Navy Department - Office of Naval Research

NAVAL RESEARCH LABORATORY
Washington, D. C.

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Chemistry Division - Physical & Inorganic Section

30 September 1946

QUARTERLY PROGRESS REPORT ON THE MEASUREMENT OF THE PHYSICAL AND CHEMICAL PROPERTIES OF THE SODIUM-POTASSIUM ALLOY. No. 1

by
C. T. Ewing, R. R. Miller

FR-3010

\- Report P-3010 -

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NRL Problem P-149

ABSTRACT

The alloys of Potassium-Sodium are under study as a heat transfer medium. Physical and chemical properties, along with measurements of heat transfer coefficients on an engineering scale, are being studied. This report is concerned more with the description of apparatus and methods than with measured results; however, preliminary measurements on density and viscosity are included.

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INTRODUCTION

Authorization

The study on the physical and chemical properties of Potassium Sodium Alloy was authorized by BuShips Project 990/46.

Statement of Problem

1. The program of study presented and discussed with personnel of the Bureau has been followed with respect to the phases of problem being investigated by the Laboratory and contracted to the Mine Safety Appliance Company See App. A). This report combines the results obtained by the two groups along with other data pertinent to the program.

2. The Laboratory has designed and constructed apparatus to measure some of the physical properties of alloys of potassium and sodium. The properties to be measured immediately were viscosity, thermal conductivity, specific heat, and the determination of the liquid solid phase diagram. Other properties such as densities, heat transfer coefficients and a study of the handling of the alloy are being conducted under a Laboratory contract with the Mine Safety Appliances Company of Pittsburgh, Pa. Other properties and characteristics which appear to deserve study will be determined to the extent justified by the project. Certain of the unseen difficulties are being solved. They are problems inherent in purification, transferring and maintaining the alloy in suitably pure condition. The careful purification of blanketing gases and transferring them in glass free from rubber tubing has been necessary to maintain purity of the alloys. The purification of the metals and alloys has been satisfactory for the desired measurements only when the alloys were freshly distilled or stored with extreme care. Distillations so far have been made in glass; however, a distillation unit of metal is nearing completion.

3. While results of work on the program is not as far advanced as was anticipated for this date, the status of the active measurements are reported in the following paragraphs.

PHYSICAL PROPERTY MEASUREMENTS

Alloy Samples

4. Seven (7) samples of alloy have been chosen as standards for the measurement of all physical properties and 200 pounds of each has been made up by and stored at the Mine Safety Appliances Company plant. The samples were chosen with respect to the published phase diagram such that freezing points of the samples would essentially define the phase diagram itself. The composition of the samples is given below with their corresponding numbers.

Sample	Wt. % K	Wt. % Na
1	100	0
2	93	7
3	80	20
4	66	34
5	44	56
6	33	67
7	0	100

Viscosity

5. Preliminary measurements on viscosity were reported in NRL Report P-2931, 14 August 1946 (App. B). The measurements reported were for 43.3% potassium from 65.5°C to 600°C. The viscosity in centipoises was 0.514 at 65.5° falling with temperatures at a decreasing rate to 0.256 at 600° with a slight rise indicated between 600 and 700°C. These values were reported with a probable error of ± 10%. The accuracy cannot be claimed as being any better at this date, but the indicated rise in the viscosity above 600°C has not been substantiated.

6. The metal apparatus in use was described in the above report. Measurement of viscosity of the 65% potassium alloy is underway. In addition to the apparatus, a quartz Ostwald viscometer has been constructed and is ready for calibration. The distillation in glass indicates that pure alloy will present a suitable meniscus in a transparent viscometer. It will be usuable on a few hundred degrees, if not over the full range.

Density

7. The density of the alloys were measured by MSA by the method of weighing a plumb-bob in the liquid alloys. This method was previously used by Rinck for the determination of density at elevated temperatures on sodium and potassium. The densities were measured over a range from room temperature to 700°C with constant and what appeared to be satisfactory values obtained only at the higher temperature range. From 350 to 450°C, a point, depending on the composition, developed below which reproducible values could not be obtained with the plumb-bob method. For lower temperatures, a dilatometer was used which gave reproducible values. However, in some cases the density against temperature curves for the two methods do not have exactly the same slope. For the 50-50 mixture, the density varied from 0.876 gm/cc at 100°C to 0.738 gm/cc at 700°C, while sodium varied from approximately 0.94 to approximately 0.775 of the same temperature range. The density of potassium over the same temperature range varied from appoximately 0.82 to 0.67. The report on density from MSA is enclosed as App. C.

Specific Heat

8. A metal Dewar flask apparatus has been constructed of mild iron and stainless steel. The containing flask is of mild iron with a nickel plate on the exterior and neck of thin

stainless steel tube. The inside container is threaded into the housing flask which has a nickel plated interior. The vacuum space is maintained at low pressure by continual pumping. The heater, stirrer and thermocouple are placed in the flask through thin stainless tubes which are closely baffled through the neck section to reduce convection from the metal surface.

9. Preliminary measurements have indicated that the specific heat of the alloy can be calculated directly from the specific heat of the elements and the concentrations. The specific heat against temperature curves appears to follow a gradually falling curve for the 43.3% K alloy indicating no sharp change in the molecular state of the alloy.

10. This unit has shown satisfactory results on preliminary operation and should furnish data on specific heat in a relatively short time.

Thermal Conductivity

11. An apparatus has been designed and constructed which in plan is similar to that used by Professor Bidwell of Lehigh University, for the study of heat conduction in molten metals. It is essentially a vertical cylinderical container with a heater at the top of the sample and a heat well at the bottom. The whole unit is raised to a constant temperature and then with added heat in the top heater, an equilibrium is established, and from the measure of the gradients in the sample and insulation, the heat conductivity of the sample can be calculated. This method appears to be more satisfactory for the alloys than others which have been reviewed and discussed, and is the opinion of Professor Bidwell that the apparatus will give the desired accuracy on measurements. Measurements will be made in the second quarter. It is planned to have Professor Bidwell employed as a consultant on this phase of the problem. Measurements were made on thermal conductivity of 51.7% sodium, 48.3% potassium alloy for the Argonne Laboratory by the Battelle Memorial Institute. Measured results given in watts cm^{-2} cm $°C^{-1}$ were 0.258 at 100°C to 0.284 at 500°C. Copy of the report is enclosed as App. D.

Liquid-Solid Phase Diagram

12. An impressive amount of work has been done on this phase diagram and the later values appear to be in good accord. Thus it may be necessary only to check a few compositions of well purified metals in order to arrive at a satisfactory conclusion concerning the solid-liquid diagram, Apparatus has been set-up in which the freezing point of the liquid will be determined. In all probability this phase of the problem can be satisfactorily cleared up in a period of a month or two.

Vapor-Liquid Phase

13. During the work at this laboratory on the distillation of potassium for the production of oxide, the vapor liquid equi-

librium for the alloys was of interest. The problem was suggested to NDRC at the time, and Dr. G. B. Kistiakowsky as Chief Investigator studied the vapor liquid phase and published a report of the measured values. A copy of this report is enclosed as App. E.

Temperatures at which KNa alloys "wet" metals.

14. A nickel crucible which could be maintained at elevated temperatures by an integral heater was enclosed in a glass flask where the atmosphere could be controlled. Samples of metals could be raised and lowered into the alloy in the crucible by means of a glass shaft which rotated through a ground glass joint and extended over the crucible. Samples were connected to the shaft by thin wire which was wound on or off the shaft as the sample was raised or lowered. The meniscus between the alloy and the metal was observed during the lowering of the sample to determine at what temperature the metal surface was "wet" by the alloy. A depressed meniscus was recorded as not "wetting" while a flat or raised meniscus at the metal was recorded as "wetting". The strip metal samples were allowed to submerge in the KNa alloy between dipping tests to maintain them at the temperature of the liquid alloy. The results recorded for metals and alloys are given below.

Summary of all conclusions on "wetting" tests

Metal	30%K(by wt)	45%K	65%K
Soft Iron	270°C	(a) 275°C (b) 330° 295°	(c) 310°C
Stainless Steel	260°	(a) 260° (b) 370° 290	(c) 320°
Nichrome	(b)340° 320°	(a) 270° (a) 275° 330°	340°
Nickel	(b)350° 345°	(a) 320° 320°	350°

(a) These tests were the first ones run, when mineral oil was used and possibly contaminated the metal sample.

(b) It was believed that the thermocouple was slightly in error during these tests.

(c) These two temperatures were not actually reached; but were approached closely enough to give a satisfactory prediction.

Heat Transfer Coefficient

15. A fluid film on a solid is the greatest cause of resistance to heat flow from a moving fluid to the solid. A measurement of the resistance of heat flow in a system can be made by a complete measurement of the temperatures in a vicinity of heat transfer boundaries or it may be determined indirectly by calculations. The equation for the calculations has been derived by MSA and is given in App. F. The resistance to heat flow of an individual film is dependent on two dimensionless groups; the Reynolds Number and the Prandtl Number. The effects of the Reynolds Number are well known, but the effects are unknown for very low Prandtl Numbers. The Prandtl numbers for KNa alloy are much lower than those for fluids normally used for heat transfer medium. The method described in App. F. is designed to isolate the Prandtl number factor.

CONCLUSION

A study on the measurements of the properties is being continued.

Program on the Study of Sodium Potassium Alloy
25 June 1946

This program is planned to be carried out by Naval Research Laboratory with some of the engineering features and measurements subcontracted to Mine Safety Appliance Company at Pittsburgh, Pa.

Physical Properties

A. Solid-liquid phase diagram. - NRL: Apparatus is being assembled to determine freezing points on the alloys on hand and compositions to be made here. This appears necessary to check on the composition of samples since freezing points can be readily taken. - MSA: May also collect some data.

B. Liquid-Vapor phase diagram (no work planned immediately)

C. Specific Heat apparatus being constructed. No MSA work planned.

D. Viscosity - NRL: Apparatus for measurements in the planning stage.

E. Thermal Conductivity - NRL: Drawing of an apparatus is under way. The liquid thermal conductance apparatus in common use must be redesigned for alloy.

F. Density - MSA: MSA is making density measurements on the density of the alloys by the method of Rinck-i.e., weighing a metal plumb-bob in the alloy over a range of temperatures.

NRL has planned to make some measurements on density in glass over the lower part of the temperature range. MSA has requested one or two of the glass bulbs we planned on using. They will no doubt make measurements in them over a similar range.

