SELECTED BIBLIOGRAPHY AND ABSTRACTS
OF HIGH-TEMPERATURE OPTICAL PROPERTIES
AND THEIR MEASUREMENT

By D. W. Gates
Space Sciences Laboratory

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This bibliography was prepared to list the sources containing emissivity and absorptivity data on materials at extremely high temperatures. Experimental work to determine data in these listings was done using both the absolute and comparative methods for obtaining values. In the absolute method the values were calculated by knowing the power input and losses and the resulting surface temperature of the sample. In the comparative method the values were obtained by a comparison of sample and blackbody radiation at the same temperature. Data available from these two methods are limited and are also inconsistent in value from one laboratory to another. Terminology in the various sources is not consistent, but definition conflicts are being resolved. One very difficult problem in comparing results in these sources is to recognize the possible error in measurements made at high temperatures, especially errors in determining temperatures of samples above 1500° K. The sample temperature and degree of specularity must be known, but present values are neither accurate nor reliable when experiments are duplicated. Accurate data for emission and absorption in the optical wavelength band of the spectrum for materials at high temperatures are necessary in heat transfer analyses and radiometric instrumentation in satellites. Emphasis in this bibliography was placed on listings giving information about the instrumentation used in the experimental work. Thus, the experimental techniques, equipment, and efforts of the
experimenters to characterize the materials used and methods to evaluate the errors are given in the sources in this bibliography.
SELECTED BIBLIOGRAPHY AND ABSTRACTS OF HIGH-TEMPERATURE OPTICAL PROPERTIES AND THEIR MEASUREMENT

By

D. W. Gates

SPACE SCIENCES LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS
SELECTED BIBLIOGRAPHY AND ABSTRACTS OF HIGH-TEMPERATURE OPTICAL PROPERTIES AND THEIR MEASUREMENT

INTRODUCTION

Historically, this bibliography is the result of a search for elevated temperature values of emission and absorption and the decision that experimental work was necessary. Emphasis is placed here on instrumentation, and both the absolute and comparative methods are included. The value is obtained in the absolute technique by a knowledge of the power input and losses and the resulting surface temperature of the sample, or by a comparison of sample and blackbody radiation at the same temperature in the comparative method. The experimental techniques, equipment, and efforts of the experimenters to characterize the materials used and to evaluate their errors are given.

Available data are limited and inconsistent in value from one laboratory to another. Terminology is not consistent, but definition conflicts are gradually being resolved. However, one very difficult problem is the measurement of high temperatures, especially above 1500°K. The sample temperature and degree of specularity must be known, but present values are neither accurate nor reliably reproducible.

Various investigators in the field were contacted to try to insure that the bibliography, which includes information concerning available equipment, is as complete as possible to mid-1967. Some of the articles of special interest were abstracted to facilitate entry by the user into this area of research.

BIBLIOGRAPHY


A device that can be used for the measurement of the absolute reflectivity or reflectance of metals, paints, etc. is described. The unit is used in conjunction with a Perkin-Elmer Model 83 monochromator equipped with an NaCl prism for the wavelength range 1.0 to 15.0 microns. Preliminary results for MgO, polished copper, molybdenum, and electrolytic gold are presented.


Methods, optical pyrometers, emissivity, reflected radiation, "total" radiation pyrometry, emissivity as affecting radiation pyrometry, flame radiation, and color temperature are among the topics discussed. This represents an attempt to present briefly some of the methods by which the laws of radiation are applied to the measurement and control of high temperatures. Strong emphasis has been placed on sources of error, particularly those resulting from uncertain and variable emissivities of radiating bodies.


While the emphasis is on coating development, some details are given of the measuring techniques.


Methods used to obtain oxide coatings of high emissivity suitable for application to the radiative cooling of hypersonic aircraft are presented. Values of total hemispherical emissivity were obtained for several high-temperature materials including type 347 stainless steel and Haynes alloys C, X, and 25. Tests were also conducted on tungsten and Haynes alloy B, but because of the nature of the oxide coatings produced, values of emissivity were not obtained. Measurements of the total normal emissivity of flame-sprayed coatings of alumina and zirconia are also included.


The measurements are presented for both as-received and polished test specimens together with a brief description of the equipment and procedures used. Results of investigations of the surface condition of these materials as obtained by x-ray diffraction methods and metallurgical techniques are presented to indicate the type of surface on which these measurements were made.


