278 4117 leg
LA-3834-MS

MASTER

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Total Hemispherical Emissivity Measurements
by the Heat Pipe Method

UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

This report expresses the opinions of the author. It has not been edited. It does not necessarily reflect the opinions or views of the Los Alamos Scientific Laboratory.

Printed in the United States of America. Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Report written: November 10, 1967

Report distributed: April 4, 1968

Total Hemispherical Emissivity Measurements
by the Heat Pipe Method

by

J. E. Deverall

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

TOTAL HEMISPHERICAL EMISSIVITY MEASUREMENTS BY THE HEAT PIPE METHOD

by

J. E. Deverall

ABSTRACT

The heat pipe appears to have great potential for determining the total hemispherical emissivities of surfaces. If a heat source is located inside a heat pipe, the heat input to the system is accurately known. All of the heat input must be radiated from the external surface of the heat pipe and if the surface is isothermal, the total emissivity can be determined. The heat pipe, with its two-phase fluid flow, has this ability to maintain isothermal conditions over large areas and provides a simple, accurate method for emissivity measurements. By using various heat pipe containers and plating or spraying the containers with different materials, the emissivities of numerous materials can be established. The total emissivities of several different surfaces have been determined over a wide temperature range using a variety of heat pipe sizes and operating fluids. The results indicate that accurate, absolute measurements can be made by this method.

INTRODUCTION

A heat pipe¹ is a thermal conductance device which transfers heat by mass flow of a fluid utilizing the latent heat of vaporization. The fluid is continuously evaporating and condensing, establishing a two-phase system, which results in essentially isothermal operation.² Heat addition into one section of the heat pipe is distributed throughout the other section by flow and condensation of vapor. Completion of the cycle is obtained with the return of condensate to the evaporator through a capillary wick structure. By proper choice of working fluids, heat pipes can be constructed for operating temperatures from below 0° to 2000°C. They have numerous practical applications ranging from low temperature thermal control in satellites³ to high temperature thermionic power converters.⁴

The ability of a heat pipe to transfer heat isothermally also provides a simple, accurate method for determining emissivities of surfaces.

One major advantage of this method is that it measures the total hemispherical emissivity, necessary for many radiant heat transfer calculations, rather than the total normal emissivity usually measured by other methods. It is an absolute method and does not depend upon any standards or accurate calibrations of radiation detecting devices. By proper design of a heat pipe, a heat source can be located inside the pipe so that the total heat input must be transferred from the surface of the pipe. If heat rejection is solely by radiation, then the total emissivity of the heat pipe's surface can be readily determined. The heat pipe provides a large isothermal surface sample so attachment of temperature measuring devices causes negligible errors. By using different materials for the heat pipe container and plating, cladding, oxidizing, or spraying the containers, the emissivities of numerous surfaces can be established. A wide temperature range can be covered by using different operating fluids. The object of

Fig. 1. Heat Pipe Design

this work was to demonstrate that the heat pipe provides an accurate, absolute method for determining total hemispherical emissivities of materials.

HEAT PIPE CONSTRUCTION

Although the heat pipes used in this work were made in different sizes and of different materials, the basic design as shown in Fig. 1 was the same for each. The pipes consisted of an outer tube which was the condenser area and a re-entrant tube, containing the heater, which was the evaporator area. The inner surface of the outer tube and the outer surface of the re-entrant tube were lined with layers of 100 mesh screen and connected at the heater end with a screen bridge to form the capillary wick structure. Closure of the pipe was made by welding appropriate end caps into each end of the outer tube. The re-entrant tube arrangement of one heat pipe is shown in Fig. 2 along with the electric cartridge type heater used. Temperatures of the surface were measured by 10 chromel-alumel thermocouples spot welded along the length of the pipe.

The heat pipes were suspended by fine wires in a frame, as shown in Fig. 3, to eliminate heat loss by conduction. Only the circumferential area of the pipe was used for the emissivity measurements so the ends were insulated to eliminate axial radiation. The tests were made in a vacuum chamber so there was no heat rejection by convection and, with negligible conduction and end losses, essentially all of the heat input to the system was radiated from the test surface.