G. Surface Tension - NRL: No immediate plans.

H. Electrical Conductivity - NRL: Empericals relation have been presented between the electrical and thermal conductivity. They will be examined and measurements made at this time, only if they appear to be of value in perfecting heat conductivity data.

I. Magnetic Susceptibility - NRL or MSA (No work planned immediately)

Chemical Properties

A. General Reactions

(1) With H_2O NRL: Now under way; MSA: In small heat

APPENDIX A

interchanger type models.

(2) Reaction with halogenated compounds NRL and organics (gasket materials) MSA

Deoxidation and decarbonization of metals and alloys. NRL and MSA and Chicago. - Methods not yet planned at NRL or MSA.

Argonne Laboratory at Chicago has some data showing carbon is removed from steel by alloys, and that stainless steel shows corrosion probably due to the oxygen layer.

Organic reaction with alloy NRL with no definite plans at present. Would be of interest on problem of gaskets for system if necessary.

Methods of Handling, Storing, Shipping and Transfering.- MSA. NRL will furnish what data is available from the work here.

Contaminants of Potassium Sodium Alloy -- Oxides Nitrides, Sulfides, carbides, hydrides, carlonyl, hydroxides.

NRL plans are for this work to be delayed to a little later date or contracted out to a University.

Experimental heat transfer unit - MSA,

A. Construction
B. Operation to verify research information (1), (2), (3) and (4):

(1) Determine heat transfer coefficients

(a) Stationary
(b) Low Reynolds numbers
(c) High Reynolds numbers

(2) Tube bundle
(3) Pumps
(4) Valves and fittings
(5) Life at 1200°F and at 1500°F

Corrosion and Erosion:

A. Corrosion
B. Erosion
C. Methods to minimize (A) and (B)

Continue on work in Chicago

APPENDIX A

Navy Department - Office of Research and Inventions

NAVAL RESEARCH LABORATORY
Washington, D.C.

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CHEMISTRY DIVISION - PHYSICAL AND INORGANIC SECTION

14 August 1946

PRELIMINARY REPORT ON VISCOSITY DETERMINATIONS ON A POTASSIUM-SODIUM ALLOY

By R. Ruskin, C.T. Ewing, and
R.R. Miller

- Report P-2931 -

* * *

Approved by:

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ABSTRACT

An Ostwald type viscometer has been used to measure values of viscosity on a potassium-sodium alloy which was 43.4% potassium by weight. Viscosity of the alloy at 72°C was 1.267 relative to water at the same temperature. The values at higher temperatures were calculated from the volumes of alloy flowing per second at those temperatures, and the constant determined for the apparatus at 72°C.

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INTRODUCTION

A. Authorization

1. This project was authorized by BuShips Project Order No. 990/46 dated June 24, 1946.

B. Statement of Problem

2. The project covers the library and laboratory research necessary to arrive at satisfactory values for the physical properties of Sodium and Potassium alloys. The viscosity has been determined, on an alloy, for 43.4% K by weight. These values are the basis of this preliminary report.

C. Known Facts Bearing on the Problem

3. Absolute viscosities may be calculated from measurements made in a number of different types of apparatus. The type of apparatus to be used is determined to a great extent by the characteristics of the liquids under study. For the alloys which are particularly reactive with moisture and oxygen, completely closed viscometers are necessary. A preferred method of getting absolute viscosity; that is the falling-ball method with calculations based on Stoke's Law would be somewhat difficult at the high temperatures in an opaque viscometer. The more readily used method is a variation of the Ostwalt viscometer where the amount of alloy flowing in the capillary tube can be determined against time. At the same temperatures and under the same pressure head, measurements made on two fluids will give a viscosity measurement of one relative to the other. Water is customarily used as a reference fluid and then from the absolute viscosity of water, the absolute viscosity of the alloy at the same temperature can be calculated. This is the procedure which has been followed in the measurements tabulated at the end of the report. The relative viscosity has been calculated from the relation

$$\frac{n_1}{n_2} = \frac{d_1 t_1}{d_2 t_2}$$

where n_1 and n_2 are the viscosities of alloy and water respectively, d_1 and d_2 the densities, t_1 and t_2 the time required for equal volume of the fluids to flow. From the relative viscosity multiplied by the absolute viscosity of water at the same temperature, the absolute viscosity of the metals is determined at that temperature. This value of the viscosity with the relation $n = \frac{k}{v}$ gives a value for the constant k for the apparatus. n was the viscosity of the alloy and v the volume of alloy flowing in unit time. In this preliminary study the value of k was considered constant for the temperature range. This constant, with the volumes determined at temperature intervals, was used to calculate the absolute viscosity over the temperature range given.

METHODS

A. Apparatus

4. An apparatus consisting of two horizontal tanks connected by a small capillary tube was constructed so that an upper tank (#1 on plate 1) and the coil of the capillary tube were enclosed in an electrically-heated furnace. The other tank was placed on the platform of the dial scales which gave continuous readings of the weight of that container. The bottom or #2 container was also connected to #1 container by 1/4" tubes through which the alloy could be forced from #2 to #1 container with the aid of moderate gas pressure. The 1/4 tubing was sealed off by a cold trap at the point shown as #3 on plate #1.

5. The capillary and return tubes were of such length and flexibility that weights of the order of 2 grams would cause a reflection on the dial scales. The dimensions of the capillary tube were 0.238 cm. inside diameter and 629 cm. in length.

6. The gas used in the viscosity studies was helium which had been purified by passing it over reduced copper at 450°C and then through reactivated charcoal at liquid nitrogen temperature.

B. Operation

7. From Plate 1, the operation of the unit was carried out as follows: The alloy was run through the valve #4 into container #2 until approximately 900 grams had entered the container. Valve #4 was then closed and helium pressure put on the #2 container through tube #5 which forced some gas back through the capillary tube, but at the same time exerted sufficient pressure on the alloy to cause it to flow through the cold trap (#4) into container #1. When #2 was nearly empty, as indicated by the scale reading, the pressure was released and the trap frozen in liquid nitrogen to form a seal against the return of the alloy by this route. The whole container and capillary tube were brought to desirable temperature and, with a pressure head adjusted to the desired value, the weight of the alloy which flowed through the capillary into container #2 was determined against time. The trap was then thawed and the operation repeated at various pressures and temperatures as desired.

RESULTS

8. Measurements were made on water at 72°C with the pressure head at 6.65 cm. of Hg. This gave 1.374 grams (1.407 cc) of water per

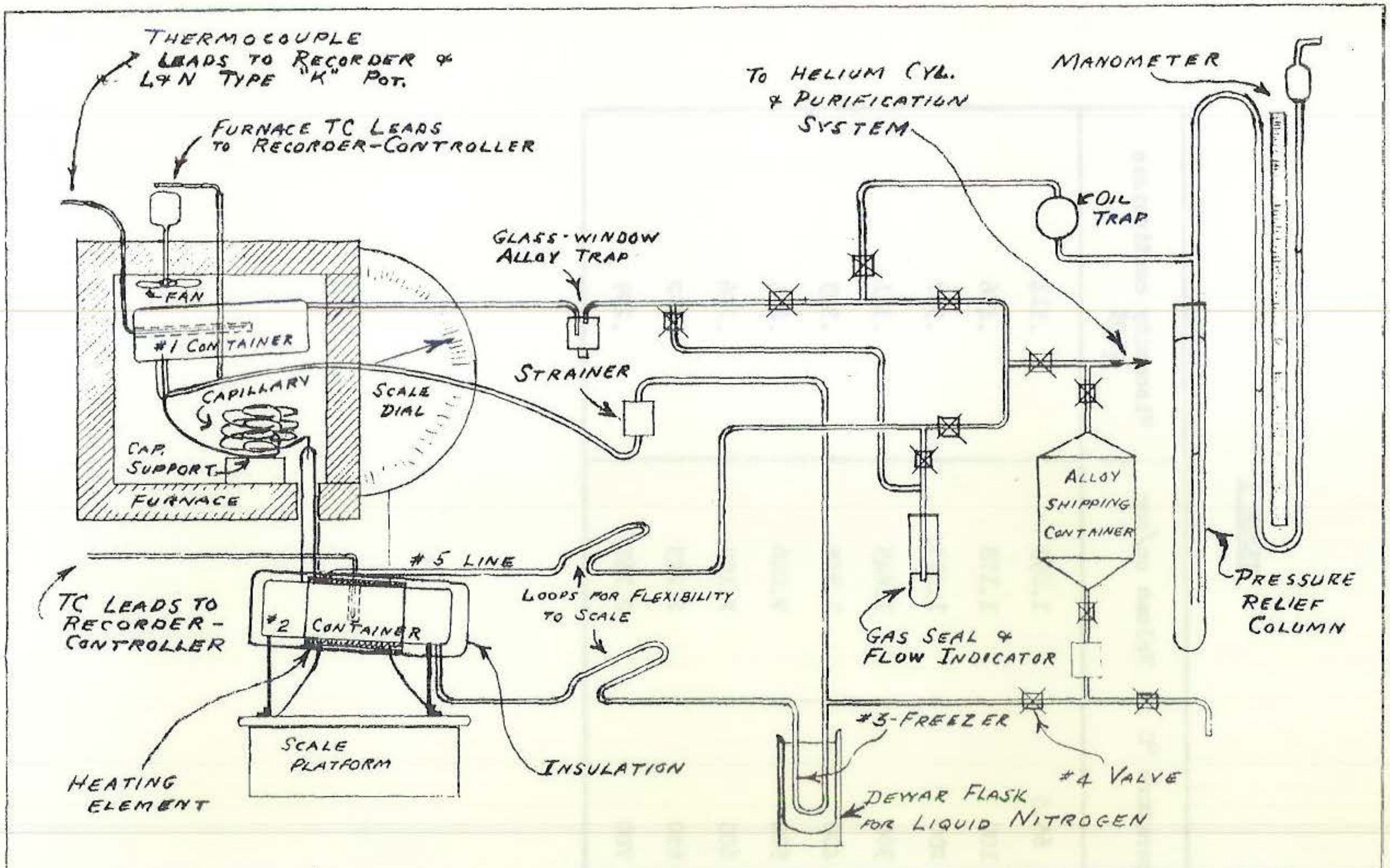
second. Measurements were then made on the alloy over the temperature range. At the same pressure head and from a curve of grams of alloy per second against temperature, 1.110 grams of alloy flowed per second. This gave 1.267 as a relative viscosity of the alloy at 72°C. This value multiplied by 0.3952, the absolute viscosity of water, gives 0.501 as the absolute viscosity of the alloy at 72°C. Then with the constant determined as mentioned in paragraph 3, the absolute viscosity was caluclated at several temperatures over the range from 65.5°C to 700°C. The value for k was calculated as 0.5611 and the results on the viscosity are given in Table 1 and plotted on Plate 2. Along with this curve, values for pure sodium and potassium are given. These values were those published by Y.S. Chiong, Proc. Roy. Soc. London A157, 264(1936).

