Designation: E 408 – 71 (Reapproved 1996)$^{\epsilon 1}$

Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques[1]

This standard is issued under the fixed designation E 408; 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 6 was added editorially in May 1996.

1. Scope

1.1 These test methods cover determination of the total normal emittance (Note) of surfaces by means of portable, inspection-meter instruments.

NOTE 1—Total normal emittance (ϵ_N) is defined as the ratio of the normal radiance of a specimen to that of a blackbody radiator at the same temperature. The equation relating ϵ_N to wavelength and spectral normal emittance [ϵ_N (λ)] is

$$\epsilon_N = \int_0^\infty L_b(\lambda, T)\epsilon_N(\lambda)d\lambda / \int_0^\infty L_b(\lambda, T)d\lambda \quad (1)$$

where:

$L_b(\lambda, T)$	=	Planck's blackbody radiation function $= c_1\pi^{-1}\lambda^{-5}(e^{c_2/\lambda T} - 1)^{-1}$,
c_1	=	3.7415×10^{-16} W·m^2,
c_2	=	1.4388×10^{-2} m·K,
T	=	absolute temperature, K,
λ	=	wavelength, m,
$\int_0^\infty L_b(\lambda, T)d\lambda$	=	$\Delta\pi^{-1}T^4$, and
Δ	=	Stefan-Boltzmann constant = 5.66961×10^{-8} W·m^2·K^{-4}

1.2 These test methods are intended for measurements on large surfaces when rapid measurements must be made and where a nondestructive test is desired. They are particularly useful for production control tests.

1.3 *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. Summary of Test Methods

2.1 At least two different types of instruments are commercially available for performing this measurement. One type measures radiant energy reflected from the specimen (Test Method A),[2] and the other type measures radiant energy emitted from the specimen (Test Method B).[3] A brief description of the principles of operation of each test method follows.

2.1.1 *Test Method A*—The theory employed in Test Method A has been described in detail by Nelson et al[4] and therefore is only briefly reviewed herein. The surface to be measured is placed against an opening (or aperture) on the portable sensing component. Inside the sensing component are two semicylindrical cavities that are maintained at different temperatures, one at near ambient and the other at a slightly elevated temperature. A suitable drive mechanism is employed to rotate the cavities alternately across the aperture. As the cavities rotate past the specimen aperture, the specimen is alternately irradiated with infrared radiation from the two cavities. The cavity radiation reflected from the specimen is detected with a vacuum thermocouple. The vacuum thermocouple views the specimen at near normal incidence through an optical system that transmits radiation through slits in the ends of the cavities. The thermocouple receives both radiation emitted from the specimen and other surfaces, and cavity radiation which is reflected from the specimen. Only the reflected energy varies with this alternate irradiation by the two rotating cavities, and the detection-amplifying system is made to respond only to the alternating signal. This is accomplished by rotating the cavities at the frequency to which the amplifier is tuned. Rectifying contacts coupled to this rotation convert the amplifier output to a d-c signal, and this signal is read with a millivoltmeter. The meter reading must be suitably calibrated with known reflectance standards to obtain reflectance values on the test surface. The resulting data can be converted to total normal emittance by subtracting the measured reflectance from unity.

2.1.2 *Test Method B*—The theory of operation of Test Method B has been described in detail by Gaumer et al[5] and is

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

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[2] A satisfactory instrument for this type of measurement is the Infrared Reflectometer Model DB 100, manufactured by Gier-Dunkle Instruments, Inc., Torrance, CA.

[3] A satisfactory instrument for this type of measurement is the Model 25A Emissometer, manufactured by the Lion Research Corp., Cambridge, MA.

[4] Nelson, K. E., Leudke, E. E., and Bevans, J. T., *Journal of Spacecraft and Rockets*, Vol 3, No. 5, 1966, p. 758.

[5] Gaumer, R. E., Hohnstreiter, G. F., and Vanderschmidt, G. F., "Measurement of Thermal Radiation Properties of Solids," *NASA SP-31*, 1963, p. 117.

briefly reviewed as follows: The surface to be measured is placed against the aperture on the portable sensing component. Radiant energy which is emitted and reflected from the specimen passes through a suitable transmitting vacuum window and illuminates a thermopile. The amount of energy reflected from the specimen is minimized by cooling the thermopile and the cavity walls which the specimen views. The output of the thermopile is amplified and sensed by a suitable meter. The meter reading must be calibrated with standards of known emittance.

3. Limitations

3.1 Both test methods are limited in accuracy by the degree to which the emittance properties of calibrating standards are known and by the angular emittance characteristics of the surfaces being measured.

3.2 Test Method A is normally subject to a small error caused by the difference in wavelength distributions between the radiant energy emitted by the two cavities at different temperatures, and that emitted by a blackbody at the specimen temperature. Test Method B also has nongray errors since the detector is not at absolute zero temperature. The magnitude of this type of error is discussed by Nelson et al.[4]

3.3 Test Method A is subject to small errors that may be introduced if the orientation of the sensing component is changed between calibration and specimen measurements. This type of error results from minor changes in alignment of the optical system.

