-65-927

AGN-8141

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FIGURE 20. LATENT HEAT DETERMINATION AT 1907.3°F (SECOND EXPERIMENT)

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Each set of data at a given temperature and power was fitted by least square analysis to a third degree polynomial (except at 1900°F) and the latent heat value was then obtained at each datum temperature by solving for the intersection of each pair of curves. The results of these calculations are presented in Table 3.

As an additional check of the validity of the method, three sets of experiments were run at 1300°F with power levels of 112, 224 and 350 w (Figure 12). The solutions obtained by mutually solving each pair of equations are shown below:

$$P = 112 \text{ \& } 350 \text{ w, } h_{fg} = 816.8 \text{ Btu/lb}$$

$$P = 224 \text{ \& } 350 \text{ w, } h_{fg} = 814.9 \text{ Btu/lb}$$

$$P = 112 \text{ \& } 224 \text{ w, } h_{fg} = 819.9 \text{ Btu/lb}$$

It is seen that good agreement was obtained between these three solutions, the maximum deviation from the mean being 2.5 Btu/lb ($\pm 0.3\%$).

It was observed at 1500°F that a shift in the readings of the differential thermocouple was occurring at the end of the experiment: it was therefore decided to re-run this experiment. As can be seen by comparing Figures 14 and 15, the two sets of data obtained during the second experiment shifted to the right; nevertheless, the value of latent heat obtained from each set did not vary by more than 0.45%. A similar phenomenon occurred at 1900°F; however, during an attempt to run a second set of data, a slight leak in the boiler vessel around the thermocouple weld prevented obtaining a sufficient number of data points.

The latent heat values obtained at each temperature and deduced by the double measurement method is presented in Table 3. A linear equation was fitted to these data with the following result in English units:

$$h_{fg} = 948.5 - 0.1044T$$

where h_{fg} is the latent heat of vaporization in Btu/lb and T the temperature in °F; and in the "Système International":

$$h_{fg} = 9.063 \times 10^4 - 17.09T$$

where h_{fg} is in absolute joules/gram mole and T is in °K.

Table 3

RESULTS OF LATENT HEAT DATA REDUCTION

Temperature °F	Experimental Latent Heat, h_{fg} , Btu/lb	Calculated Value (equation) h_{fg} , Btu/lb	Deviation From Calculated Value %
1008.0	838.4	843.3	-0.58
1097.3	834.6	834.0	+0.07
1198.1	830.1	823.5	+0.80
1297.6	816.8	813.1	+0.46
1297.6	814.9	813.1	+0.22
1297.6	819.9	813.1	+0.84
1407.2	805.0	801.6	+0.42
1504.9	778.6	791.4	-1.6
1504.9	782.1	791.4	-1.2
1607.7	777.4	780.7	-0.42
1708.6	765.3	770.2	-0.64
1804.8	768.8	760.1	+1.1
1907.3	745.7	749.4	-0.49
1907.3	756.8	749.4	+0.99

The standard error of estimate of the data is equal to 6.6 Btu/lb or 0.8% at mid-range. Figure 21 compares the results obtained with those of other investigators (Refs. 3, 5, and 6).

B. VAPOR PRESSURE

The 89 data points obtained from 977 to 1910°F are listed in Table 4. A typical vapor pressure hysteresis loop is shown in Figure 22. The data points were first plotted in the form $\log_{10} P$ vs $10^4/T$ with pressure in psia and temperature in degrees Rankine (Figure 23). Since the data fell extremely close to a straight line, two-term equations of the form $\log_{10} P = a - b/T$ could be fitted to the data (where a and b are constants). The equation obtained by least square correlation was

$$\log_{10} P = 5.31574 - \frac{7707.31}{T+459.7}$$

with P in psia and T in °F.