Six different heat pipes were used and by plating, spraying, and grit-blasting the pipes, the emissivities of two or more surfaces could be measured with one pipe. Three different working fluids (water, phenyl ether, and potassium) were used so measurements were possible over the temperature range from 40° to 640°C. The heat pipes are shown in Fig. 4 with their specifications listed in Table I.

Fig. 2. Re-Entrant Heater Tube

Fig. 3. Test Assembly

TEST APPARATUS

The vacuum chamber was a brass tube 8 in. o.d. by 36 in. long fitted with flanges at each end to provide for O-ring vacuum seals. The chamber wall temperature was controlled by water cooling through

copper coils soldered to the outside wall and the temperature measured by thermocouples peened into the wall. The inside of the chamber was coated with lamp black to provide an essentially constant-temperature, black surface for the heat pipe to

Fig. 4. Heat Pipe Specimens

TABLE I
Heat Pipe Specifications

Heat Pipe	Length In.	Diam In.	Material	Heater Size In.	Surfaces	Fluid	Temp. Range °C
A	27	1-3/8	#347 S.S.	3/4 x 5-1/2	Polished Grit Blast Gold Plate Black Paint	Phenyl Ether	180-320
B	24	1-1/2	Copper	7/8 x 4-1/2	Gold Plate	Water	40-130
C	24	1-1/2	Copper	7/8 x 4-1/2	Polished Grit Blast	Water	40-130
D	24	1-1/2	Nickel	7/8 x 4-1/2	Polished	Water	40-130
E	12	1-1/4	#347 S.S.	1/2 x 6	Polished	Water Potassium	40-130 340-640
F	12	1	#347 S.S.	1/2 x 2	Polished Gold Plate	Potassium	340-640

radiate to. One end of the chamber was connected to a vacuum system consisting of a liquid nitrogen trap, an oil diffusion pump, and forepump. A removable plate at the other end, equipped with feed-throughs for the heater leads and thermocouple wires, provided access to the chamber for inserting test assemblies. Power was supplied to the heater

by a filtered d.c. power supply through a circuit containing precision resistances for accurate measurement of current and voltage with the potentiometer. Vacuums of better than 10^{-6} mm Hg could be maintained in the system as measured by the Philips gage. The complete test apparatus is shown in Fig. 5.

Fig. 5. Test Apparatus

TEST PROCEDURE

After each heat pipe had been loaded with fluid and thermocouples attached, it was suspended in the support frame and the assembly inserted into the vacuum chamber. The chamber was then evacuated and the heater turned on and adjusted until the heat pipe attained equilibrium at the lowest temperature level in the desired range. When the vacuum was 10^{-6} mm Hg, a set of readings was taken and the heater power then increased until the next temperature level was established. Readings were taken at each temperature level up to the highest temperature in the range and then the procedure repeated at decreasing temperature levels. No readings were taken until temperature equilibrium was established and the vacuum was 10^{-6} or better.

The emissivity values were calculated by using the voltage-current measurements as input power, the average of the 10 thermocouple readings for radiation temperature, and the chamber temperature as the sink temperature.

RESULTS

The total hemispherical emissivities of seven different surfaces were measured using four heat pipe sizes and three working fluids.

The emissivities of nickel and copper are shown in Fig. 6. The copper heat pipe was used to measure two different surfaces. Measurements were first made with a polished surface and then the heat pipe was grit-blasted to create a rough, dull surface. This increased the emissivity by a factor of 5. Water was the working fluid for both the nickel and copper pipes and the temperature range was from 40° to 130°C.

Fig. 6. Total Hemispherical Emissivity of Copper and Nickel

An example of using one heat pipe to determine the emissivities of four different surfaces is shown in Fig. 7. This test was made with heat pipe "A" using phenyl ether as the working fluid and measurements were made between 180° and 320°C. The pipe was first polished to obtain the emissivity of polished #347 stainless steel. The surface was then grit-blasted and the emissivity measured was approximately twice that of the polished surface. A coat of flat black paint on the grit-blast surface produced an emissivity of 0.85. After these tests were completed the pipe was re-polished and gold-plated for measurements of a gold as-plated surface.