3.4 Test Method A is subject to error when curved specular surfaces of less than about 300-mm radius are measured. These errors can be minimized by using calibrating standards that have the same radius of curvature as the test surface.

3.5 Test Method A can measure reflectance on specimens that are either opaque or semi-transparent in the wavelength region of interest (about 4 to 50 µm). However, if emittance is to be derived from the reflectance data on a semi-transparent specimen, a correction must be made for transmittance losses.

3.6 Test Method B is subject to several possible significant errors. These may be due to (*1*) variation of the test surface temperature during measurements, (*2*) differences in temperature between the calibrating standards and the test surfaces, (*3*) changes in orientation of the sensing component between calibration and measurement, (*4*) errors due to irradiation of the specimen with thermal radiation by the sensing component, and (*5*) errors due to specimen curvature. Variations in test surface temperature severely limit accuracy when specimens that are thin or have low thermal conductivity are being measured. Great care must be taken to maintain the same temperature on the test surface and calibrating standards. Meter readings are directly proportional to the radiant flux emitted by the test surface, which in turn is proportional to the fourth power of temperature. Changes in orientation of the sensing component between calibration and test measurement introduces errors due to temperature changes of the thermopile. The relatively poor vaccuum around the thermopile results in variations in convection heat transfer coefficients which are affected by orientation.

3.7 Test Method B is limited to emittance measurements on specimens that are opaque to infrared radiation in the wavelength region of interest (about 4 to 50 µm).

3.8 The emittance measured by Test Method B is an intermediate value between total-normal and total-hemispherical emittance because of the relationship between the thermocouple sensing elements and the test surface. The close proximity of the thermopile to the relatively large test surface allows it to receive radiation emitted over a significant angle (up to 80°). This error (the difference between total-normal and total-hemispherical) emittance can be as large as 10 % on certain types of specimens (such as specular metal surfaces).

4. Procedure

4.1 Calibration procedures for both test methods of measurement are jointly discussed because of their similarity. In Test Method A infrared reflectance properties of calibrating standards must be known, and for Test Method B emittance values of standards are utilized. Following an appropriate warm-up time, calibrate the readout meter. Adjust the meter to give the correct reading when measuring both high and low emittance (or reflectance) standards. Repeat calibration of the meter several times at short time intervals until the correct readings can be obtained near each end of the scale. Typical high and low emittance (low and high reflectance) standards may consist of black paint (or preferably a blackbody cavity) and polished high-purity aluminum, respectively. Measure the thermal radiation properties of the standards independently with an absolute instrument, and maintain the standards in a clean condition thereafter.

4.2 In Test Method B care must be taken to prevent stray radiant energy from entering the sensor. This can occur if the test surface is not sufficiently flat or is not opaque.

4.3 In Test Method B the test surfaces and calibrating standards must be maintained at the same temperature. If thin (less than about 0.7 mm thick) conducting specimens are to be measured, they should be bonded to a thick metallic substrate. Specimen temperature changes can be noted by observing whether the indicated meter reading drifts with time.

4.4 In Test Method B the orientation of the sensor must be the same for both calibration and test surface measurements.

4.5 After the meter has been properly calibrated, place the test surface over the aperture of the measuring instrument. The resulting meter reading of Test Method A is then the infrared reflectance for blackbody radiant energy at near room temperature, or in Test Method B, a meter reading that can be converted to emittance using the manufacturer's emittance/meter reading conversion data. In Test Method A, obtain the emittance by subtracting the reflectance from unity. It is recommended that the instrument be recalibrated as soon as possible after measuring the test surface. If the meter calibration has changed, repeat the entire calibration and readout procedure. It is recommended that at least three readings be taken for each test specimen, and the results averaged, to minimize statistical errors. It is also recommended that both laboratory and working emittance (or reflectance) standards be maintained, and that they be kept clean.

5. Report

5.1 Report the following information:

5.1.1 Name and pertinent other identification of the test material,

5.1.2 Name and pertinent other identification or traceability of the surfaces used for calibration,

5.1.3 Emittance (or reflectance) values assumed for calibration surfaces,

5.1.4 Locations on the surface area at which emittance (or reflectance) measurements were performed (not applicable for small individual test specimens),

5.1.5 Ambient temperature,

5.1.6 For Test Method A the indicated meter reading (reflectance) shall be recorded for three successive measurements. An average of the three values shall than be calculated and subtracted from one to obtain the emittance,

5.1.7 For Test Method B the indicated meter reading shall be recorded for three successive measurements. These meter readings shall be converted to emittance using the manufacturer's data, and then averaged, and

5.1.8 Date and time the measurements were taken.

6. Keywords

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