Table 4

VAPOR PRESSURE DATA

TEMPERATURE		EXPERIMENTAL	CALCULATED	DEVIATION FROM
°F	°R	PRESSURE	PRESSURE	CALCULATED VALUE
		psia	psia	%
985.1	1444.8	0.9671	0.9599	-0.80
996.0	1455.7	1.064	1.050	-1.3
1007.3	1467.0	1.160	1.153	-0.70
1017.1	1476.8	1.238	1.250	+0.96
1026.4	1486.1	1.354	1.347	-0.52
1017.8	1477.5	1.257	1.257	0.00
1006.9	1466.6	1.160	1.150	-0.87
994.9	1454.6	1.064	1.040	-2.3
977.3	1437.0	0.9090	0.8959	-1.5
1086.2	1545.9	2.127	2.138	+0.51
1092.4	1552.1	2.224	2.239	+0.67
1098.3	1558.0	2.321	2.338	+0.73
1104.0	1563.7	2.418	2.437	+0.78
1109.1	1568.8	2.514	2.529	+0.59
1103.8	1563.5	2.418	2.433	+0.62
1098.8	1558.5	2.321	2.346	+1.1
1092.9	1552.6	2.224	2.247	+1.0
1086.5	1546.2	2.127	2.143	+0.75
1192.5	1652.2	4.448	4.476	+0.63
1195.8	1655.5	4.574	4.573	-0.02
1199.0	1658.7	4.642	4.668	+0.56
1201.7	1661.4	4.738	4.750	+0.25
1208.1	1667.8	4.932	4.949	+0.34
1204.3	1664.0	4.835	4.830	-0.10
1198.6	1658.3	4.642	4.656	+0.30
1195.0	1654.7	4.555	4.549	-0.13
1191.7	1651.4	4.448	4.452	+0.09
1294.9	1754.6	8.316	8.377	+0.73
1298.8	1758.5	8.510	8.567	+0.67
1302.4	1762.1	8.708	8.746	+0.43
1305.7	1765.4	8.892	8.912	+0.22
1309.1	1768.8	9.090	9.086	-0.04
1305.5	1765.2	8.896	8.902	+0.07
1302.0	1761.7	8.698	8.726	+0.32
1298.5	1758.2	8.510	8.553	+0.50
1294.3	1754.0	8.316	8.349	+0.40
1402.5	1862.2	15.05	15.03	-0.13
1404.8	1864.5	15.27	15.21	-0.39
1407.1	1866.8	15.48	15.39	-0.58
1409.1	1868.8	15.70	15.54	-1.0
1413.1	1872.8	16.01	15.86	-0.95
1410.4	1870.1	15.75	15.65	-0.64
1408.9	1868.6	15.55	15.53	-0.13
1404.7	1864.4	15.24	15.20	-0.26
1399.9	1859.6	14.85	14.83	-0.13
1495.8	1955.5	23.72	23.85	+0.54
1499.8	1959.5	24.17	24.12	-0.21
1503.8	1963.5	24.70	24.57	-0.53
1509.0	1968.7	25.26	25.17	-0.36
1512.8	1972.5	25.70	25.61	-0.35
1508.9	1968.6	25.28	25.15	-0.52
1504.6	1964.3	24.77	24.66	-0.45
1499.9	1959.6	24.26	24.13	-0.54
1495.6	1955.3	23.75	23.66	-0.38
1600.2	2059.9	37.35	37.51	+0.43
1604.5	2064.2	37.97	38.19	+0.58
1614.7	2074.4	39.75	39.84	+0.23
1618.3	2078.0	40.24	40.43	+0.47
1614.0	2073.7	39.60	39.72	+0.30
1606.5	2066.2	38.55	38.51	-0.10
1600.8	2060.5	37.70	37.60	-0.27
1598.1	2057.8	37.20	37.18	-0.05
1594.4	2054.1	36.60	36.61	+0.03

Table 4 (cont'd)
VAPOR PRESSURE DATA

TEMPERATURE		EXPERIMENTAL	CALCULATED	DEVIATION FROM
$^{\circ}\text{F}$	$^{\circ}\text{R}$	PRESSURE	PRESSURE	CALCULATED VALUE
		psia	psia	%
1701.1	2160.8	55.80	56.09	+0.52
1705.4	2165.1	56.81	57.01	+0.35
1709.4	2169.1	57.75	57.88	+0.22
1714.1	2173.8	58.80	58.91	+0.19
1717.1	2176.8	59.41	59.58	+0.29
1711.7	2171.4	58.18	58.38	+0.34
1708.0	2167.7	57.45	57.57	+0.21
1705.4	2165.1	56.80	57.01	+0.37
1698.4	2158.1	55.25	55.51	+0.47
1798.0	2257.7	79.75	79.79	+0.05
1802.5	2262.2	80.80	81.05	+0.31
1807.2	2266.9	81.70	82.38	+0.83
1810.7	2270.4	82.80	83.38	+0.70
1813.2	2272.9	83.80	84.10	+0.36
1810.6	2270.3	82.85	83.35	+0.60
1806.5	2266.2	81.85	82.18	+0.40
1802.7	2262.4	80.90	81.10	+0.25
1797.8	2257.5	79.64	79.73	+0.11
1899.3	2359.0	112.1	111.8	-0.27
1901.1	2360.8	113.8	112.5	-1.2
1903.9	2363.6	114.9	113.5	-1.2
1907.8	2367.5	116.2	114.9	-1.1
1910.0	2369.7	117.4	115.7	-1.5
1902.7	2362.4	113.7	113.0	-0.62
1901.2	2360.9	112.7	112.5	-0.18
1897.5	2357.2	111.3	111.2	-0.09