Method for measuring the temperature dependence of hemispherical emissivity of metals; presents typical results obtained. Although the method is not generally applicable to all types of metals, it may be particularly appropriate for special cases. Pt and Cu results are given.


Total normal emittance of various uncoated and coated ceramic materials was investigated as a function of temperature. Total radiation measurements were made, and two blackbodies used to calibrate systems. Rance is given up to 5000°F.


The term reflectance is used to denote the characteristic of a system rather than a property and includes the effects of surface roughness, oxide layers, evaporated films, and any type of surface contamination. Spectral reflectance of materials is paramount in the control and prediction of spacecraft temperatures, and the subject is covered as follows: types of reflectometers, Coblentz, integrating-sphere, and Gier-Dunkle blackbody. Each system has certain inherent errors, and different techniques are required for different spectral regions.

Emissivity and absorptivity measurements have been made for the following conditions:

1. Total normal emittance from -300° to +3000° F
2. Normal spectral emittance at 0.665 microns wavelength up to 3000° F
3. Solar absorptivity at ambient temperature
4. Normal spectral absorptivity in the 1 to 13 micron wavelength range from 200° to 1850° F

Equipment and techniques are described, but no results are shown.


Three systems are described for measuring the total hemispherical, total normal and spectral normal emittance of opaque solids: Cary Spectrophotometer, Hohlraum Reflectometer, and Total Hemispherical-Emittance Measuring Apparatus. Comparison is made with results from several other sources of data and range is given as being from 0.4 to 25 microns wavelength and temperatures from -150 to beyond 1000° C.


Proceedings of the conference are given as in the title of the book, and the last section presents a review of radiation environments in space and a theoretical model for optimizing passive temperature control in slowly changing environments.


The importance of radiation as a means of cooling high supersonic and hypersonic speed aircraft is discussed to show the need for measurements of the total hemispherical emissivity of surfaces. The theory underlying the measurements of the total hemispherical emissivity of surfaces is presented, readily duplicable apparatus for performing the measurements is described, and measurements for stably oxidized Inconel, Inconel X, stainless steel 303, and titanium alloy RS-120 are given for the temperature range from 600°F to 2000°F.


This is a compilation of original test data on emittance and reflectance of coated materials suitable for use at elevated temperatures. A very good coverage of the literature from 1940 through 1959.


The emittances of various refractory materials were determined at temperatures from 800°F to 5000°F. These measurements were made by comparing the irradiance from a sample of the material to that from a blackbody cavity maintained at the same temperature. A thermopile-type detector was employed.

Small disc-shaped specimens were heated in an inert atmosphere by placing them on a disc that was inductively heated by a flat induction coil. The specimen temperature was measured by surface thermocouples and by optical pyrometer. The optical pyrometer readings were corrected to true temperature for the measured emittance by thermocouple calibration, gray body assumption, and spectral measurements.

The emittances of platinum, pyrolytic graphite, tungsten, molybdenum, carbides, oxides, nitrides, and silicides were determined to their destruction temperatures. Several coatings including the W-2, silicized finishes, chrome oxides, and other specially treated surfaces were also evaluated. The emittances of the different materials varied considerably with temperature and demonstrated many inflections that could usually be associated with material phase changes and expansion coefficients, but quite often were unpredictable.


This paper is one of a series concerned with a program to determine values of total emittance of various materials which may possibly be used as construction materials for the radiative cooling of high supersonic and hypersonic aircraft. These materials include chemically oxidized Inconel, aluminum oxide and chromium oxide base paints, silicon carbide base ceramics, and chromium/aluminum oxide cermets.


Eight transparent protective coatings for gold were evaluated with respect to their ability to withstand temperatures of 1000°C and not to significantly increase the low total emittance of the substrate. Thin coatings, of the order of 100 mm, of vacuum evaporated SiO, Al₂O₃ and WO₃ were found to be highly satisfactory. Samples with a protective topcoat over gold which in turn was applied over a diffusion barrier coating of CeO₂, were able to maintain a total normal emittance of less than 0.1 for up to 20 hours at 1000°C in air.
A second aspect of the work was the study of the spectral normal emittance in the 1 to 5 micron wavelength range at 1000°C of sintered binary mixtures or pure compounds to correlate the spectral emittance of the pure components. No correlation was found. In most cases, the spectral emittance at any wavelength for the binary mixtures was between the values for the spectral emittance of the pure compounds. In some cases, however, the spectral emittance at a given wavelength was higher or lower than for either of the pure components.