TABLE 1

Temperature °C	Volume cc/sec	Viscosity centipoises ±10%
65.5	1.093	.514
100	1.178	.476
200	1.415	.397
300	1.645	.341
400	1.855	.303
500	2.046	.274
600	2.193	.256
650	2.223	.252
700	2.167	.259

P-2931

PLATE-1



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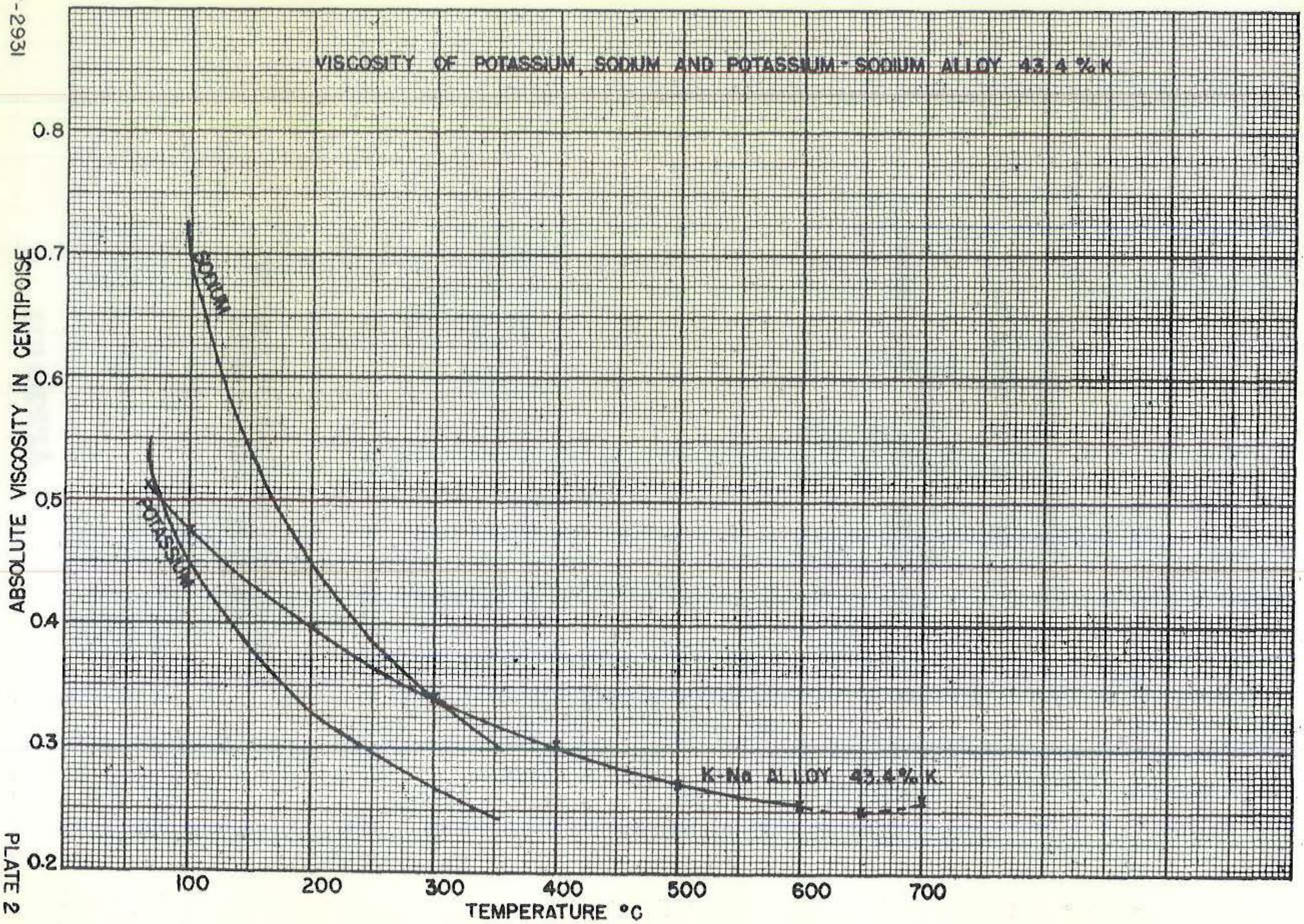

PLATE 2

PRELIMINARY REPORT #1

DENSITY OF THE SYSTEM K-NA

by
C. B. Jackson
G. A. Wieczorek and A. Van Andel

MINE SAFETY APPLIANCES COMPANY
Callery, Pennsylvania

October 1, 1946

APPENDIX C

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ABSTRACT

Measurements of the density of seven standard samples of K-Na alloys of various compositions were made and two density vs temperature °C curves are shown for each of the seven samples. Measurements of density from the melting point up to about 200°C were made using glass dilatometers, and from 300 to 700°C the density values were calculated from a measurement of the buoyancy of a copper plunger suspended in the various alloys. A series of curves show the variation of density with composition of alloy at 50° intervals from 0°C to 250°C and at 100° intervals from 300°C to 700°C. The 250°C curve data was extrapolated from the dilatometer data because it seemed to fit the density curves for each master sample better than extrapolated buoyancy data.

INTRODUCTION

A. Authorization

This project was carried out under Task Order I of Contract N6ori-146 dated 26 June 1946.

B. Statement of Problem

Contract calls for Laboratory Research necessary to arrive at satisfactory values for the physical properties of sodium and potassium alloys. The density has been determined on 7 standard samples of alloy. These values along with curves are supplied in this report. Composition-density isotherms permit the estimation of this density of any NaK alloy from melting point to 700°C with ± 0.5% accuracy.

C. Known Facts Bearing on the Problem

Two common methods of measuring the density of a homogeneous liquid are: (a) the measurement of the buoyant effect of liquid alloy on a plunger suspended in the alloy at different temperatures. (b) The measurement of the volume of a mass of the liquid in a dilatometer as it changes with temperature. This density is calculated from the equation $d = \frac{m}{v}$. Both methods were used at Mine Safety Appliances Company, method (a) at high temperature and method (b) at low temperature.

Two main difficulties to be encountered are the procurement of a good uniform sample that is representative of the master sample in the standard sample pot, and the prevention of any exposure whatsoever of the sample to oxygen or moisture during sampling and weighing or during the experiment while readings are being taken. It has already been demonstrated by Rinck that below 300 or 400°C it is very difficult to determine density by measuring buoyancy because of surface tension and other phenomena that limit sensitivity of the balance and prevent sufficient accuracy.

METHODS

A. Apparatus - High Temperature Measurements

An apparatus as shown in Plate 1 consisting of a nickel tube 15" long 1" inside diameter which contained an alloy sample approximately 5" deep was enclosed in an electrically heated, well-insulated furnace. The tube was closed at the top by a plug through which a brass tube was inserted (equipped with a side arm for nitrogen flow) and which permitted the passage of a plunger suspended by a nickel wire attached to a glass thread. The balance was placed on a table over the furnace, insulated against heat on the bottom. The suspension was made from the left hand pan down through a tiny hole drilled through pan, balance, and table. Power input to the furnace was regulated by a large rheostat. The temperatures were measured

by [illegible]
the bottom of the [illegible] tube, and the other at the side of the tube at approximately the level of the alloy. The two temperatures were kept within 2°C in operation, and both were calibrated to read correctly to within .25°C. Correct freezing points were obtained with these thermocouples on known samples, which indicates that lag in temperature was negligible. The nitrogen was purified by a hot copper furnace at about 400°C, a $CaCl_2$ tower and a P_2O_5 tower. At end of experiments the alloy was silvery on the surface after 10 to 15 hours.

B. Operation - High Temperature Measurements

The plunger was weighed in air to .0001 g. and its volume calculated by weighing while suspended in distilled water. Using density of water and copper from the handbook and coefficient of expansion of copper by Haring & Davy (Phys. Soc. 2-47 P 337 (1935) a value for the volume of the plunger at any temperature up to 700°C could be calculated. This value equals the volume of the alloy displaced. The weight of this displaced alloy was taken as weight of plunger suspended in air minus weight of plunger suspended in alloy. Corrections to weight in vacuum were considered negligible, since brass weights were used.

C. Apparatus - Low Temperature Measurements

Glass dilatometers used by Mine Safety Appliances Company were two pyrex dilatometers calibrated by Naval Research Laboratory and checked by Mine Safety Appliances Company. See Plate 2. They were cleaned carefully and weighed after each filling. No appreciable change in calibration took place since great care was exercised in preventing damage to the glass during testing. Dilatometers were clamped in a mineral oil bath heated by brass immersion heater with variac regulator and stirred constantly. Temperature was measured with thermometer calibrated by U. S. Bureau of Standards and accurate to 0.1°C. The bath varied about 0.1°C at points near the dilatometers. Readings were taken on heating only because the alloy wets the glass rather easily and prevents cooling and repetition of readings.

D. Operation - Low Temperature Measurements

Dilatometers were weighed in air suspended by a glass thread, and values were corrected to weighing in vacuo. They were flushed with nitrogen free from O_2 and H_2O. Alloy was introduced through a long capillary tube. Dilatometers were weighed again, the difference giving weight of alloy. Two samples of one alloy were run simultaneously and an analysis made for K content. The volumes of the dilatometers were corrected for thermal expansion using coefficient = 0.000025. Glass capillaries were used for alloys of low freezing point and copper capillaries were used for alloys of high freezing point.

At low temperatures duplicate runs were made on master samples 2, 3, 4, 5 and 6; one run was made on sample 1, and no runs were made on sample 7. It was found that the alloys richer in potassium generally wetted the glass dilatometers above 150°C rather easily with the slightest vibration and made it difficult to get readings. Results obtained on sample 3, the eutectic, were higher than would be expected if the density-composition curves were straight or nearly so, indicating that there may be a maximum in the curves in this range of composition. Results on samples 4 and 6 were lower than was expected and is believed to be due to occluded air bubbles in the dilatometer. Improved methods of filling the dilatometer and increasing the temperature range of available readings will provide abundant data for the next progress report, particularly on those of the master samples for which present data seems in any way unjustifiable. Probably the density-composition curves for 0 and 50°C should not be straight lines as shown on Plate 10.