The emissivity of polished #347 stainless steel between 40° and 640°C is shown in Fig. 8. This curve was obtained from measurements using three different size heat pipes and three working fluids. The results were very consistent over the range when changes were made from one working fluid to another and there was good agreement between measurements made with two different size heat

Fig. 7. Emissivities of Four Surfaces Measured with One Heat Pipe

Fig. 8. Total Hemispherical Emissivity of Polished #347 Stainless Steel

pipes using potassium.

The emissivity of gold as-plated between 50° and 410°C is shown in Fig. 9. In this case three heat pipes were used, each with a different working fluid. Heat pipe "B" was made of copper and pipes "A" and "F" were #347 stainless steel. Each of the pipes was first nickel plated before the gold plate was put on. Several attempts were made to obtain the emissivity of this surface at higher temperatures, however, in each case the emissivities measured changed with time due to diffusion of the gold into the stainless steel. After the heat pipe had been operated continuously for nine days at 420° the emissivity measured was three times that of the original value. At higher temperatures the gold plate would completely disappear in a day or two.

DISCUSSION

The results of this work demonstrate that the heat pipe provides a simple, accurate method for making absolute measurements of total hemispherical emissivities. It can be used over a wide temperature range by proper selections of heat pipe sizes and working fluids. A list of suitable fluids and their working ranges is shown in Table II. The

Fig. 9. Total Hemispherical Emissivity of Gold As-Plated

TABLE II
Heat Pipe Fluids

Fluid	Operating Range °C
Water	25-150
Phenyl ether	150-320
Cesium	360-700
Rubidium	380-700
Potassium	340-800
Sodium	450-850
Lithium	900-1300

working range is determined by the vapor pressure. Too low a vapor pressure results in nonisothermal operation and too high a vapor pressure creates containment problems.

At very high temperatures the major problem is the construction of high output heaters as the power required varies as the fourth power of temperature. A plot of the radiation emitted per inch of length from a 1-1/2 in. diam tube versus temperature is shown in Fig. 10. These curves show that with relatively black surfaces at higher temperatures, heater outputs in the kilowatt range would be required. The heaters cannot be too large in diameter relative to the outer tube diameter as a small vapor passage would cause large pressure drops and nonisothermal operation. The heater section can be made longer, however, for increased capacity. As the pipes are operated in vacuum, heater elements can be made with refractory metals for high temperature operation.

The accuracy of measurements made by this method depends upon the accuracy of the watts input and temperature measurements, uniformity of heat pipe surface temperatures, and minimizing extraneous heat losses. The watts input can be measured very accurately by the potentiometer using appropriate shunts in the heater circuit with negligible I^2R losses in the leads. With the thermocouples spot welded to the surface, temperature measurements of the surface within 1°C should be possible. For some surfaces spot welding is not possible but accurate measurements can still be made by clamping the thermocouples to the pipe. A uniform surface temperature is not difficult to attain with heat pipes as the two-phase fluid throughout the container tends to keep it isothermal. This is demonstrated

Fig. 10. Radiation from 1-1/2 in. O.D. Tube

by sample data, shown in Table III, for several test runs with heat pipes "D" and "F". The maximum deviation from the average temperature is only 2°C and as this occurs at only one temperature point at the end of the pipe, over 90% of the test area is isothermal within $\pm 1^\circ\text{C}$. This ability of the heat pipe to maintain isothermal conditions is one of the main features of this method for measuring emissivity as emitted radiation depends upon the fourth power of the absolute temperature and large errors result from nonisothermal conditions. Any non-condensable gases in the system will cause a gradient at the end of the pipe so it is important to outgas all parts before assembly and to load the fluid under a good vacuum. Extraneous heat losses can be made very small by proper insulation of the ends of the heat pipe and suspending the pipe by

