



Standard Test Method for Measuring Heat Flux Using a Copper-Constantan Circular Foil, Heat-Flux Transducer¹

This standard is issued under the fixed designation E 511; 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.

1. Scope

1.1 This test method describes the measurement of radiative or convective heat flux, or both, using a transducer whose sensing element **(1, 2)**² is a thin circular metal foil. While benchmark calibration standards exist for radiative environments, no uniform agreement among practitioners or government entities exists for convective environments.

1.2 The values stated in SI units are to be regarded as the standard. The values stated in parentheses are provided for information only.

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 Method

2.1 The purpose of this test method is to facilitate measurement of heat flux from radiant or convective sources, or from a combination of the two.

2.2 The circular foil heat flux transducer generates a millivolt output in response to the rate of thermal energy absorbed (see Fig. 1). The circular metal foil sensing element is mounted in a metal heat sink around its perimeter, forming a reference thermocouple junction due to their different thermoelectric potentials. A second thermocouple junction is formed at the center of the foil using a fine wire of the same metal as the heat sink. When the sensing element is exposed to a heat source, heat energy is absorbed at the surface of the circular foil and conducted radially to the heat sink. This establishes a parabolic temperature gradient between the center and edge of the foil. The temperature gradient produces a thermoelectric potential, E , between the center wire and the heat sink that will vary in proportion to the heat flux, q'' . With prescribed foil diameter, thickness, and materials, the potential E is linearly proportional

to the heat flux q'' absorbed by the foil. This relationship is described by the following equation:

$$E = Kq''$$

where:

K = a sensitivity constant determined experimentally.

2.3 For linear response, the heat sink of the transducer normally is made of copper and the foil of thermocouple grade constantan. This combination of materials produces a linear output over a temperature range from -45 to 232°C (-50 to 450°F). The linear range results from offsetting effects of temperature-dependent changes in the thermal conductivity and Seebeck coefficient of the constantan. All further discussion is based on the use of these two metals, since engineering practice has demonstrated they are commonly the most useful.

3. Characteristics and Limitations

3.1 The principal response characteristics of a circular foil heat flux transducer are sensitivity, full-scale range, and the time constant, which are established by the foil diameter and thickness. For a given heat flux, the transducer sensitivity is proportional to the temperature difference between the center and edge of the circular foil. To increase sensitivity, the foil is made thinner or its diameter is increased. The full-scale range of a transducer is limited by the maximum allowed temperature at the center of the foil. The range may be increased by making the foil smaller in diameter, or thicker. The transducer time constant approximately is proportional to the square of the foil diameter, and is characterized by **(3)**:

$$\tau = \rho c d^2 / 16k$$

where the foil properties are:

ρ = density,

c = specific heat,

d = foil diameter, and

k = foil conductivity.

3.2 Foil diameters and thicknesses are limited by typical manufacturing constraints. Maximum optimum foil diameter to thickness ratio is 4 to 1 for sensors less than 2.54 mm diameter. Foil diameters range from 25.4 mm to 0.254 mm, with most gages between 1.02 and 6.35 mm. The time constants, τ , for a 25.4-mm and 0.254-mm diameter foil are 6 s and 0.001 s, respectively. For constantan, the time constant is approximated

¹ This test method is under the jurisdiction of ASTM Committee E21 on Space Simulation and Applications of Space Technology and is the direct responsibility of Subcommittee E21.08 on Thermal Protection.

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