At high temperatures it was found that alloys richer in potassium permitted more sensitivity in weighing the buoyancy of the plunger, and thus better density values were obtained below 400°C in the case of K or K-rich alloys. The data on pages 4 to 7 show the different runs as the temperature increased, and as it decreased for each run as long as the balance showed sensitivity.

In the table below, $_1$ is the coefficient of thermal expansion calculated from the straight line drawn from the dilatometer data at low temperatures, and $_2$ is that for the buoyancy data at higher temperatures. Density figures for the temperature range above that covered by the dilatometer data and below that covered by the buoyancy data are obtained from the extension of the straight lines for each set of data until they intersect.

Coefficient of Cubical Expansion of NaK Alloys

$V = V_o(1 + \ T)$

Std. Spl.	T° Range	$_1X10^4$	T° Range	$_2X10^4$	Analysis % K
1	M.P. to 380	3.149	380 to 700	3.542	98.8
2	M.P. to 330	3.204	330 to 700	3.258	91.7
3	M.P. to 330	3.289	330 to 700	3.219	78.6
4	M.P. to 220	2.968	220 to 700	3.199	65.9
5	M.P. to 300	3.436	300 to 700	3.133	43.4
6	M.P. to 300	3.051	400 to 700	3.144	29.4
7	Not run at low temp.		400 to 700	3.459	0.2

Density Data for Standard Sample #1

T°C	Density	T°C	Density
Dilatometer		Buoyancy	
125	.8130	493	.721
132	.8120	550	.709
139.2	.8102	694	.676
147	.8082	693	.676
160	.8048	573	.706
Buoyancy		544	.713
312	.769	525	.718
358	.757	495	.724
372	.751	482	.728
405	.743	461	.732
409	.741	444	.737
455	.732	398	.744
496	.721	388	.750

Density Data for Standard Sample #2

Dilatometer		Buoyancy	
85.5	.8294	340	.769
94.4	.8271	342	.767
101.0	.8255	341	.767
108.0	.8239	388	.756
115.5	.8219	399	.752
123.0	.8200	483	.733
131.0	.8180	506	.728
138.0	.8162	579	.713
144.0	.8138	581	.714
151.2	.8129	627	.704
156.0	.8116	671	.694
		689	.690
115.5	.8255	694	.689
123.0	.8234	644	.701
131.0	.8215	606	.709
138.0	.8197	565	.720
144.0	.8183	532	.726
151.2	.8164	484	.739
157.6	.8149	434	.745
165.2	.8130	428	.750
171.4	.8114	420	.751
178.5	.8097		
185.0	.8081		

Density Data for Standard Sample #3

T°C	Density Dilatometer
112.3	.8442
122.0	.8421
127.5	.8404
135.2	.8385
142.3	.8366
149.0	.8349
157.0	.8328
164.5	.8309
171.1	.8293
178.2	.8274
184.8	.8259
196.7	.8225
204.0	.8206
	Buoyancy
404	.768
476	.756
515	.747
537	.739
579	.732
614	.724
651	.716
658	.715
641	.717
593	.719

T°C	Density Buoyancy
462	.760
500	.750
535	.740
566	.734
595	.728
620	.721
644	.716
678	.709
690	.705
700	.702
700	.702
699	.703
685	.708
672	.711
642	.718
616	.725
557	.735
550	.737
463	.758
389	.775
371	.779

Density Data for Standard Sample #4

Dilatometer	
63.6	.8656
67.7	.8646
66.2	.8650
72.0	.8635
79.1	.8615
81.0	.8609
86.0	.8595
92.0	.8578
98.6	.8559
105.5	.8543
112.7	.8542
120.0	.8523
126.8	.8505
161.8	.8468
169.1	.8447
175.8	.8429
181.7	.8410
188.3	.8391

Buoyancy	
510	.760
577	.745
672	.721
633	.736
534	.758
395	.790
465	.768
499	.762
562	.750
607	.740
658	.728
709	.719
704	.719
634	.738
532	.763
528	.766
429	.781
416	.783

Density Data for Standard Sample #5

T°C	Density Dilatometer	T°C	Density Dilatometer
23.8	.9119	96.8	.8863
25.2	.9109	103.4	.8848
26.7	.9113	110.0	.8827
49.8	.9029	142.0	.8749
86.0	.8937	148.8	.8729
23.8	.9083	155.8	.8710
25.2	.9087	163.5	.8689
26.7	.9082	Buoyancy	
49.8	.9024	499	.7867
85.0	.8929	500	.787
110.3	.8816	566	.771
119.6	.8795	559	.771
127.2	.8775	635	.757
134.5	.8756	632	.756
142.0	.8735	699	.742
148.8	.8717	700	.742
155.8	.8698	582	.771
163.5	.8680	508	.788
172.0	.8658	447	.802
95.9	.8867	381	.813
		350	.820

Density Data for Standard Sample #6

Dilatometer		Buoyancy	
57.1	.9037	468	.820
61.0	.9026	466	.818
68.0	.9007	462	.819
73.0	.8992	512	.799
80.6	.8971	582	.785
87.7	.8950	585	.784
93.5	.8933	691	.760
		678	.764
141.2	.8909	634	.773
149.0	.8888	573	.788
156.8	.8868	514	.802
165.0	.8847	478	.811
172.3	.8829	435	.816
180.2	.8804		
188.0	.8783		
196.3	.8761		
202.5	.8745		
206.2	.8733		
212.0	.8717		

Density Data for Standard Sample #7

T°C	Density
	Buoyancy
96	.938 (Hackspill)
504	.838
540	.818
543	.817
595	.803
665	.786
712	.778
650	.792
601	.801
552	.811
503	.821

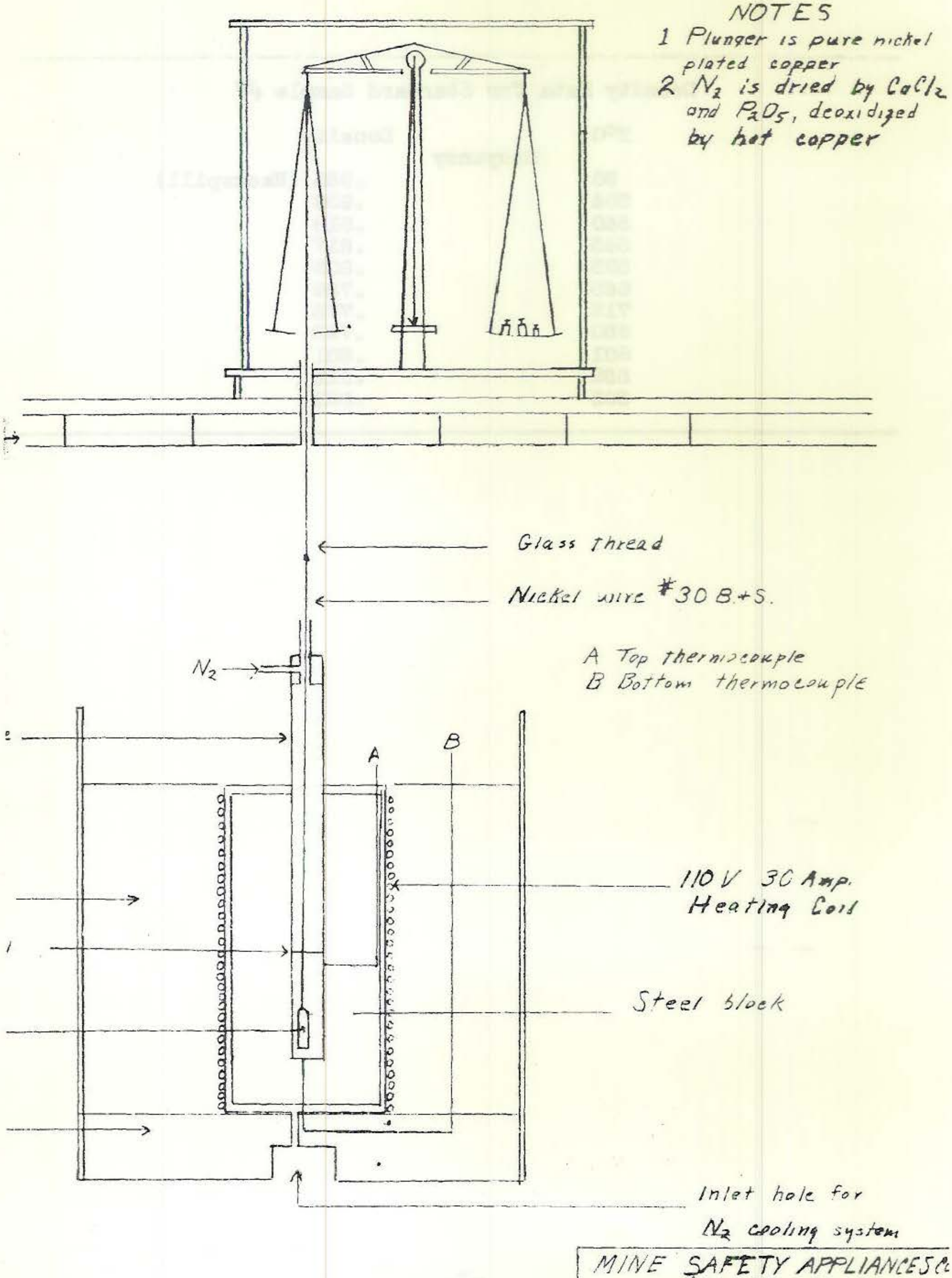


Plate 1

MINE SAFETY APPLIANCES Co.
CALLERY, PA.
K-NA DENSITY APPARATUS
10-2-46 R.T.