A technique for measuring the total normal emittance and the spectral emittance of nonconductors at high temperatures is presented. Total normal emittance data are presented for various thicknesses of boron nitride at temperatures from 1200°F to 1900°F. Spectral emittance data are also presented for boron nitride from 0.5 micron to 15 microns at 1400°F.


A continuation that includes much of the previous DMIC Memo 103.


An apparatus has been designed, built, and tested that will measure the total hemispherical emittance, total normal emittance, normal and hemispherical spectral emittance, angular distribution of radiation and resistivity of metals from 1000°K to their melting points. The flat ribbon sample is resistance heated while held in a mount capable of 230° rotation in a vacuum of 10⁻⁶ torr. The apparatus and measuring techniques are described and examples of resulting data given.


Technique for determining total hemispherical emittance in vacuum is described. Method is based on the principle that if fins which are identical in every respect except emittance are heated at one end to the same temperature and in the same environment, the temperature drop along the length of the fin is a function of the emittance only. An analysis of the fin parameters needed for particular temperature ranges indicates that this method is practical for temperatures from -100°F to 1350°F or above. Emittance determinations are based on a comparative technique rather than on an analytical calculation. Good agreement, however, is obtained by comparing the correlation to analytical determinations of emittance.


Paper describes a method by which the spectral emittance of a sample may be determined conveniently over a wide temperature range by use of an arc-imaging furnace. By measuring the radiation at a chosen wavelength incident on the sample and measuring the same radiation reflected from the sample, we may determine their ratio, and thus obtain the reflectance of the sample. From the value of reflectance so determined, we may now deduce the spectral emittance.


A method is described for measuring total emittance of translucent materials in such a manner that any effect of subsurface temperature gradients can be observed. The axial temperature distribution of a disc-shaped specimen is controlled by relative positioning of a plasma torch heating the front face and a propane torch heating the rear face. Total radiation leaving the front face is measured with a thermopile detector, and corrections are applied to account for the reflection of plasma emission. Temperatures are measured internally on the specimen axis by utilizing small blackbody cavities drilled radially to the centerline. Results are presented to 4600°F for zirconium oxide.


This paper presents a rapid, total-normal-emittance-measurement technique useful for comparative tests. The heat source is a 10 kw tungsten-filament lamp whose energy is focused on the specimens with two 36-inch parabolic mirrors. The method described is useful between 1000 - 3000°F with all tests conducted in air. Accuracy depends on surface temperature measurements, with an accuracy of +5% and -10% when the thermocouples are used and an accuracy which depends on the deviation of the specimen from a gray body when an optical pyrometer is used.


An eight-chambered vacuum calorimetric apparatus for measuring and evaluating the total hemispherical emittance of high-temperature radiator coatings is describer. The method for obtaining emittance values is presented, and an error analysis identifies the important parameters. A detailed description of the sample heating and temperature-measuring systems are also given. Preliminary results confirm the suitability of the apparatus for measuring emittances with an accuracy of ±5%.

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Apparatus to measure the total hemispherical and directional total and spectral emittance in the temperature range of 400° to 2000°C is described. The device consists of a water-cooled evacuated chamber in which a sample formed into a modified Mendenhall wedge enclosure is heated electrically by its own resistance. The sample can be rotated in azimuth while viewed externally through a double-slit collimating optical system. Total or spectral emittance is determined by comparing emitted radiation from the surface to radiation emitted from the enclosure as detected by a vacuum thermocouple used with or without a monochromator.


Equipment is described which was used to measure simultaneously the spectral and total normal emittance of materials in the temperature range from 400° to 1800°F while contained in ambient and vacuum environments. Equipment design, set-up, and experimental procedures are presented. Also included is a description of present activities directed towards the assembly of equipment which will help improve experimental accuracy and also provide for angular emittance measurements in order to obtain more comprehensive data.


