ASTM

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Standard Test Method for
Normal Spectral Emittance at Elevated Temperatures of Nonconducting Specimens[1]

This standard is issued under the fixed designation E 423; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Section 11 was added editorially in May 1996.

INTRODUCTION

The general physical properties of ceramic materials combine to make thermal gradients a serious problem in the evaluation and use of thermal emittance data for such materials. Ceramic materials in general tend to be somewhat translucent, and hence emit and absorb thermal radiant energy within a surface layer of appreciable thickness. Ceramic materials in general also tend to have low thermal conductivity and high total emittance as compared to metals. These properties combine to produce thermal gradients within a heated specimen unless careful precautions are taken to minimize such gradients by minimizing heat flow in the specimen. The gradients tend to be normal to a surface that is emitting or absorbing radiant energy. As a further complication, the gradients tend to be nonlinear near such a surface.

When a specimen is emitting from a surface layer of appreciable thickness with a thermal gradient normal to the surface, it has no unique temperature, and it is difficult to define an effective temperature for the emitting layer. Emittance is defined as the ratio of the flux emitted by a specimen to that emitted by a blackbody radiator at the same temperature and under the same conditions. It is thus necessary to define an effective temperature for the nonisothermal specimen before its emittance can be evaluated. If the effective temperature is defined as that of the surface, a specimen with a positive thermal gradient (surface cooler than interior) will emit at a greater rate than an isothermal specimen at the same temperature, and in some cases may have an emittance greater than 1.0. If the thermal gradient is negative (surface hotter than interior) it will emit at a lesser rate. If the "effective temperature" is defined as that of an isothermal specimen that emits at the same rate as the nonisothermal specimen, we find that the effective temperature is difficult to evaluate, even if the extinction coefficient and thermal gradient are accurately known, which is seldom the case. If spectral emittance is desired, the extinction coefficient, and hence the thickness of the emitting layer, changes with wavelength, and we have the awkward situation of a specimen whose effective temperature is a function of wavelength.

There is no completely satisfactory solution to the problem posed by thermal gradients in ceramic specimens. The most satisfactory solution is to measure the emittance of essentially isothermal specimens, and then consider the effect of thermal gradients on the emitted radiant flux when attempting to use such thermal emittance data in any real situation where thermal gradients normal to the emitting surface are present.

1. Scope

1.1 This test method describes an accurate technique for measuring the normal spectral emittance of electrically non-conducting materials in the temperature range from 1000 to 1800 K, and at wavelengths from 1 to 35 μm. It is particularly suitable for measuring the normal spectral emittance of materials such as ceramic oxides, which have relatively low thermal conductivity and are translucent to appreciable depths (several millimetres) below the surface, but which become essentially opaque at thicknesses of 10 mm or less.

1.2 This test method requires expensive equipment and rather elaborate precautions, but produces data that are accurate to within a few percent. It is particularly suitable for research laboratories, where the highest precision and accuracy are desired, and is not recommended for routine production or acceptance testing. Because of its high accuracy, this test method may be used as a reference method to be applied to production and acceptance testing in case of dispute.

1.3 This test method requires the use of a specific specimen size and configuration, and a specific heating and viewing technique. The design details of the critical specimen furnace are presented in Ref (**1**),[2] and the use of a furnace of this design is necessary to comply with this test method. The transfer optics and spectrophotometer are discussed in general terms.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*
E 349 Terminology Relating to Space Simulation[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *spectral normal emittance*—The term spectral normal emittance (Note 4) as used in this specification follows that advocated by Jones (**2**), Worthing (**3**), and others, in that the word emittance is a property of a specimen; it is the ratio of radiant flux emitted by a specimen per unit area (thermal-radiant exitance) to that emitted by a blackbody radiator at the same temperature and under the same conditions. Emittance must be further qualified in order to convey a more precise meaning. Thermal-radiant exitance that occurs in all possible directions is referred to as hemispherical thermal-radiant exitance. When limited directions of propagation or observation are involved, the term directional thermal-radiant exitance is used. Thus, normal thermal-radiant exitance is a special case of directional thermal-radiant exitance, and means in a direction perpendicular (normal) to the surface. Therefore, spectral

normal emittance refers to the radiant flux emitted by a specimen within a narrow wavelength band and emitted into a small solid angle about a direction normal to the plane of an incremental area of a specimen's surface. These restrictions in angle occur usually by the method of measurement rather than by radiant flux emission properties.

NOTE 1—All the terminology used in this test method has not been standardized. Definitions E 349 contain some approved terms. When agreement on other standard terms is reached, the definitions used herein will be revised as required.

4. Summary of Test Method

4.1 The principle of the test method is direct comparison of the radiance of an isothermal specimen at a given temperature to that of a blackbody radiator at the same temperature. The details of the method are given by Clark and Moore (**1,4**).

NOTE 2—With careful attention to detail, overall accuracy of ± 2 % can be attained.

4.2 The essential features of the test method are (*1*) the use of a cylindrical sample that rotates in an electrically heated furnace and attains essentially isothermal conditions, and (*2*) the use of electronic controls to maintain the host specimen and blackbody reference at the same temperature.