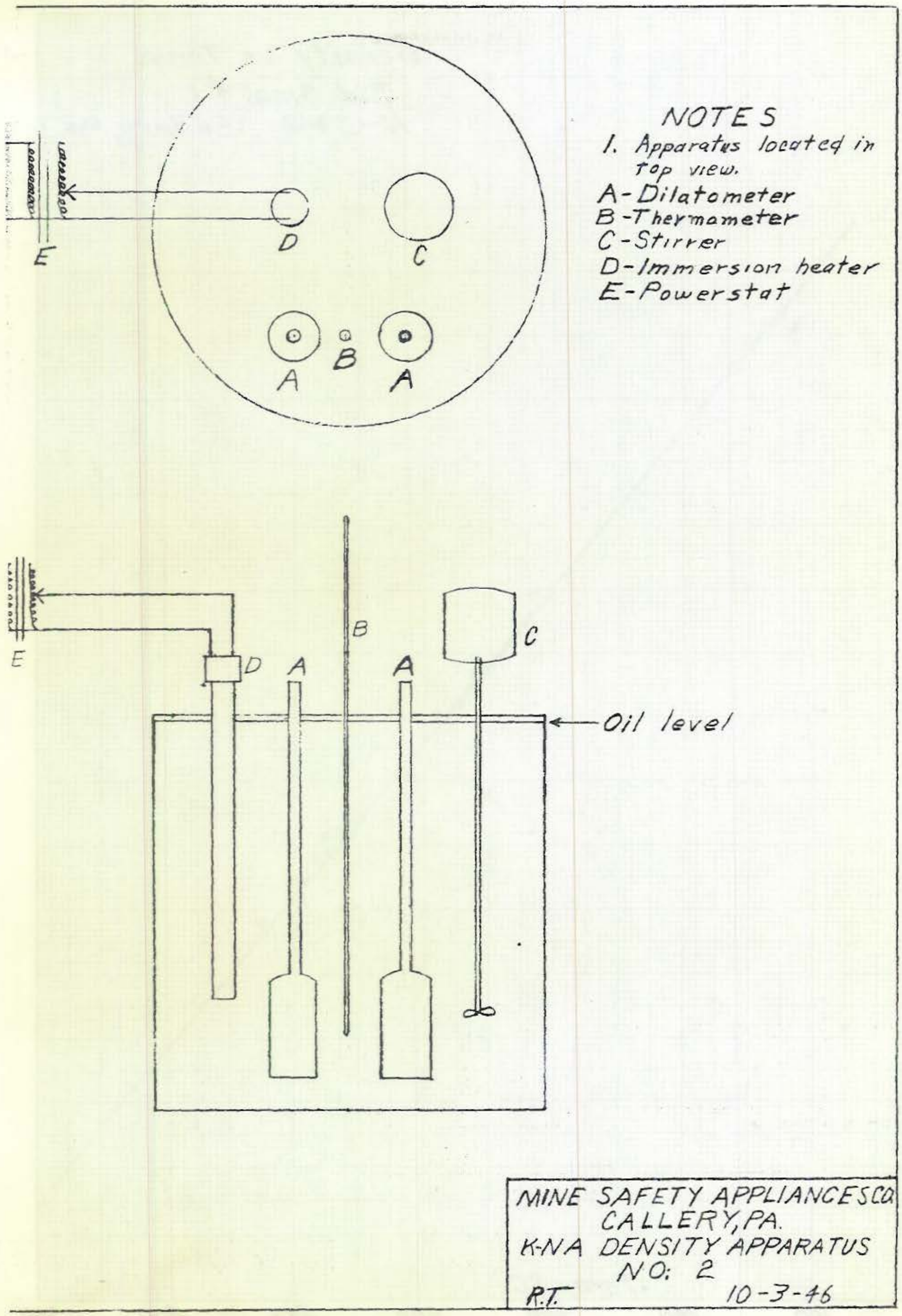
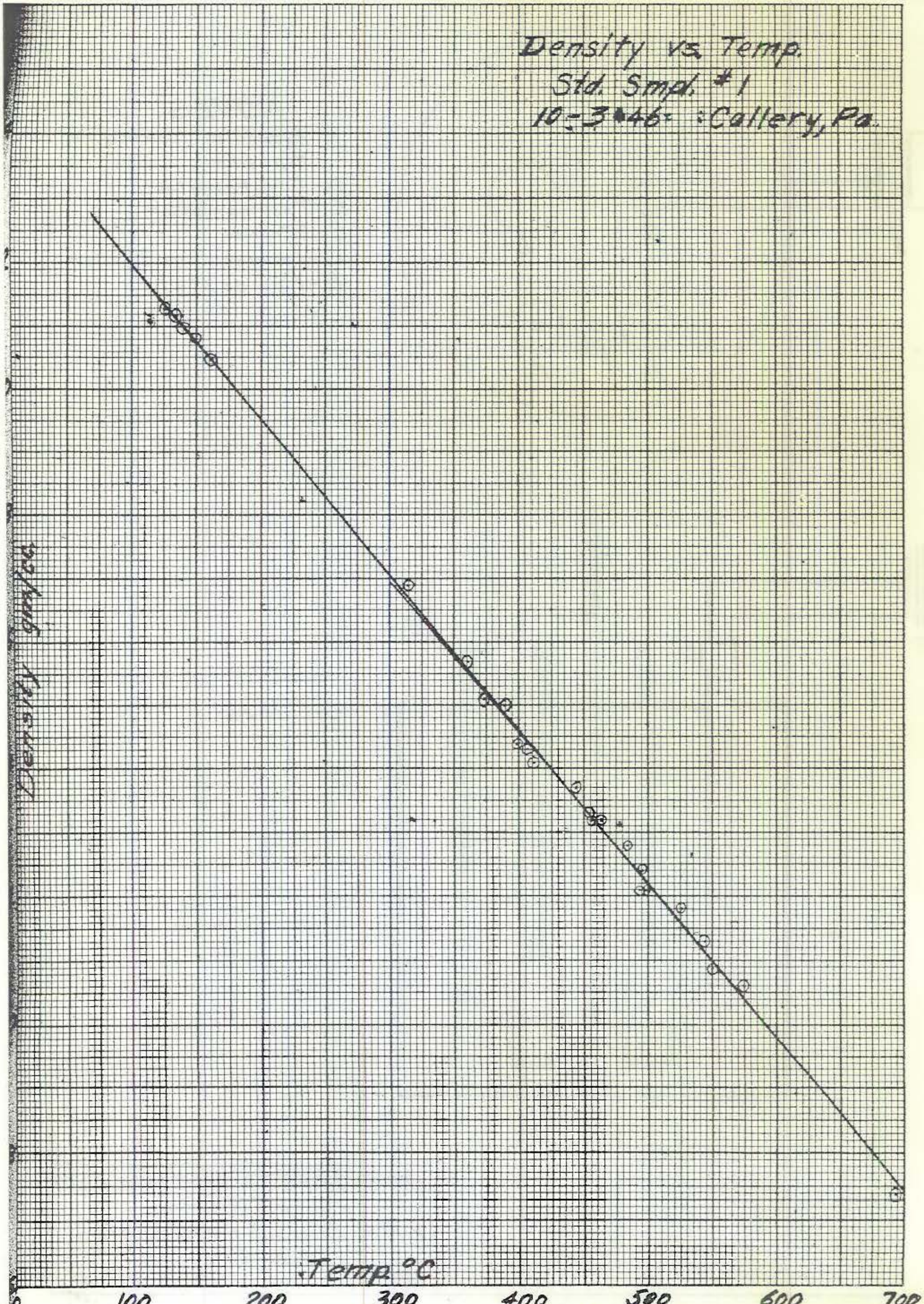
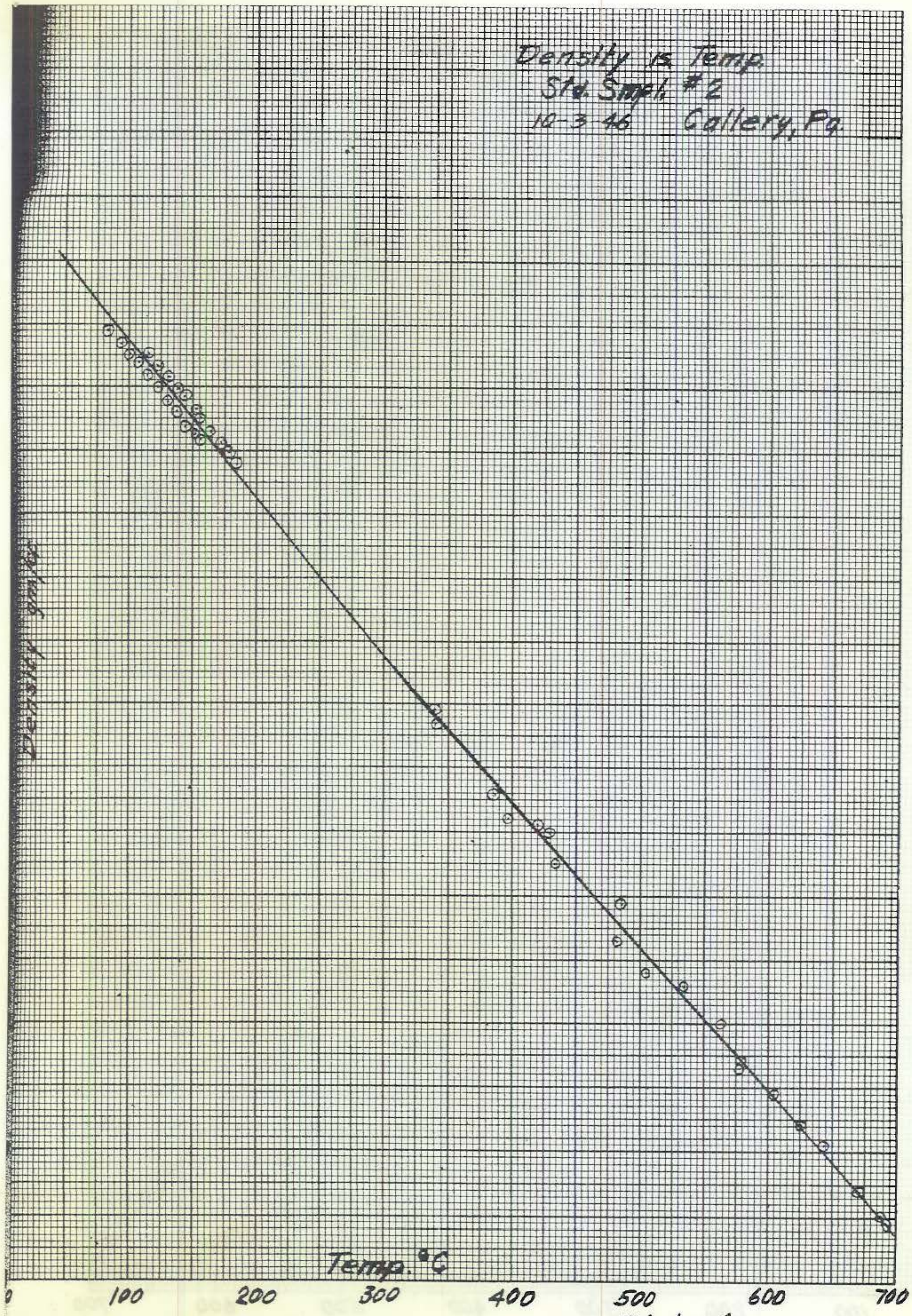