Attention is called to several pitfalls that often beset investigators who make thermal emittance studies. The pitfalls mentioned include the following:

1. Conflicting meanings of several frequently used terms as found in the literature, each meaning having authoritative sponsorship

2. Incomplete and hence potentially misleading descriptions of specimens on which reported data are based

3. Reference of emissivity or emittance as a property of a surface rather than a volume property (influenced by the surface)

4. Occasional omission of diffuse reflection from analyses of the optical properties of inhomogeneous bodies

5. Failure to observe the restrictions on conditions that are required for validity of basic equations

6. Uncertainties as to the effective temperature peculiar to specimens having low absorption indices

7. Lack of suitable physical standards

Several suggestions are made for avoiding or minimizing the consequences of the pitfalls discussed.


An apparatus was designed and constructed to determine spectral normal emittance of materials in an environment closely simulating the vacuum of space. The apparatus is capable of measuring spectral emittance of structural materials or coatings over a wavelength range accounting for the major portion of the blackbody energy at the temperature at which these measurements are made (0.5 to 1.2 microns claimed). Comparison is made of the radiant intensity normal from a specimen tube surface to that of a small blackbody hole drilled in the tube wall. Ratio of these intensities at a given wavelength is a very close approximation to the spectral normal emittance of the specimen surface. Evaluation of errors from several sources is included — scattered light from the NaCl window, scattered white light in the monochromator, and quality of the blackbody hole in the specimen tube.


Design and construction of a special apparatus capable of measuring emittances up to 3000°F is described. The method of determination of the total hemispherical emittance by comparison with a blackbody is the basis of the technique herein employed. If the temperatures and the areas of the unknown surface and the blackbody are made equal, the method becomes simply the determination of the ratio of the rates of emission.


Because many materials change in radiation characteristics with increasing temperature, it has become increasingly important to determine emittance values directly instead of by the comparatively easier method of computing emittance values from reflectance data. This is particularly true if the material is partially transparent to radiation. A new apparatus is being built to extend the capability for evaluating emittance from the currently available 1500°F to at least 4000°F. The technique being applied is to rotate specimens in a high-temperature furnace which is also utilized as a blackbody radiation source. The analytical techniques used to establish speed of rotation, field of view, and other design problems are discussed. A review of other radiation test equipment is also presented.


Determination of total normal emittance of 304 Stainless, A-7 Carbon steel and borated graphite for use in the nuclear reactor under construction at Monroe, Mich. Temperature range is 600° to 9500°K.


Equipment was developed for measuring the temperature dependence of the total hemispherical emittance of metal and alloy strips to 1200°C using direct heating in a constant-temperature, blackbody vacuum chamber. Precise specimen dimensions and thermocouple positioning are requisite to the method and the techniques developed to accomplish these are described. Results are presented which show the effects of specimen reaction with the measuring environment and specimen-oxide reactions. Electrical resistivity of the specimen was obtained from the data taken in a determination. Finally, a discussion and comparison of results with those made at Lockheed are given (paper by A. I. Funai).


Several test rigs were designed and constructed to measure total hemispherical emittance over a wide range of temperatures under conditions which simulate the vacuum of space. Method used in all is to compare the electrical power dissipated from an isothermal test section of a resistance-heated specimen to the total emissive power of a blackbody operating at the specimen temperature. Total hemispherical emittance is determined as a function of temperature from 200° to 2200°F and total hemispherical emittance as a function of time at fixed elevated temperatures. Specimens were either coated metal strips or coated thin-walled metal tubes. Data are compared with those of other investigators.


Total normal emittance measurements were made on small specimens with shallow reference holes of circular cross section. The ratio of the radiant flux density from the surface to the flux density from the hole was measured and this value then converted to emittance by a theoretical expression based on hole dimensions. The expression applies only to diffusely reflecting materials. Measurements were made on oxidized nickel, oxidized Inconel, sintered alumina, and polished high-purity graphite over a temperature range up to 2150°K.


A double-beam ratio-recording infrared spectrometer was modified to record directly the normal spectral emittance of strip specimens that are heated by passing a current through them. A laboratory blackbody furnace and a hot specimen at the same temperature serve as sources for the respective beams. Temperature equalization is achieved by means of a differential thermocouple. Automatic data processing equipment corrects for "zero-line" and "100%-line" errors on the basis of previously recorded calibrations and also computes from the spectral data, as the measurement progresses, total emittance or absorptance for radiant energy having any known spectral distribution of flux.