4.3 A theoretical analysis (**5**) was made of thermal gradients in the rotating cylinder, supplemented by measurements of the temperature and temperature changes indicated by a small thermocouple imbedded 0.025 mm below the surface of a specimen of alumina, as the specimen rotated in front of a water-cooled viewing port. In brief, it was found that (*1*) the temperature fluctuations at the surface of the specimen were inversely related to the speed of rotation, and because negligibly small (2 K or less) at speeds of rotation greater than 50 r/min, and (*2*) the temperature indicated by a radiation shielded thermocouple suspended in the center of the rotating specimen was the same within 1 K as the average temperature indicated by the embedded thermocouple at speeds of rotation greater than 10 r/min.

NOTE 3—An electronic-null, ratio-recording spectrophotometer[4] is preferred to an optical-null instrument for this use. Special precautions may be necessary to obtain and maintain linearity of response of an optical-null instrument if the optical paths are not identical to those of the instrument as manufactured. Clark and Moore (**1**) describe linearity calibration of an optical-null instrument.

5. Significance and Use

5.1 The significant features are typified by a discussion of the limitations of the technique. With the description and arrangement given in the following portions of this test method, the instrument will record directly the normal spectral emittance of a specimen. However, the following conditions must be met within acceptable tolerance, or corrections must be made for the specified conditions.

5.1.1 The effective temperatures of the specimen and blackbody must be within 1 K of each other. Practical limitations arise, however, because the temperature uniformities are often not better than a few kelvins.

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[1] This test method is under the jurisdiction of ASTM Committee E-21 on Space Simulation and Applications of Space Technology and is the direct responsibility of Subcommittee E21.04 on Space Simulation Test Methods.

Current edition approved March 19, 1971.

[2] The boldface numbers in parentheses refer to the references listed at the end of this test method.

[3] *Annual Book of ASTM Standards*, Vol 15.03.

[4] The Perkin-Elmer Model 13-U prism spectrophotometer is one of several instruments found suitable for this test method.

5.1.2 The optical path length in the two beams must be equal, or, preferably, the instrument should operate in a nonabsorbing atmosphere, in order to eliminate the effects of differential atmospheric absorption in the two beams. Measurements in air are in many cases important, and will not necessarily give the same results as in a vacuum, thus the equality of the optical paths for dual-beam instruments becomes very critical.

Note 4—Very careful optical alignment of the spectrophotometer is required to minimize differences in absorptance along the two paths of the instrument, and careful adjustment of the chopper timing to reduce "cross-talk" (the overlap of the reference and sample signals) as well as precautions to reduce stray radiation in the spectrophotometer are required to keep the zero line flat. With the best adjustment, the "100 % line" will be flat to within 3 %.

5.1.3 Front-surface mirror optics must be used throughout, except for the prism in prism monochromators, and it should be emphasized that equivalent optical elements must be used in the two beams in order to reduce and balance attenuation of the beams by absorption in the optical elements. It is recommended that optical surfaces be free of SiO_2 and SiO coatings: MgF_2 may be used to stabilize mirror surfaces for extended periods of time. The optical characteristics of these coatings are critical, but can be relaxed if all optical paths are fixed during measurements or the incident angles are not changed between modes of operation (during 0 % line, 100 % line, and sample measurements). It is recommended that all optical elements be adequately filled with energy.

5.1.4 The source and field apertures of the two beams must be equal in order to ensure that radiant flux in the two beams compared by the apparatus will pertain to equal areas of the sources and equal solid angles of emission. In some cases it may be desirable to define the solid angle of the source and sample when comparing alternative measurement techniques.

5.1.5 The response of the detector-amplifier system must vary linearly with the incident radiant flux, or must be calibrated for linearity, and corrections made for observed deviations from linearity.

6. Apparatus

6.1 *Spectrophotometer*—The spectrophotometer used for the measurement of spectral normal emittance is equipped with a wavelength drive that provides automatic scanning of the spectrum of radiant flux and a slit servomechanism that automatically opens and closes the slits to minimize the variations of radiant flux in the comparison beam. For most materials the wavelength band-pass of the instrument is generally smaller than the width of any absorption or emission band in the spectrum to be measured. Operation of the spectrophotometer at a higher sensitivity level or in a single-beam mode can be used to evaluate band-pass effects. In a prism instrument, several prism compositions can be used to cover the complete wavelength range; however, a sodium chloride prism is typically used to cover the spectral range from 1.0 to 15 μm, and a cesium bromide prism to cover the spectral range from 15 to 35 μm. As a detector, a vacuum thermocouple with a sodium chloride window is used in the spectral range from 1 to 15 μm, and a vacuum thermocouple with a cesium bromide window in the spectral range from 1 to

35 μm. A black polyethylene filter is used to limit stray radiation in the 15 to 35-μm range.

6.1.1 In order to reduce the effects of atmospheric absorption by water vapor and carbon dioxide, especially in the 15 to 35-μm range, the entire length of both the specimen and reference optical paths in the instrument must be enclosed in dry nonabsorbing gas[5] (dew point of less than 223 K) by a nearly gastight enclosure maintained at a slightly positive pressure relative to the surrounding atmosphere.

6.2 *Specimen Furnace*—Fig. 1 is a schematic drawing of the specimen furnace used at the National Institute of Standards and Technology. The high-temperature alumina core surrounding the specimen is wound with 0.8-mm diameter platinum-40 % rhodium wire. The winding is continuous to the edges of the rectangular opening that is cut into the core to permit entrance of the viewing port. A booster winding of the same wire positioned on the outer alumina core, as indicated in Fig. 1, is used to compensate for the large heat losses at the center.