NOTES
1. Apparatus located in top view.
A-Dilatometer
B-Thermameter
C-Stirrer
D-Immersion heater
E-Powerstat
D
C
E
A
B
A
B
C
E
D
A
A
Oil level
MINE SAFETY APPLIANCES CO.
CALLERY, PA.
K-NA DENSITY APPARATUS
NO: 2
R.T.
10-3-46

Plate 2



Density vs. Temp.
Std. Smpl. #1
10-3-46 Callery, Pa.
Density
Temp. °C
0
100
200
300
400
500
600
700

Plate 3


Density vs. Temp.
Std. Smpl. #2
10-3-46 Callery, Pa.
Density gm/cc
Temp. °C
0
100
200
300
400
500
600
700
Plate 4

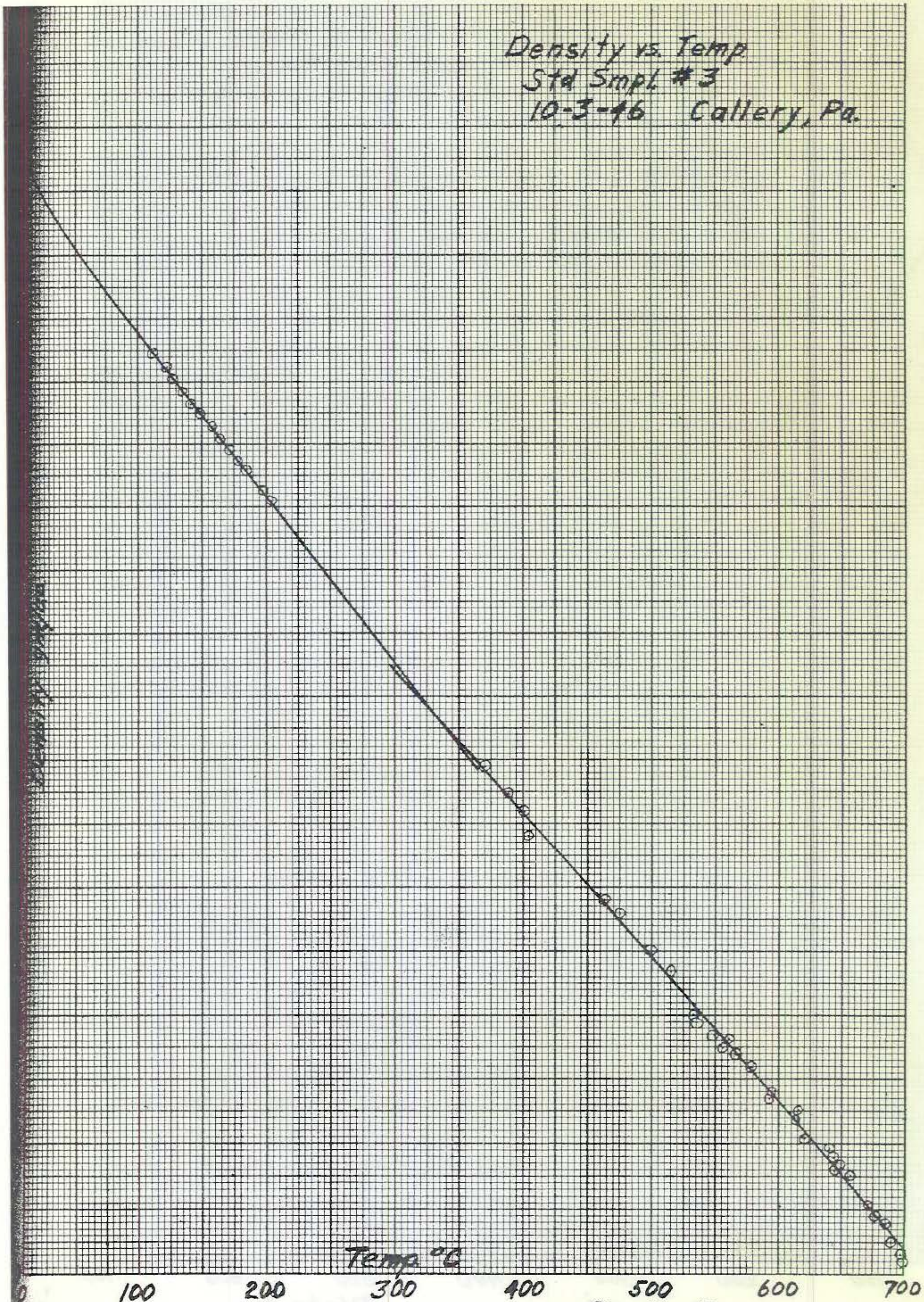

Density vs. Temp
Std Smpl #3
10-3-46 Callery, Pa.
Temp °C
0
100
200
300
400
500
600
700

Plate 5

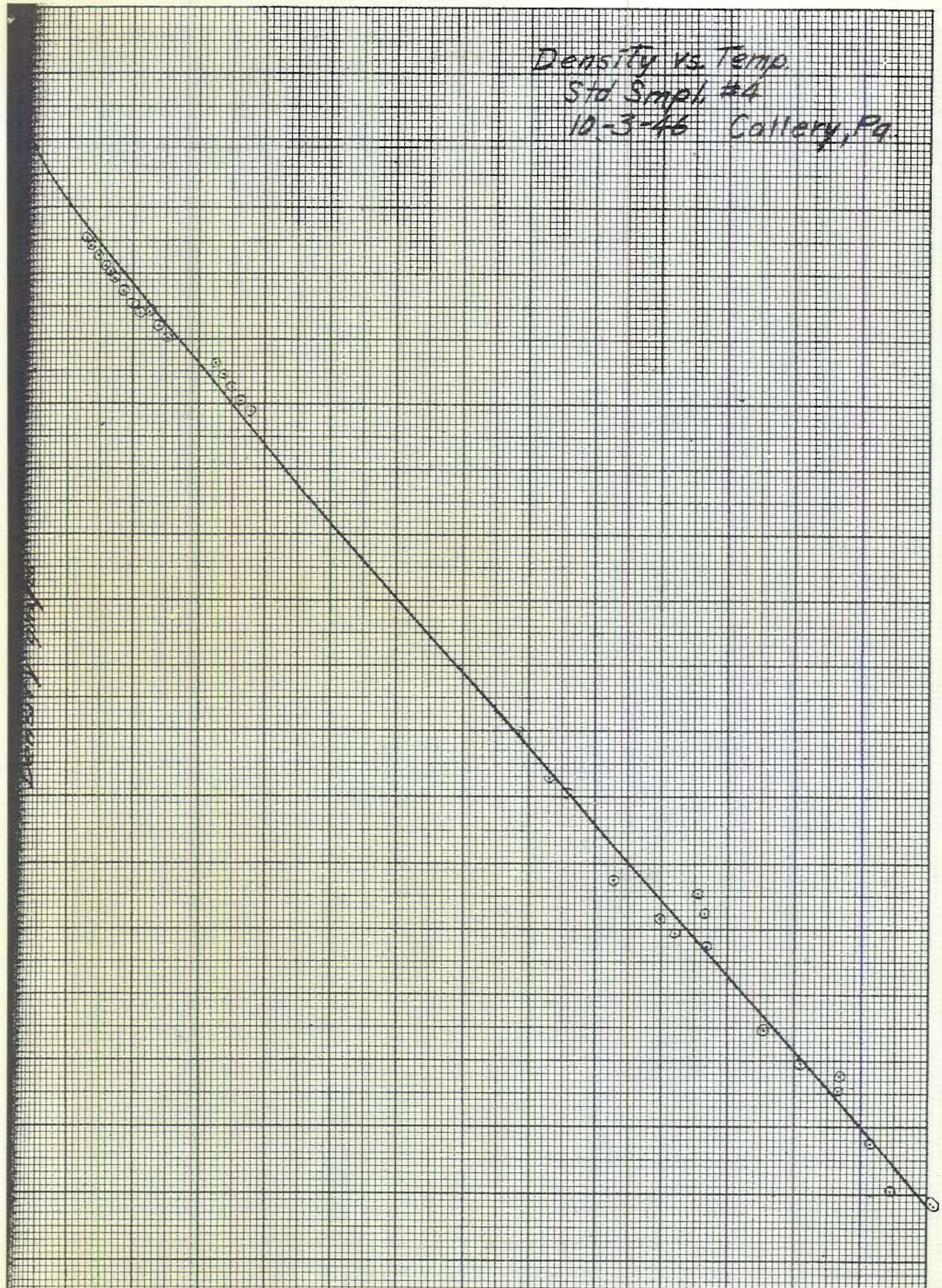
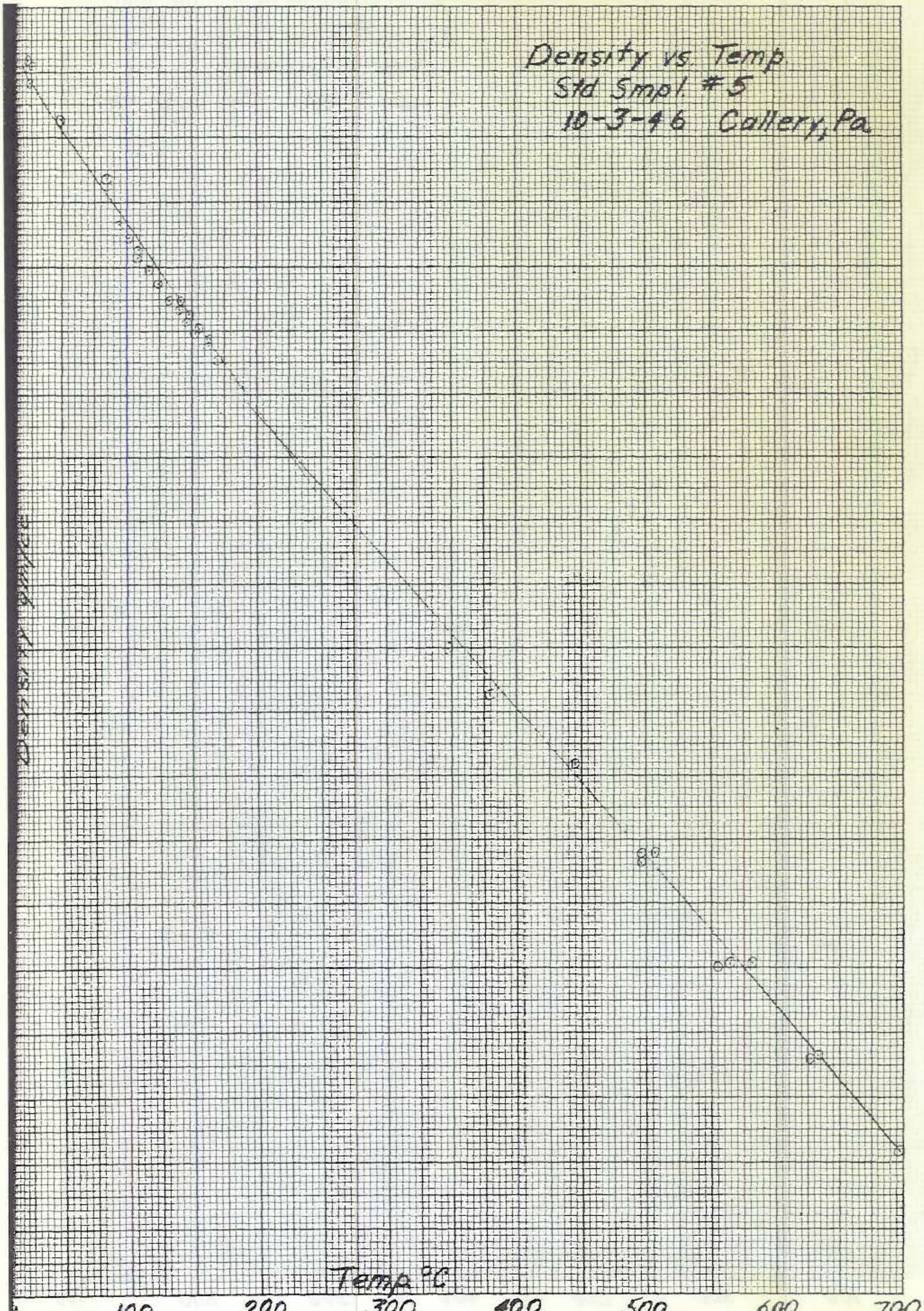