Described is a system for the measurement of spectral emittance; certain operating difficulties are considered, and results for a metal and for a ceramic coating are presented to reveal satisfactory operation at temperatures from 1500° to 2000°F.


A method and apparatus is described for the measurement of spectral normal emittance in air of a variety of materials. The system permits measurements to be performed over a wavelength region of 1 through 15 microns and over a temperature range of 600° to 1800°F with an accuracy of ±5%. The advantages of this system are described. Results obtained by this system are compared with results reported by another observer using a different technique.


The adaptation of the NRDL flash method to the measurement of the thermal diffusivity of metals and ceramics at high temperatures is described. A high intensity short duration light pulse from a xenon flash lamp is the source and the problems are discussed in this report.


This manual covers the general instructions necessary to assemble, operate, and maintain the equipment used in making thermal-expansion, thermal-conductivity, and heat-capacity measurements at temperatures from 500° to 5000°F. Ordering information for space parts and materials is given in the Appendix.


Total emittances of the silicide coatings developed for tungsten, tantalum, molybdenum, and niobium have been measured. Measuring technique is also described in some detail.


Discussion is given of calorimetric radiation characteristic determinations, and reference is made to more complete descriptions given in NASA SP-31 under authors Gaumer, Caren, McKellar, Streed, Stewart, Frame, and Funai.

An investigation was undertaken to evaluate the effects of two plasma spray powders, tungsten and zirconia, and four substrate materials, glass, stainless steel, tungsten, and copper, on the particle-to-substrate bond. All substrates except glass were metallurgically polished; the glass had a sufficiently smooth surface so that mechanical interlocking would not contribute to the resultant bond. It was found that the thermal conductivity of the substrate greatly influences the particle-to-substrate bond, whereas, in general, the physical properties of the spray powder have only a slight influence on the bond.

An equation was derived relating the normal spectral emittance of an optically inhomogeneous, partially transmitting coating applied over an opaque substrate to the thickness and optical properties of the coating and the reflectance of the substrate at the coating-substrate interface.

105. Miller, L. W.; and Tatro, L. D.: Total Optical Emissivity and Electrical Resistivity of U$^{0.3}$ and Zr$^{0.7}$ in the Temperature Range 1400° to 2800°K. W-7405-ENG-36, LAMS-2965, November 19, 1963. [Los Alamos Scientific Lab., N. Mex.]


Objectives of this book are stated to be:

1. Identification and evaluation of NASA contributions to the science and technology of inorganic coatings

2. Preparation of a report suitable for the dissemination of NASA contributions in a form which will assist the commercial economy

Chapter 6, Measurement of Optical Properties of Coatings, includes 500° to 1500°K and 1500°K and up. There is also a bibliography.


Spectral total reflectance (0.23 to 2.65 microns) spectral normal emittance (1-15 microns) curves are presented for high temperature, oxidation-resistant, intermetallic compounds. Major emphasis was given to sintered samples of aluminides, borides, beryllides, and silicides. Also studied were several pack cementation coatings.


This is one in a series of reports on a research program aimed at developing equipment and procedures suitable for reliable measurements of the total and spectral emittance of both metals and nonmetals in the temperature range 1400° - 2500°K. This program was started in 1961 and continued through 1965.

110. Wilson, R. G.: Determination of the Hemispherical Spectral Emittance of Carbon, Graphite, Zirconia, and Ablation Material Chars from 0.37 to 0.72 Microns and 3000° to 6000°F. NASA TM S-51017, March 4, 1964. [Langley Research Center, NASA]


The spectral normal emittances of oxidized Inconel, Inconel-X, and type 347 stainless steel were determined at temperatures of 900°, 1200°, 1500°, and 1800°F over a wavelength range of 1 to 15 microns. Polishing, grit blasting, etching, or combinations of these preparations were used as preoxidation treatments. Large effects of variations in oxidation times and preoxidation treatments were found.


This paper gives a discussion of three problem areas in the field of thermal radiation of solids:

1. Calculation, from first principles, of the optical constants $n$ and $k$ of homogeneous materials, such as metals and dielectrics.

2. Theories of the radiation characteristics of rough surfaces, of inhomogeneous materials such as powders, and of composite materials.

3. Computational complexity having to do with radiation and conduction interchange on a macroscopic scale in complex structures such as space vehicles.

New approaches are urgently needed in most of these problem areas.