6.2.1 The water-cooled viewing port is machined from copper, and its inner surface is curved to the same radius as the specimen. A shield of platinum foil, 0.05 mm thick, surrounds the outer surfaces of the port, including the edges that face the specimen. This helps to isolate the viewing port thermally from the furnace interior. The inner surfaces of the viewing port and the portion of the platinum shield nearest the specimen are blackened to minimize the possibility of errors from reflected radiation. The opening at the inner end of the port is 3 mm wide by 12.7 mm high.

6.2.2 The alumina support tube (Fig. 1) is surface ground to the same tolerance as given in 7.1 for the test specimen. The spindle is driven by a ⅛-hp motor that is coupled to a gear reducer. With the arrangement used, the rotation of the specimen can be adjusted to any speed in the range from 1 to 300 r/min.

6.2.3 The design of the furnace shell is such that the furnace can be operated in an inert atmosphere, as well as in air. Glass-metal seals are used for power leads and rubber O-ring seals are used for the shell ends, as well as for a sodium chloride viewing window. The thrust bearings are designed to provide a reasonably gastight seal at the point where the spindle shaft enters the shell.

6.2.4 Axial temperature gradients in the specimens are reduced to low values by adjusting the power to the booster coil. The gradients are measured by sighting a micro-optical pyrometer on a rotating specimen through the viewing port. No temperature differences from top to bottom should be observed for any of the specimens at 1200 K. At 1400 K, the top may be as much as 2 K higher than the bottom, while at 1600 K, the top may be as much as 6 K higher. The precision to which the pyrometer can be read is about 2 K. The specimen thermocouple is located in the center of the specimen cavity and is shielded from furnace radiation as shown in Fig. 1.

6.3 *Blackbody Furnaces*—Fig. 2 is a schematic of the blackbody furnace used at the National Institute of Standards and Technology. Two of these are required in the measurement

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[5] CO_2-free air at a dew point of less than 223 K has been found satisfactory.
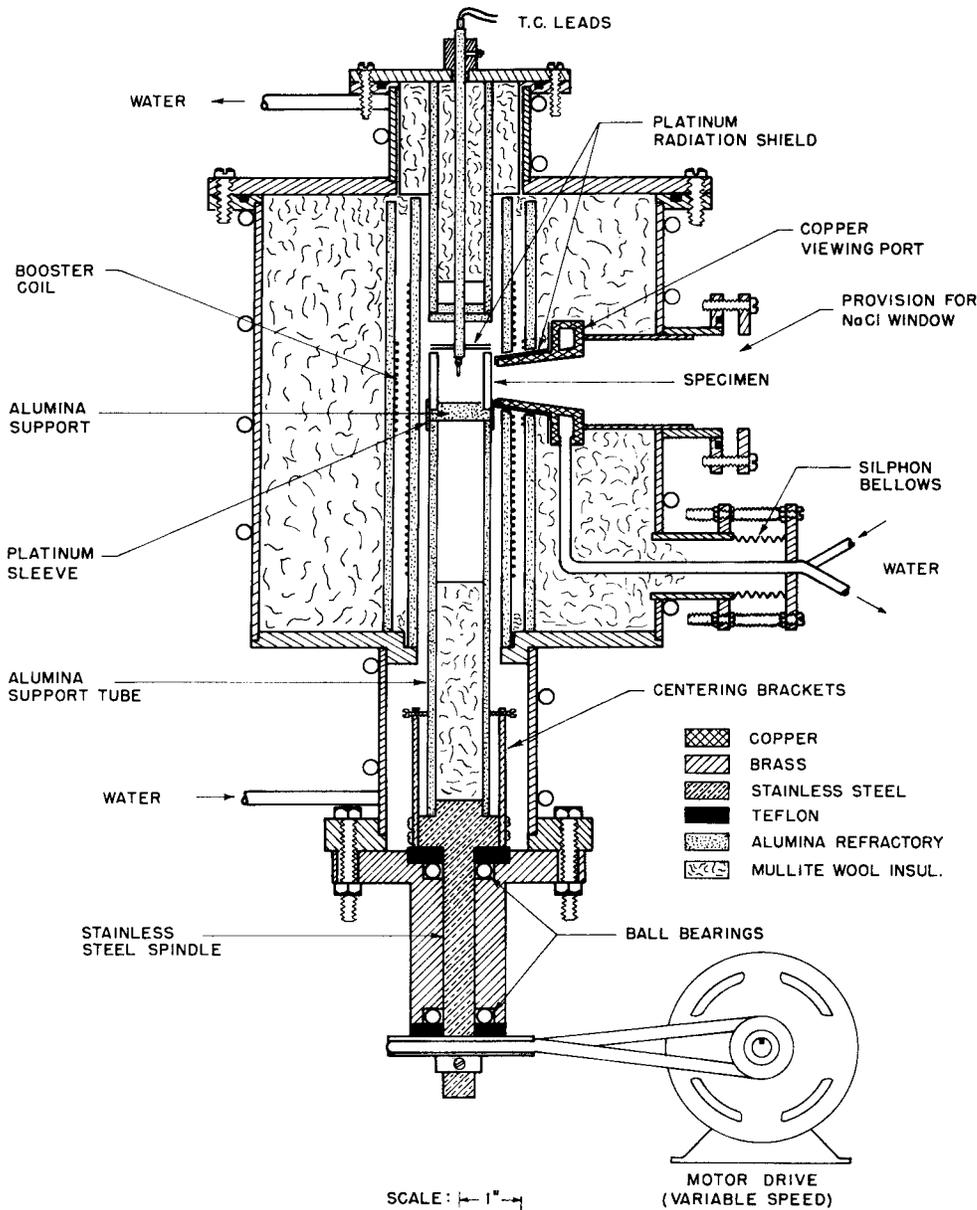
FIG. 1 Specimen Furnace