FIGURE 22. TYPICAL VAPOR PRESSURE HYSTERESIS LOOP AT 1300°F
TEMPERATURE, °F

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FIGURE 23. LINEAR PLOT OF VAPOR PRESSURE OF POTASSIUM

The standard error of estimate on the pressure was found to be 0.65%. The normal boiling temperature calculated from the above equation is 1398.1°F. Boiling points determined by AGN and four other investigators are listed below:

COMPARISON OF NORMAL BOILING POINT OF POTASSIUM

<u>Source of Data</u>	<u>Boiling Point, °F</u>
AGN	1398.1
Bonilla, Columbia University (Ref. 7)	1388.95
NRL (Equation 1, Ref. 3) C. Ewing	1393.7
NRL (Equation 2, Ref. 3) C. Ewing	1394.1
BMI (Ref. 5) L. Walling	1402.4
Weatherford (Ref. 6)	1395

The vapor pressure curve, plotted using the equation on page 51 is compared with the curves of Bonilla (Ref. 7), Ewing (Ref. 3), Walling (Ref. 5) and Weatherford (Ref. 6) in Figure 24. It is seen that good agreement exists. In comparing the results of other investigators with those of AGN, it was found that at 1000°F, Bonilla's equation gave a pressure 9% higher, Ewing's (Equation 1) 0.15% lower, Walling's 5.6% lower, and Weatherford's 0.46% lower; at 1900°F, Bonilla's result was 1.14% higher, Ewing's 0.65% higher, Walling's 0.38% higher and Weatherford's 1.88% lower.

It is interesting to note that, although Ewing's results for the vapor pressure deviate only slightly from AGN's, the slopes of the curves, $\frac{dP}{dT}$ calculated from the vapor pressure equations are 9.7 and 13.3% higher for Ewing's curve at 1000° and 1900°F, respectively.

Calculated values, using the regression equations, are presented in Table 5.