Steady-state radiation heat transfer through layers where both scattering and absorption occur within the layers is treated analytically by means of one-dimensional fluxes. The set of simultaneous equations — consisting of a heat-balance equation, an equation for the flux in the direction of heat flow, and an equation for the flux in the opposite direction — has a general solution to which boundary conditions are applied to derive expressions for desired quantities for an arbitrary layer. In this way the transfer through a layer and the emission from it, as well as its temperature distribution, are derived in terms of the absorption and scattering coefficients of the layer, the index of refraction, the lattice conductivity, and the heat applied to it. The treatment includes the effects of surface reflections. Radiation transfer through nonradiating layers is also treated in order to provide equations for obtaining the absorption and scattering coefficients from optical transmission measurements.
One of the necessary design criteria for a solar thermal-cycle power system aboard a spacecraft is the thermal radiation properties of the surface on which the solar energy is absorbed. A coating which selectively absorbs solar energy but does not radiate infrared energy gives increased absorber efficiency over a nonselective blackbody at lower solar flux concentrations and higher temperatures. An interference coating consisting of multiple layers of alumina and molybdenum on a molybdenum substrate gave a solar absorptance of 0.83 and an emittance of 0.11 at 1000°F. A selective black surface, beryllium plus 1 percent copper alloy anodized in sodium hydroxide produced a very hard and durable coating with a solar absorptance of 0.91 at room temperature and a solar absorptance of 0.87 with an emittance of 0.30 at 1000°F.
A laser-source integrating sphere reflectometer was designed and built to measure the reflectance of specimens at high temperatures. Calibrated for linearity of response of 0.632 microns wavelength by means of a shallow cylindrical cavity with a variable depth-to-radius ratio, having a lining of known reflectance. Ellipsoidal mirror reflectometer was calibrated for all known errors in the 1 to 7.5 micron wavelength range. Preliminary tests showed that the flux emitted by a hot specimen at temperatures up to 2500°K will not invalidate the reflectance measurement. Preliminary analysis indicates the errors in measurement of absolute reflectance with this equipment should not exceed 2 percent. Review of the literature on relation of thermal radiation properties to other properties of materials is presented, together with a summary of the work done in an effort to compute the spectral emittance of rhodium.


The normal total emissivities and relative radiant intensities of several complex ceramic oxides were determined theoretically. It was found that the total emissivities for many of the complex solids seemed to follow an equation which states that the normal total emissivity of a complex solid is equal to the sum of the products of the normal total emissivity and the ratio of the mass/densities (relative volume ratio or the mole ratio) of each of the compounds initially present. On a molecular basis, it was found that the vibratory modes of many of the complex ceramic compounds are nearly similar to the cumulative vibratory modes of the simple ceramic compounds.
This report describes the preparation and thermal radiation properties of a number of intermetallic compounds and coatings.


A technique used to measure total normal emittance that employs a Gier-Dunkle Portable Emissivity Inspection System is explained in detail. This is then compared with the familiar heated cavity Hohlraum-type measurement which gives a value to total normal emittance by summing spectral data. Emittance values obtained from samples measured on both systems are compared, and an analysis of some of the errors inherent in each measuring technique is given.


Several authors have made the assumption that Kirchhoff's Law holds for the apparent local spectral emittance and apparent local spectral absorbance of any point on the interior surface of a cavity. The correctness of this assumption is demonstrated under certain general conditions, and its practical application to the total flux absorbed by a cavity or spacecraft is derived. An easy method for determining the total flux emitted from such a nonisothermal cavity is found when the distribution of the apparent local spectral emittance of the isothermal cavity is known. Total flux emitted from a nonisothermal cylindrical cavity for several arbitrary cases of temperature distribution on the interior surface of the cavity is calculated, and the integral equation for a diffuse cavity, whose wall emittance varies with position on the wall, is transformed to an equation having a symmetric kernel.
In order to eliminate the effect of spatial and angular sensitivity of infrared detectors and obtain accurate measurements in the infrared, several averaging devices are presented, which distribute the flux as uniformly as possible over the entire sensitive area of the detector. Tests to establish the averaging capability and useful wavelength range are shown.