system and are made to be as nearly identical as possible. The inner cavity of the furnaces is formed of fused alumina bonded with 20 weight % of a calcium aluminate cement. This mixture, which sets hydraulically, is mixed with 17.5 weight % of water and vibrated into a greased plaster mold. The mold is made by using a grooved alumina tube as a pattern; a brass mandrel is positioned at the center of the mold to form the outline of the cavity. After allowing 20 h for curing, the core is removed from the mold, dried in an oven for 24 h, and then heated to 1925 K for 1 h. It is later wound with 0.8-mm diameter platinum-40 % rhodium resistance wire.

6.3.1 An alumina disk with a 12.7 by 3-mm center slit is placed over the front end of the cavity to reduce heat losses by radiation. The viewing port is formed with mullite wool, over which is placed a thin layer of alumina cement. The shaping of the port is facilitated by use of a tapered aluminum mandrel machined especially for the purpose.

6.3.2 All furnace thermocouples (including the one for the specimen furnace) are made of 0.5-mm diameter platinum—platinum-10 % rhodium wire that has been calibrated. Two-hole alumina tubing is used to insulate the leads. This tubing is inserted into an alumina sleeve that is cemented into the core so that when the thermocouple is inserted, it is nearly flush with the side wall of the cavity. With this arrangement, the spectrophotometer does not "see" the thermocouple bead, but rather is "looking" at the back of the cavity, which is largely isothermal. Of course, no important deviation from blackbody conditions will result from the presence of the thermocouple at the center of the cavity if the cavity is isothermal and if there is no separation between the alumina sleeving and the thermocouple tubing. However, a small clearance may be present, and this clearance will show up as a tiny dark crescent when
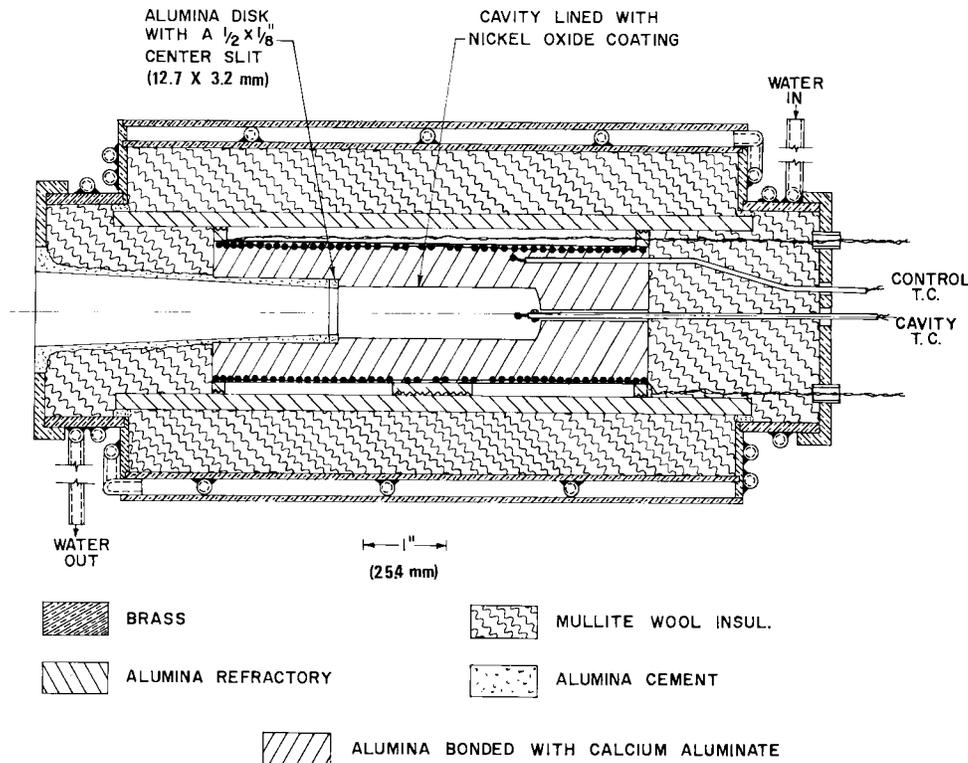
ALUMINA DISK
WITH A $\frac{1}{2}$ x $\frac{1}{8}$"
CENTER SLIT
(12.7 X 3.2 mm)

CAVITY LINED WITH
NICKEL OXIDE COATING

WATER
IN

CONTROL
T.C.

CAVITY
T. C.

WATER
OUT

|←— I"—→|
(25.4 mm)

▨ BRASS   ▨ MULLITE WOOL INSUL.