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Table 5

VAPOR PRESSURE AND LATENT HEAT OF VAPORIZATION OF POTASSIUM, AS
COMPUTED FROM THE REGRESSION EQUATIONS

ENGLISH SYSTEM				SYSTÈME INTERNATIONAL		
Temperature		Pressure	Latent Heat	Temperature	Pressure	Latent Heat
[°] F	[°] R	psia	Btu/lb	[°] K	Atm. abs.	abs. joule/ g mole
900	1359.7	0.4438	854.6	760	0.03270	77640
925	1384.7	0.5618	852.0	780	0.04560	77300
950	1409.7	0.7052	849.4	800	0.06255	76960
975	1434.7	0.8781	846.8	820	0.08449	76620
1000	1459.7	1.085	844.1	840	0.1125	76270
1025	1484.7	1.332	841.5	860	0.1478	75930
1050	1509.7	1.623	838.9	880	0.1918	75590
1075	1534.7	1.966	836.3	900	0.2460	75250
1100	1559.7	2.367	833.7	920	0.3122	74910
1125	1584.7	2.832	831.1	940	0.3921	74570
1150	1609.7	3.370	828.5	960	0.4879	74220
1175	1634.7	3.989	825.9	980	0.6016	73880
1200	1659.7	4.697	823.3	1000	0.7357	73540
1225	1684.7	5.505	820.7	1020	0.8926	73200
1250	1709.7	6.422	818.0	1032.1	1.000	72990
1275	1734.7	7.458	815.4	1040	1.075	72860
1300	1759.7	8.625	812.8	1060	1.285	72510
1325	1784.7	9.934	810.2	1080	1.527	72170
1350	1809.7	11.40	807.6	1100	1.803	71830
1375	1834.7	13.03	805.0	1120	2.116	71490
1398.1	1857.8	14.696	802.6	1140	2.469	71150
1400	1859.7	14.84	802.4	1160	2.866	70810
1425	1884.7	16.84	799.8	1180	3.310	70460
1450	1909.7	19.05	797.2	1200	3.805	70120
1475	1934.7	21.48	794.6	1220	4.353	69780
1500	1959.7	24.14	791.9	1240	4.960	69440
1525	1984.7	27.06	789.3	1260	5.627	69100
1550	2009.7	30.24	786.7	1280	6.358	68750
1575	2034.7	33.71	784.1	1300	7.158	68410
1600	2059.7	37.47	781.5	1320	8.030	68070
1625	2084.7	41.55	778.9	1340	8.977	67730
1650	2109.7	45.96	776.3	1360	10.00	67390
1675	2134.7	50.72	773.7	1380	11.11	67050
1700	2159.7	55.85	771.1			
1725	2184.7	61.35	768.5			
1750	2209.7	67.26	765.8			
1775	2234.7	73.58	763.2			
1800	2259.7	80.34	760.6			
1825	2284.7	87.55	758.0			
1850	2309.7	95.23	755.4			
1875	2334.7	103.4	752.8			
1900	2359.7	112.1	750.2			
1925	2384.7	121.3	747.6			
1950	2409.7	131.0	745.0			
1975	2434.7	141.3	742.4			
2000	2459.7	152.1	739.7			

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VI. CONCLUSION AND EVALUATION

The work reported here represents a substantial advance in the knowledge of thermophysical properties of potassium, particularly in the determination of the latent heat of vaporization. The method used (i.e., double measurements for eliminating the heat losses in the latent heat results) has proven to be sound and capable of yielding accurate results provided certain precautions are observed. From the knowledge gained during testing and operation of the apparatus, it appears that the accuracy of this determination could be further improved by slight modifications of the apparatus.

The results demonstrate the limitations of the calculational methods, as is evident from the relatively large divergence of results obtained by the use of almost identical vapor pressure data in conjunction with the Clapeyron equation and of different methods for calculating the molecular weight and specific volume of the vapor along the saturation line. These discrepancies are undoubtedly due, in part, to the fact that although the vapor pressure data obtained by various investigators was in close agreement (0.1 to 0.6% from 1000 to 1900°F), the slopes of the curves, which are used in the Clapeyron equation, vary substantially (9.7% to 13%), especially at the higher temperatures.

The vapor pressure determination obtained in the same apparatus shows generally good agreement with the results of other investigators and thus gives added confidence in these measurements.

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REFERENCES

1. The Determination of the Latent Heat of Vaporization, Vapor Pressure, Enthalpy, Specific Heat, and Density of Liquid Rubidium and Cesium up to 1800°F, Aerojet-General Nucleonics Report AGN-8090, January 1964.
2. J. K. Roberts and A. R. Miller, Heat and Thermodynamics, 5th ed., New York, Interscience Publishers, Inc., 1960
3. C. T. Ewing, et al., High Temperature Properties of Sodium and Potassium, Twelfth Progress Report for Period 1 July to 30 September 1963, NRL Report 6094
4. J. P. Stone, et al., High Temperature Properties of Sodium, Potassium, and Cesium, Thirteenth Progress Report, NRL Report 6213
5. J. F. Walling, et al., The Vapor Pressure and Heat of Vaporization of Potassium from 480 to 1150°C, Report BATT-4673-T3, Battelle Memorial Institute Report to NASA, April 30, 1963
6. W. D. Weatherford, Jr., et al., Properties of Inorganic Energy-Conversion and Heat-Transfer Fluids for Space Applications, Southwest Research Institute, WADD-TR-61-96, 1961
7. C. F. Bonilla, et al., Vapor Pressure of Alkali Metals, III. Rubidium, Cesium, and Sodium-Potassium Alloy (NaK) up to 100 Pounds per Square Inch, Proceedings of 1962 High-Temperature Liquid-Metals Heat Transfer Technology Meeting, Brookhaven National Laboratory, BNL-756 (C-35)

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