The infrared radiation properties and characteristics of titanium-boronitride were investigated in the wavelength region extending from 1.0 to 10.0 microns at a temperature of 1300 K. The normal spectral emissivity, integrated normal total emissivity, and infrared radiation intensity curves of this material for two different surface conditions were determined. Additional radiation studies were made using a mathematical interpretation based on the normal total emissivity and weight-to-density ratios of the individual constituents.

It has been observed experimentally that the emittance of polished metals can be markedly increased by roughening the surface, by a factor of as much as 2 or 3. For nonmetals and particularly white ceramic materials, on the other hand, the emittance appears to be essentially independent of surface roughness, at least for wavelengths below 7 or 8 microns. This apparent anomaly is explained on the basis of the differences in the optical properties of the two types of materials.

This paper presents an analysis of 133 replies received from a questionnaire. Subject was measurements and computations in the field of radiant heat transfer, particularly in relation to the national space program and military applications. The results from the questionnaire are supplemented to give a
broad picture of the current status and future requirements in measurements of thermal emittance, measurements of infrared reflectance, and computational methods for radiant heat transfer. A brief review of the Russian literature in the field is included.


The objective of this continuing program is to develop equipment and procedures for measuring the important thermal radiation properties of materials at temperatures up to the melting point of the most refractory material and to develop physical standards for checking such equipment and procedures.

Specific coverage in this report includes:

1. Development of the laser-source integrating sphere reflectometer
2. An error analysis of the shallow cavity technique for measuring normal spectral emittance
3. Study of the feasibility of preparing emittance standards for use at temperatures above 1400°K (about 2000°F)


The infrared radiation properties and characteristics of the ternary solid titanium boronitride were investigated in the wavelength region from 1.0 to 10.0 microns wavelength at 1300°K. The normal spectral emittance, integrated normal total emittance, and infrared radiation intensity were determined for this material with both rough and polished surfaces. The normal
total emissivity of the material was also calculated based on the weighted average of the normal total emissivities of the constituent compounds. The results are in good agreement with the experimental values.


Report of work completed on the following:

1. Completion of the development and calibration of a rotating cylinder procedure for measuring normal spectral emittance of nonconducting materials at temperatures in the range of 1200° to 1600°K

2. Analysis and calibration of an ellipsoidal mirror reflectometer

3. A study of the relation between surface roughness and geometric distribution of flux reflected from a surface


Measurement of spectral normal and total hemispherical emittance of materials from 200° to 3100°F at pressures down to 10^{-3} and to times of over 5000 hours has been accomplished.

AUTHOR INDEX TO REFERENCES

Abbott, G. L., 42, 54, 64
Alderman, J. L., 108
Alvares, N. J., 42, 54, 96
Alvarez, G. H., 129, 130
Askwyth, W. H., 65, 75, 81
Atkinson, W. H., 114
Autio, G. W., 124
Bastian, R., 73, 90
Bernstein, J. B., 37
Betz, H. T., 21
Bevans, J. T., 14
Blau, H. H., Jr., 36, 38, 40
Bradley, D., 49
Brandenberg, W. M. 123
Brandes, E. A., 11
Browning, M. E., 94
Burks, T. L., 99, 111
Butler, C. P., 28
Carrera, N. J., 48
Casey, F. W., Jr., 26, 62
Chaffee, E., 36, 38
Champetier, R. J., 143
Clark, H. E., 108, 116, 141
Claussen, O. W., 123
Clayton, W. A., 66, 70
Comstock, D. F., Jr., 68
Counts, C. R., III, 111, 129, 130
Cox, R. L., 59, 69
Crompton, M., 29
Curry, R., 65
Davis, R. L., 142
Deem, H. W., 39, 41, 45, 47, 63
DeSantis, V. J., 87
DeVos, J. C., 13
DeWitt, D. P., 126
Dike, P. H., 15
Dotson, L. E., 56
Douglas, E. A., 16
Dunkle, R. V., 14, 30
Dunn, S. T., 126, 133, 136, 142
Dyer, J., 73, 90
Emanuelson, R. C., 142
Emslie, A. G., 117
Entwhistle, A. G., 49
Eubanks, A. G., 67
Evans, R. G., 70
Fischer, H., 40
Fries, M., 70
Funai, A. I., 71, 115
Gannon, R. E., 120
Gardon, R., 17
Gaumer, R. E., 97
Geir, S., 14
Geist, J. C., 141
Goldberg, D. M., 99
Gouffe, A., 6
Grammer, J. R., 72, 115
Gravina, A., 44, 73, 90
Greenberg, J., '18
Grenis, A. F., 60, 128, 134, 140
Grisaffe, S. J., 101
Hamaker, H. C., 7
Hamilton, D. C., 10
Harrison, T. R., 35
Harrison, W. N., 27, 33, 57, 74, 36, 104, 108
Hayes, R. J., 114
Hayes, W. D., Jr., 126
Heaney, J. B., 131
Hoch, M., 98, 127
Hoppke, M. A., 129, 130
House, R. D., 75
Huttinger, R. C., 142
Inn, E. C. Y., 28
Iyer, A. S., 127
AUTHOR INDEX TO REFERENCES (Continued)