◺ ALUMINA REFRACTORY   ▨ ALUMINA CEMENT

▨ ALUMINA BONDED WITH CALCIUM ALUMINATE

FIG. 2   Blackbody Furnace

looking into the heated cavity. The presence of a dark area of this type is undesirable, in that it will tend to generate low flux readings.

6.3.3 The alumina core material has a low emittance in the wavelength region 1 to 5 µm. Inasmuch as the cavity emittance depends, in part, on the emittance of the walls, it is desirable to line the cavity with a coating having a high emittance at the short, as well as the long wavelengths. The coating developed for this purpose consists of black nickel oxide (Ni_2O_3) bonded with 7.5 weight % of Florida kaolin. This coating is prepared as a coating slip and applied at a thickness of about 0.13 mm to the inner wall surfaces of the cavity by a dipping operation. The core is then heated to 1850 K for 1 h to bond the coating to the alumina. The spectral emittance of a cylindrical specimen of the core material coated in this way was found to be above 0.875 at all wavelengths from 1 to 15 µm when measured at 1200 K. Hence, the lowest possible cavity emittance at any wavelength from 1 to 15 µm should be 0.990 when computed by an expression derived by Gouffé (**6**). This expression assumes that the walls are diffusely reflecting and that the cavity is isothermal. The expression has been shown to predict slightly low values of emittance for cavities with large depth-to-diameter ratios (**7**).

6.4 *Temperature Gradients in Blackbody Furnaces*— Several furnace designs were tested early in the study in an attempt to minimize temperature differences within the cavity. To test for gradients, a platinum–platinum-10 % rhodium thermocouple made with 0.25-mm diameter wire was inserted into the viewing port and moved from front to back with the hot junction within 3 mm of the interior wall. A record was made of the response at each position. In almost all cases, the indicated wall temperature near the center of the cavity was

higher than that at either end. In some instances power was shunted from the central region of the furnace windings, while in other tests varying numbers of turns were omitted from the heater coil. The final configuration was that shown in Fig. 2. No shunts were used and four loops were omitted in the central region. With this arrangement, temperature probing revealed that the cavity walls near the back were colder than those in the center by the amounts indicated below (Note 5).

Approximate Cavity Temperature, K	Temperature Difference, K
1200	18
1400	14
1600	8

NOTE 5—Large uncertainties existed in temperature measurements made near the front of the cavity, because of excessive heat losses by conduction along the thermocouple leads and the protection tubing.

6.4.1 The presence of these gradients ia a potential source of error in the measurements because of (*1*) uncertainty in determining the temperature to assign to the "blackbody" radiation, and (*2*) deviations from the Planck distribution of energy caused by the nonisothermal conditions. Naturally, it would be desirable if the spectral distribution of radiated energy, $M\lambda$, was proportional to the Planck function, $M_b^{(\lambda, T)}$, $M^\lambda = \epsilon^{cav} M_b(\quad, T)$. It was not immediately evident, however, that any single temperature could be assigned to the nonisothermal cavity. Temperatures that might be considered are the temperature of a thermocouple placed in the center of the cavity, the temperature of the back wall of the cavity, or the temperature indicated by an optical pyrometer sighted on the mouth of the cavity. This latter temperature was selected, since it represented the temperature of a perfect blackbody whose radiance at 0.65 µm was the same as that of the nonisothermal

5

laboratory furnace. A theoretical analysis is presented in Appendix A of Reference (**4**) to show that when a radiance match is achieved at 0.65 µm, then the spectral distribution of radiated energy can be approximated by a Planck function over the 1 to 15-µm range with no more than a 0.5 % error.

6.4.2 The procedure used for positioning the furnace thermocouple so that its response will agree with the temperature measured with a calibrated optical pyrometer is as follows:

6.4.2.1 The furnace is first heated to the desired operating temperature and allowed to stabilize.

6.4.2.2 A micro-optical pyrometer is then sighted at the front opening of the furnace and the optical temperature of the furnace cavity is determined.

6.4.2.3 The furnace thermocouple is next moved to a position where its response indicates the same temperature as that measured with the optical pyrometer. This position is always within 25 mm of the rear wall of the cavity.

6.4.2.4 Finally, a mark is placed on the thermocouple tubing at the back of the furnace shell so that the positioning of the junction can be duplicated in subsequent determinations at the same test temperature. This positioning is checked periodically to be certain that no changes in the temperature behavior of the furnace have occurred.

6.4.3 The calibration procedure as outlined needs to be applied to only one blackbody furnace. The position of the thermocouple in the second blackbody furnace can then be adjusted by noting the shape of the spectral curve that compares the energy from these two furnaces (100 % line, see 8.2.7). At long wavelengths, small temperature differences between the furnaces lead to negligible differences in energy content of the two beams, but at short wavelengths they have a pronounced effect. Thus, if the 100 % curve is higher at 1 µm than at 9 µm, it indicates that furnace No. 2 is at a higher temperature than the reference blackbody (No. 1). The thermocouple in No. 1 is then moved to a position where it indicates a lower temperature. The automatic control equipment will then lower the temperature of No. 2 until it matches that of No. 1 and a new spectral curve is determined. This procedure is repeated until a flat 100 % line is obtained. When this condition is achieved, furnace No. 1 is at the same effective temperature as No. 2 in that it is supplying an equivalent flux to the spectrophotometer.