Density vs. Temp.
Std Smpl. #4
10-3-46 Collery, Pa.
Temp °C
100
200
300
400
500
600
700

Plate 6



Density vs. Temp
Std Smpl #5
10-3-46 Callery, Pa.
Temp °C
100
200
300
400
500
600
700

Plate 7

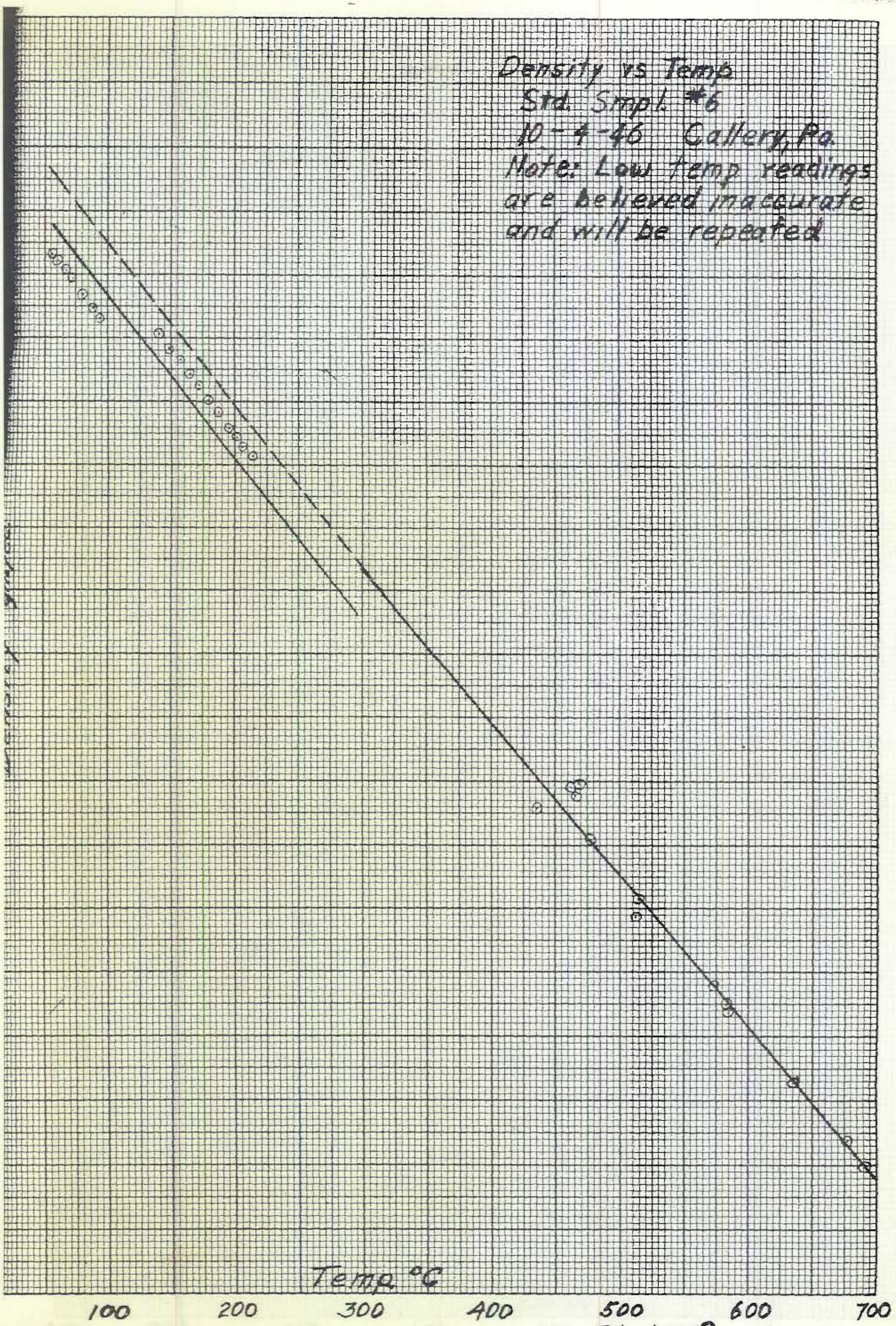

Density vs Temp
Std. Smpl. #6
10-4-46 Callery, Pa.
Note: Low temp readings
are believed inaccurate
and will be repeated
Temp °C
100
200
300
400
500
600
700

Plate 8

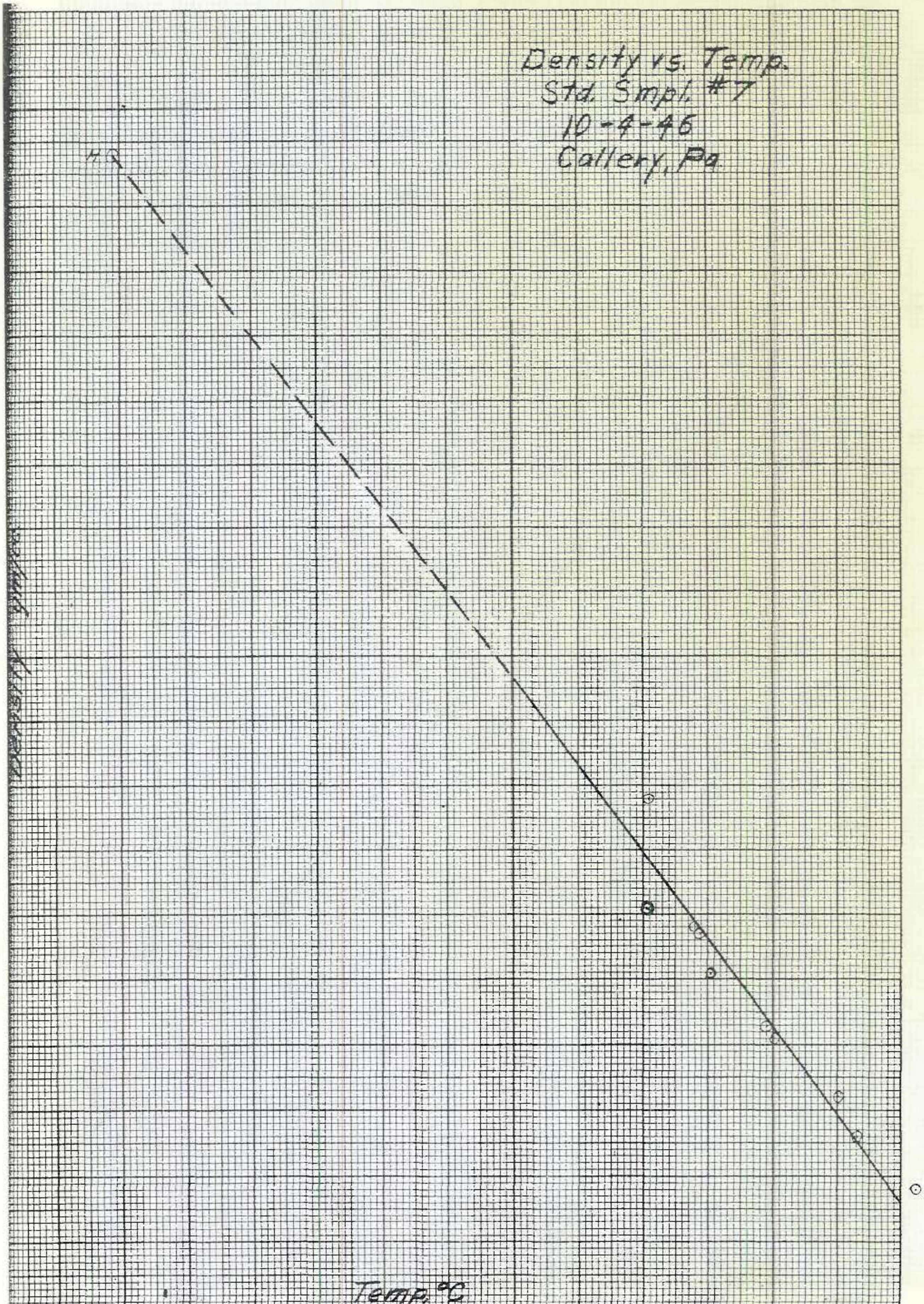

Density vs. Temp.
Std. Smpl. #7
10-4-46
Callery, Pa.
4.0
Temp. °C
100
200
300
400
500
600
700

Plate 9

This report was received from the Argonne Laboratory, Chicago as report #CT3554. The work was done at the Battelle Institute, Columbus, Ohio)

REPORT

on

DETERMINATION OF THE THERMAL CONDUCTIVITY OF SODIUM-POTASSIUM ALLOY AT ELEVATED TEMPERATURES

Report prepared by: Herbert Deem
H. W. Russell

Classification changed
to NOT CLASSIFIED
Sept. 27, 1946
Authority of;DEMED

June 5, 1946

APPENDIX D

Contract No. W-7405-eng-92

REPORT

on

DETERMINATION OF THE THERMAL CONDUCTIVITY OF SODIUM-POTASSIUM ALLOY AT ELEVATED TEMPERATURES

Report prepared by: Herbert Deem
H. W. Russell

June 5, 1946

SUMMARY

The thermal conductivity of an alloy consisting of approximately 50 per cent sodium and 50 per cent potassium by weight was determined over a temperature range of approximately 100°C to 500°C. The thermal conductivity of the alloy in watts $cm.^{-2}$ $°C^{-1}$ was 0.258 at a mean temperature of 100°C. and 0.284 at a mean temperature of 500°C. The thermal conductivity increased linearly with temperature.