fine wires to eliminate conduction losses. If the surface of the end caps can be prepared the same as the cylindrical surface then the ends can be included in the radiation area and only the heater hole and fill tube have to be insulated. When pipes are plated, oxidized, or sprayed, the end surfaces are approximately the same as the cylindrical surface, however, it is difficult to put a high polish on the end caps due to the weld joints unless electro-polishing is used. There is no convection loss as the tests are made in a high vacuum so extraneous heat losses can be reduced to negligible amounts with proper care. Comparison of emissivity values obtained in this work with values in the literature⁵ showed very close agreement, see Fig. 11. However, it is difficult to compare test results with values in the literature because it is virtually impossible to accurately define surface conditions. For polished surfaces, the porosity of the metal, method and materials used for polishing, and the presence of oxide films will have a decided effect on the emissivity. In the case of applied surfaces such as plating, plasma spray, or painting, the emissivity will vary depending upon the thickness of the applied surface and the techniques used in the application. In view of this, it would appear advisable to evaluate each method on its own merits rather than attempt to establish the accuracy of a method by comparison of test results with those of other methods. It is estimated that this method is accurate within $\pm 2\%$ and is probably more accurate than many other methods used.

Fig. 11. Comparison of Test Results with Handbook Data

TABLE III

Heat Pipe Temperature Distribution

Heat Pipe "D" - 1-1/2" o.d. x 24" long Surface - Polished Nickel Working Fluid - Water										
T. C. No.	1		2		3		4		5	
	M. V.	°C	M. V.	°C	M. V.	°C	M. V.	°C	M. V.	°C
1	1.83	45.5	2.90	71.5	3.70	90.5	4.35	106.0	5.28	129.0
2	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0
3	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0
4	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0
5	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0
6	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0
7	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0
8	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0
9	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0
10	1.83	45.5	2.90	71.5	3.70	90.5	4.27	104.0	5.20	127.0
Ave.	1.83	45.5	2.90	71.5	3.70	90.5	4.31	105.0	5.23	128.0

Heat Pipe "F" - 1" o.d. x 12" long Surface - Polished #347 Stainless Steel Working Fluid - Potassium										
T. C. No.	1		2		3		4		5	
	M. V.	°C	M. V.	°C	M. V.	°C	M. V.	°C	M. V.	°C
1	16.79	409.5	17.55	427.5	18.39	447.0	19.55	474.5	21.56	521.5
2	16.78	409.0	17.55	427.5	18.42	448.0	19.58	475.0	21.61	522.5
3	16.78	409.0	17.55	427.5	18.42	448.0	19.58	475.0	21.59	522.0
4	16.79	409.5	17.56	427.5	18.42	448.0	19.59	475.0	21.60	522.0
5	16.76	408.5	17.52	426.5	18.40	447.5	19.56	474.5	21.57	521.5
6	16.80	409.5	17.55	427.5	18.42	448.0	19.60	475.5	21.61	522.5
7	16.76	408.5	17.51	426.5	18.40	447.5	19.55	474.5	21.57	521.5
8	16.74	408.0	17.49	426.0	18.37	446.5	19.53	474.0	21.55	521.0
9	16.77	408.5	17.53	427.0	18.40	447.5	19.56	474.5	21.57	521.5
10	16.67	407.0	17.44	425.0	18.31	445.0	19.47	472.5	21.47	519.5
Ave.	16.76	408.5	17.53	427.0	18.40	447.5	19.56	474.5	21.57	521.5

REFERENCES

1. Grover, G. M., Cotter, T. P., and Erickson, G. F., "Structures of Very High Thermal Conductance," J. Appl. Phys. 35, No. 6, 1990-1991 (June 1964).
2. Cotter, T. P., "Theory of Heat Pipes," Los Alamos Scientific Laboratory Report, LA-3246-MS, February 1965.
3. Deverall, J. E., and Kemme, J. E., "High Thermal Conductance Devices Utilizing the Boiling of Lithium or Silver," Los Alamos Scientific Laboratory Report, LA-3211, October 1964.
4. Deverall, J. E., and Kemme, J. E., "Satellite Heat Pipe," Los Alamos Scientific Laboratory Report, LA-3270-MS, January 1965.
5. Gubareff, G. G., Janssen, J. E., and Torborg, R. H., Thermal Radiation Properties Survey, 2nd Ed., Honeywell Research Center, Minneapolis, Minnesota, 1960.