6.5 *Temperature Control System*—A differential thermocouple control system similar to that described by Harrison et al (**8**) shall be used to maintain temperature differences of less than 10 K between blackbody No. 1 and either the specimen furnace or blackbody No. 2. The No. 1 furnace shall be controlled, in turn, by a separate temperature controller, which maintains its temperature at ± 0.5 K. A double-pole, double-throw switch shall be used for switching the differential thermocouple controller from blackbody No. 2 to the specimen furnace.

6.5.1 The differential thermocouple controller used is actuated by the difference in signal between the thermocouple in blackbody furnace No. 1 and the thermocouple in either blackbody No. 2 or the specimen furnace. This signal is amplified by a d-c amplifier and fed to a center-zero recorder-controller. The output of the recorder-controller, which is proportional to the temperature difference between the two furnaces, is fed to a current-actuating mechanism that provides three types of current control. One type is proportional to the input signal, a second to the first time derivative of the input signal, and a third selects the frequency at which the first correction is repeated. The output from this current actuating device is fed to the coil of a saturable-core reactor, which then varies the power input to either blackbody No. 2 or the specimen furnace, so as to bring the temperature into agreement with the reference blackbody (No. 1).

6.5.2 A block diagram of the temperature control equipment is shown in Fig. 3. The system gives almost trouble-free operation at 1200, 1400, and 1600 K. However, at 1800 K, it may become largely inoperative because of excessive noise in the thermocouple signal. This may originate from electrical leakage through the alumina core material, whose electrical conductivity becomes appreciable at these very high temperatures. For this reason, measurements at 1800 K may require manual temperature control.

6.6 *Transfer Optics*—Two optical systems are required (*1*) to focus an image of the aperture of the comparison blackbody furnace (No. 1 in Fig. 4) onto the entrance slit for the comparison beam of the spectrophotometers and (*2*) to focus an image of either the aperture of the reference blackbody furnace (No. 2 in Fig. 4) or the hot specimen onto the entrance slit of the specimen beam of the spectrophotometer. The two spherical mirrors used for focusing the two beams should be identical in diameter, focal length, and coating, and should be used at the same off-axis angle, and the off-axis angle should be kept as small as possible.

6.6.1 Because of the bulk and weight of the specimen furnace, it may not be possible to mount it and the reference blackbody (No. 2 in Fig. 4) on a lathe bed so that they can be alternately located with their respective apertures at the first focus of the optical system of the specimen beam of the spectrometer. Such an arrangement is preferred, if it can be used. If not, a movable mirror (mirror *E* in Fig. 4) shall be used to image the respective apertures on the entrance slit of the monochromator alternately. Care should be taken to ensure that (*1*) the angle of incidence (measured from the normal to the mirror) on mirror *E* of the central ray of the beam from the reference blackbody furnace is the same as that of the central
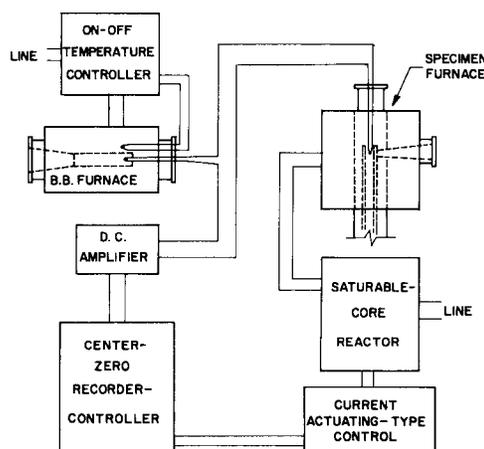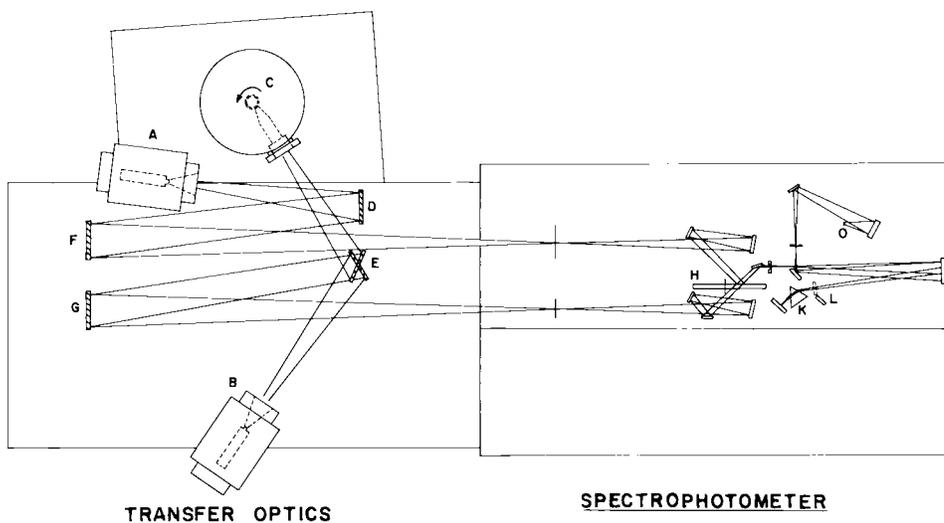