Janssen, J. E., 121
Jasperse, J. R., 36, 38
Jenkins, R. J., 92
Joseph, H. M., 104
Katz, M., 44
Katz, S., 31
Katzoff, S., 118
Kelley, D. F., 137
Kelly, F. J., 108, 125, 132, 137
Kirchner, H. P., 53
Kirk, D. D., 37
Kjelby, A. S., 76
Klein, J. D., 46, 119
Klemm, R. E., 20, 77
Kneissl, G. J., 137
Kollie, T. G., 80
Konopken, S., 77
Kozuka, T., 139
Larrabee, R. D., 19
Lazlo, T. S., 120
Levitt, A. P., 60, 134, 140
Limperis, T., 78
Lozier, W. W., 83
Lucks, C. F., 39, 41, 45, 47, 63
Lueckel, W. J., 142
Lundberg, W. R., 65
Luoma, W., 142
Lyons, G. J., 75
McAlister, E., 23
McCandless, L. C., 61, 94
McElroy, D. L., 80
McKeown, D., 123
McMahon, H. O., 8
McMahon, W. R., 50
McNicholas, H. J., 2
Malakelis, R., 93
Marsh, J. B., 36, 38
Martin, W. S., 36, 38
Metcalfe, A. F., 79
Middleton, E. K., 12
Mikk, G., 81
Miller, L. W., 105
Moffitt, G., 55
Moore, D. G., 82, 107, 116, 125, 141
Moore, V. S., 79
Morgan, W. R., 10
Morris, J. C., 22
Narasimhamurty, H. V. L., 98, 127
Noguchi, T., 139
Null, M. R., 83
Olson, O. H., 22, 31
Ornstein, L. S., 4
O'Sullivan, W. J., Jr., 43
Parker, W. J., 42, 54, 92, 112
Parmer, J. F., 136
Pears, C. D., 51, 84, 91, 95
Pearson, E. G., 94, 99
Peavy, B. A., 67
Plunkett, J. D., 106
Plyler, E. K., 27
Priest, I. G., 3
Reid, C., 23
Richmond, J. C., 25, 27, 32, 33, 57,
  85, 86, 102, 104,
  108, 126, 135, 137,
  138, 141
Riethof, T. R., 87
Riley, J. O., 3
Rolle, R. E., 100, 115
Rouse, G. F., 48
Rudkin, R. L., 92
Sanders, C., 9, 12
Scala, E., 124
Schatz, E. A., 61, 94, 99, 107, 111,
  129, 130
Schmidt, R. N., 121
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By D. W. Gates

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AUTHOR INDEX TO REFERENCES (Concluded)

Schwartz, H., 142
Seban, R. A., 52, 88, 100
Shaw, C. C., 34
Sheehan, P. J., 120
Shorten, F. J., 86, 104
Skramstad, H. K., 27, 57
Slep, W. S., 58, 89, 109, 113
Spitzig, W. A., 101
Stair, R., 27
Stetson, A. R., 79
Steward, J. E., 25
Stierwalt, D. L., 37
Streel, E. R., 72
Sully, A. H., 11
Sundheim, B. R., 18
Szeles, D. M., 78
Tatro, L. D., 105
Taylor, A. H., 1
Vassalo, F. A., 53
Voskresenskii, V., 103
Wade, W. R., 24, 26, 43, 58, 89
Walker, G. H., 62
Walker, R. F., 48
Waterhouse, R. B., 11
Wilson, R. G., 110, 122
Wolfe, W. L., 78
Wood, W. D., 39, 41, 45, 47, 63
Worthing, A. G., 5
<table>
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<tr>
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