INTRODUCTION

The use of a sodium-potassium alloy as a coolant makes some knowledge of its thermal conductivity at various temperatures quite important. No such data were available, so a measuring technique was devised and suitable apparatus constructed. It was desired to make thermal-conductivity measurements at various temperatures to approximately 500°C., and this requirement restricted the methods available. An alloy of sodium and potassium is very active chemically, thus making important the choice of container material and handling technique.

The method selected and used for the determination of thermal conductivity was essentially that developed by the U. S.

Bureau of Standards and described in Research Papers RP668 and RP669. The method, in brief, consists of heating one end of a sample, measuring its temperature gradient, and determining the quantity of heat passing through it by means of a heat flowmeter consisting of a standard metal of known conductivity at the cold end. The sample and standard are surrounded by insulation and guard tube. When handling a liquid in such measurements, it is obviously necessary to provide a confining container and also to provide for an uninterrupted heat flow into and out of the container. Stainless steel (18-8) was used as a container as its conductivity (approximately 0.20 watts $cm.^{-1}$ $°C^{-1}$) is near that of the liquid.

APPARATUS

Figure 1 shows the apparatus used for thermal-conductivity measurements of the alloy. The over-all dimensions of the stainless-steel rod were 2 cm. in diameter and 15 cm. long to conform to the U. S. Bureau of Standards method. This rod was made in two pieces with an end of each hollowed to a depth of 1 cm. with wall 0.005 inch thick. A small lip was left on each wall to facilitate joining the pieces by means of a stainless-steel weld. After welding the pieces together, an alloy container was formed with dimensions 0.789 inch long and 0.777 inch in diameter. The 0.005-inch walls represented 2.5 per cent of the alloy cross-sectional area. A small hole, representing 1 per cent of the alloy area, was drilled into the specimen chamber for use in filling. A stainless-steel tube was welded to the top, which served as an expansion reservoir, and a small section of steel tubing permitted making a flame seal after the assembly was filled with alloy.

Thermocouples of 36-gage chromel "P" and alumel wire were inserted as shown in Figure 1. Small pieces of stainless-steel tubing 0.020-inch O.D., (hypodermic needle stock), served to hold the beads firmly at the bottom of holes drilled into the stainless steel and Armoe-iron standard. Locations of the thermocouple holes were determined by means of a comparator microscope.

A stainless steel-clad copper cylinder was tin-soldered to the upper end of the assembly and served to introduce heat from the furnace. The lower end of the assembly was tin-soldered to an Armco-iron standard cylinder which, in turn, was soldered to a water-cooled cap.

The furnace was designed according to U.S. Bureau of Standards specifications, but was used in an inverted position as shown in Figure 1. By introducing heat at the top and withdrawing it from the bottom, heat transfer through the alloy by convection will not occur. Three heating coils with individual controls made possible the introduction of the desired amount of heat into the copper cylinder, and also control of the guard-ring temperature. Large-capacity storage batteries were used to heat the furnace to secure constant heat input.

Temperatures were measured at 12 points, as shown in Figure 1. They included 5 points on the stainless-steel assembly, 2 points on the Armco-iron standard, and 5 points on the guard ring. Millivolt thermocouple readings were made on a Type K Leeds and Northrup potentiometer.

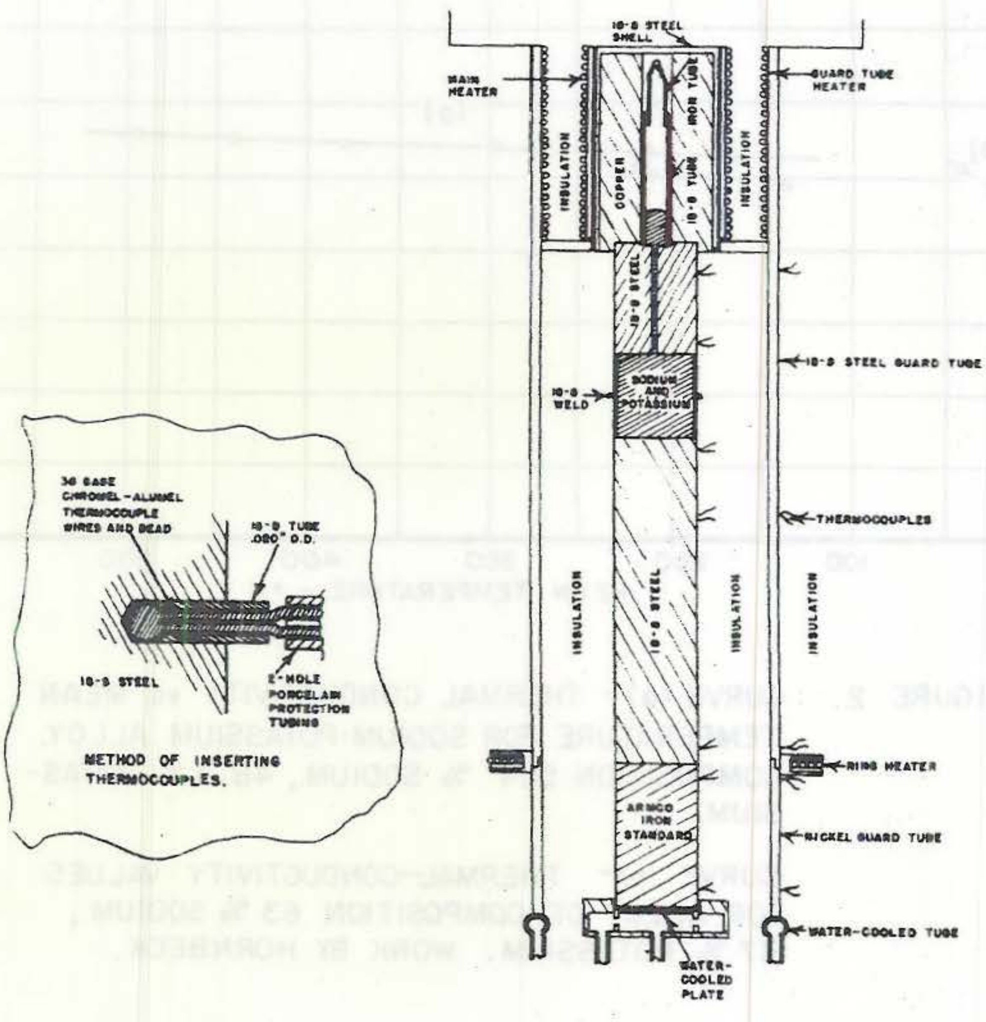


FIGURE I. APPARATUS USED FOR THERMAL-CONDUCTIVITY DETERMINATION OF SODIUM AND POTASSIUM ALLOY.

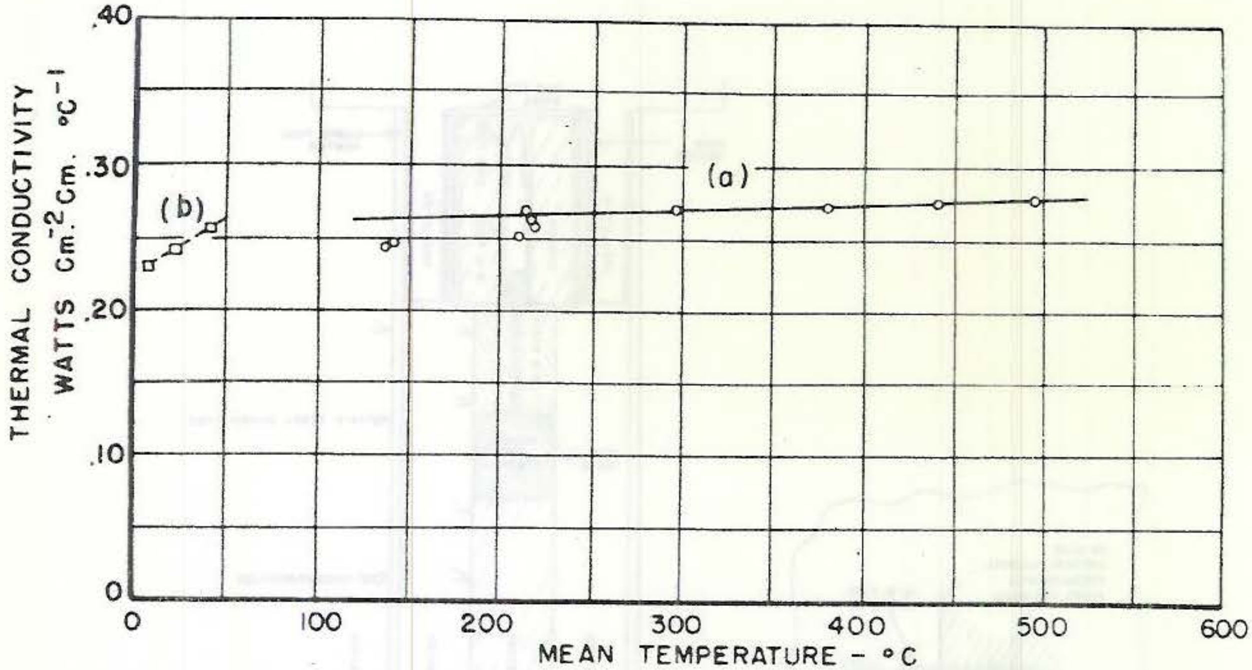


FIGURE 2. CURVE (a) - THERMAL CONDUCTIVITY vs. MEAN TEMPERATURE FOR SODIUM-POTASSIUM ALLOY. COMPOSITION 51.7 % SODIUM, 48.3 % POTASSIUM.

CURVE (b) - THERMAL-CONDUCTIVITY VALUES FOR ALLOY OF COMPOSITION 63 % SODIUM, 37 % POTASSIUM. WORK BY HORNBECK.

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