FIG. 3   Block Diagram of Temperature Control Equipment

TRANSFER OPTICS

A. Blackbody furnace No. 1
B. Blackbody furnace No. 2
C. Rotating specimen furnace
D. Flat front surface mirror
E. Movable flat mirror
F and G. spherical mirrors, 3" diam., 18" focal length

SPECTROPHOTOMETER

H. 10 c/s mirror - type chopper
K. NaCl prism
L. Movable mirror (for total normal measurements)
O. Vacuum - type thermocouple detector

FIG. 4   Schematic Diagram of Optical Paths

ray from the specimen furnace, (*2*) the respective beams are well centered on spherical mirror *G* (Fig. 4), (*3*) both beams overfill spherical mirror *G*, and (*4*) the images of the respective apertures are well-focused and well-centered on and overfill the entrance slit to the spectrometer. Stops should be provided so that mirror *E* can be quickly located and firmly fixed in either alternate position. Permanent magnets, mounted on the movable mirror mount, together with adjustable steel stops, may be used for this purpose.

7. Test Specimen

7.1 The specimens shall be hollow cylinders 25 ± 1 mm high and 25.4 + 0 − 0.5 mm in diameter with wall thicknesses sufficient to be essentially opaque, but not over 10 mm. The samples may have to be surface ground to the final diameter after fabrication. They must be cylindrical to 0.05 mm.

7.2 It is recommended that six replicate specimens of each material be measured for normal spectral emittance.

8. Procedure

8.1 The measurement procedure, in general, consists of comparing the radiance of a hot specimen to that of a laboratory blackbody furnace at the same temperature, as a function of wavelength.

8.2 *Mounting the Specimen*—The rotating assembly, including the bearings (see Fig. 1), is designed so that it can be easily removed from the specimen furnace. To mount a specimen, remove the rotating assembly from the specimen furnace and mount it in a special jig with the alumina support tube vertical. Check the centering of the alumina support tube to ensure that it is well-centered on the axis of rotation of the assembly. A feeler gage is convenient for this purpose. If the alumina support tube is not centered to about 0.05 mm, adjust the centering to bring it within this tolerance.

8.2.1 Center the specimen on top of the alumina support tube by use of an alumina support as illustrated in Fig. 1. When

centered, fix the specimen in position with high-temperature alumina cement. The maximum wobble of the specimen in the jig, after cementing, should not exceed 0.06 mm. Dry the cement in air. When the cement is dry, remove the top of the furnace, and replace the rotating assembly in the furnace. Check the centering of the specimen in the furnace from the top, and take care to ensure that there is adequate clearance between the specimen and the viewing port. Replace the furnace top.

8.2.2 Heat the specimen furnace to a temperature of approximately 1400 K over a period of not less than 4 h. Rotate the specimen at a speed of 100 r/min during the heating. When a temperature of 1400 K has been reached, remove the top of the furnace again, and check the centering of the specimen with a telescope with a calibrated reticle. Adjust the position of the rotating assembly radially by moving the bottom flange (adjustment screws for this purpose, not shown on Fig. 1, should be provided) until the average clearance between the specimen and viewing port is 0.25 mm. Wobble of the specimen, as indicated by variations in the clearance as the specimen revolves, shall not exceed 0.12 mm. When the specimen has been adjusted to the proper position, replace the furnace top.

8.2.3 Heat the two blackbody furnaces to approximately 1600 K, temperature control being attained by manual adjustment of the power input. This can be done during the period when the specimen is being mounted and adjusted.

NOTE 6—The blackbody furnaces and the specimen furnace are heated by platinum-rhodium windings. The resistance of this heater wire increases markedly with temperature. The windings should be heated slowly, particularly at low temperatures, in order to avoid burnout of the heater winding due to local heating. Start the heating at a low input voltage, and increase the voltage slowly until the winding reaches a temperature of at least 100°C.

8.2.4 When the comparison blackbody furnace has reached a temperature of about 1600 K, set the controller at 1600 K and

hold it at that temperature. Check the temperature with an optical pyrometer, and adjust the position of the control thermocouple if necessary to bring the blackbody to brightness temperature of 1600 K.

8.2.5 Turn on the automatic temperature control, and switch the reference blackbody to the saturable core-reactor power supply. Bring the reference blackbody to the same (indicated) temperature as the comparison blackbody. Check the temperature of the reference blackbody with the optical pyrometer, and adjust the position of the control thermocouple if necessary to bring its brightness temperature to 1600 K.

8.2.6 Use the optical pyrometer to check the temperature uniformity of the rotating specimen. No gradient should be detected from side to side of the aperture, and the temperature at the top of the aperture should not be more than 6 K higher than that at the bottom. If the axial gradient is more than 6 K, increase the power in the booster winding until the gradient is 6 K or less.

8.2.7 When the temperatures of all three furnaces have been checked and adjusted as required, the reference blackbody is connected to the saturable core-reactor power supply. When it has reached temperature equilibrium, adjust mirror E (Fig. 4) to project an image of the aperture of the reference blackbody onto the entrance slit of the specimen beam of the spectrophotometer (or move the reference blackbody into position to serve as the source for the specimen beam). Record the flux ratio of

the two beams over the desired spectral range. This will be the ratio of the apparent radiances of the two blackbodies, and is the 100 % line on the chart (Fig. 5). Block the beam near the reference blackbody with a highly reflective shutter and again record the flux ratio of the two beams over the desired spectral range. This will be the 0 % line on the chart (Fig. 5). Switch the saturable core-reactor power supply and control from the reference blackbody to the specimen furnace. When the temperature of the specimen has stabilized, move mirror E to focus an image of the specimen onto the entrance slit of the specimen beam of the spectrophotometer (or move the specimen furnace into position to serve as the source for the specimen beam) and record the flux ratio of the two beams over the desired spectral range. This will be the specimen line on the chart (Fig. 5).

9. Calculation

9.1 Calculate the spectral emittance, ϵ, of the specimen, at each wavelength, as the height of the specimen line, S_λ, minus the zero line, Z_λ, divided by the height of the 100 % line, H_λ, minus the zero line as follows:

$$\epsilon\lambda = (S_\lambda - Z_\lambda)/(H_\lambda - Z_\lambda) \qquad (1)$$

9.2 Repeat the above procedure for measurements at other temperatures between 1600 and 1000 K, as desired. Measurements can be made at 1800 K, but the automatic control of the specimen furnace is likely to be unsatisfactory at 1800 K.
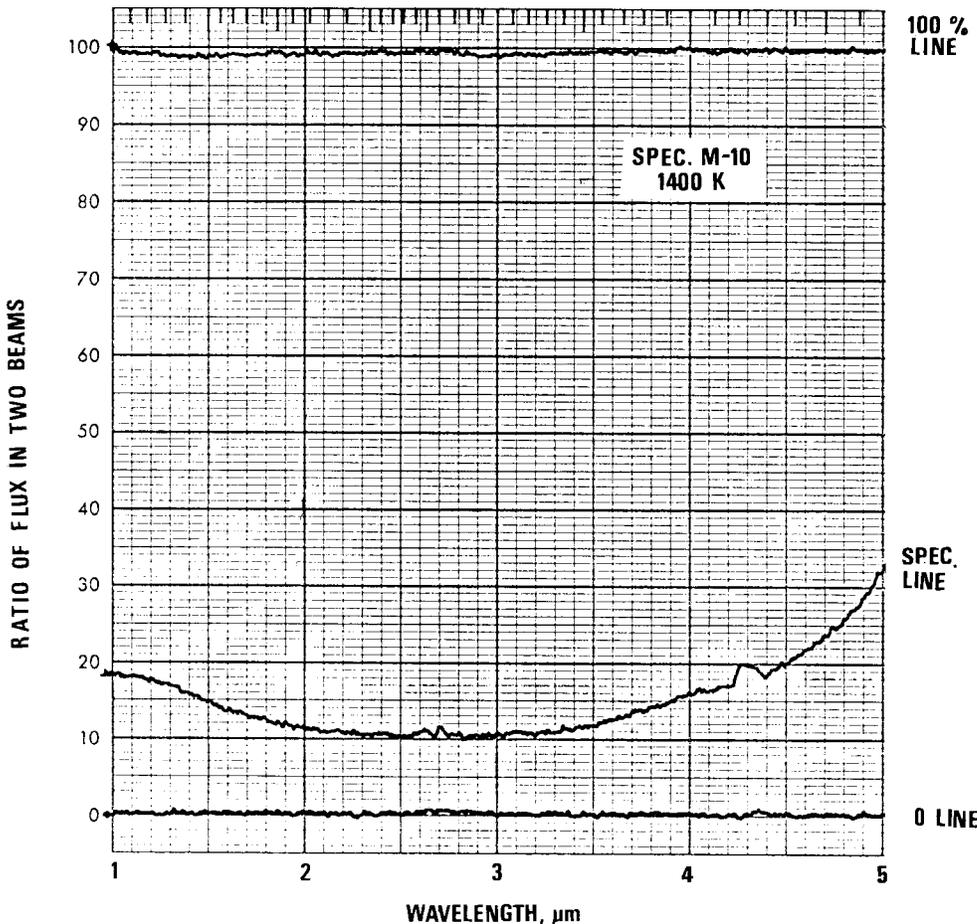

FIG. 5 Section of Recorder Chart Showing Sements of "100% Line," "Specimen Line," and "Zero Line"

8

Control of the temperature of the specimen furnace may have to be achieved by manual adjustment of power input.

9.3 *Errors*—Reference 1 contains a discussion of the possible errors of this test method. In general, if necessary precautions are taken, errors should not exceed 0.02 in normal spectral emittance.

10. Report

10.1 The test report shall include the identification of the sample, and the value for the mean and standard deviation of the six measured values of emittance at each temperature and wavelength. As an alternative, the mean value of emittance may be plotted as a function of wavelength, at intervals of not less than 0.5 µm. If the values are plotted, the standard deviations may be plotted on the same curve, or reported separately, as desired.

10.2 The test report shall include all known information about the sample. The chemical composition, grain size, and relative amount of all raw materials, mixing and forming processes used, including all pertinent data such as water content of mix, forming pressure of pressed materials, type of extruding equipment if extruded, etc.; time-temperature schedule of firing, chemical composition, density, porosity, surface finish, crystal structure and grain size of fired specimens shall be given if available.

11. Keywords

11.1 emittance; infrared emittance; material radiative property; radiative heat transfer; spacecraft thermal control; spectral normal emittance; thermal radiation

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