This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

INTERNATIONAL

Designation: E2684 – 24

Standard Test Method for Measuring Heat Flux Using Surface-Mounted One-Dimensional Flat Gages[1]

This standard is issued under the fixed designation E2684; 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 the net heat flux normal to a surface using flat gages mounted onto the surface. Conduction heat flux is not the focus of this standard. Conduction applications related to insulation materials are covered by Test Method C518 and Practices C1041 and C1046. The sensors covered by this test method all use a measurement of the temperature difference between two parallel planes normal to the surface to determine the heat that is exchanged to or from the surface in keeping with Fourier's Law. The gages operate by the same principles for heat transfer in either direction.

1.2 This test method is quite broad in its field of application, size and construction. Different sensor types are described in detail in later sections as examples of the general method for measuring heat flux from the temperature gradient normal to a surface (**1**).[2] Applications include both radiation and convection heat transfer. The gages have broad application from aerospace to biomedical engineering with measurements ranging form $0.01\ \mathrm{kW/m^2}$ to $50\ \mathrm{kW/m^2}$. The gages are usually square or rectangular and vary in size from 1 mm to 10 cm or more on a side. The thicknesses range from 0.05 to 3 mm.

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

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
C1041 Practice for In-Situ Measurements of Heat Flux in Industrial Thermal Insulation Using Heat Flux Transducers (Withdrawn 2019)[4]
C1046 Practice for In-Situ Measurement of Heat Flux and Temperature on Building Envelope Components
C1130 Practice for Calibration of Thin Heat Flux Transducers
E456 Terminology Relating to Quality and Statistics

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *heat flux*—the heat transfer per unit area, q, with units of $\mathrm{W/m^2}$ ($\mathrm{Btu/ft^2}$-s). *Heat transfer* (or alternatively heat transfer rate) is the rate of thermal energy movement across a system boundary with units of watts (Btu/s). This usage is consistent with most heat transfer books.

3.1.2 *heat transfer coefficient, (h)*—an important parameter in convective flows with units of $\mathrm{W/m^2}$-K ($\mathrm{Btu/ft^2}$-s-°F). This is defined in terms of the heat flux q as:

$$h = \frac{q}{\Delta T} \quad (1)$$

where ΔT is a prescribed temperature difference between the surface and the fluid. The resulting value of h is intended to be only a function of the fluid flow and geometry, not the temperature difference. If the surface temperature is non-uniform or if there is more than a single fluid free stream temperature, the proper definition of ΔT may be difficult to specify (**2**). It is always important to clearly define ΔT when

[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.

Current edition approved Oct. 1, 2024. Published December 2024. Originally approved in 2009. Last previous edition approved in 2017 as E2684 – 17. DOI: 10.1520/E2684-24.

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

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

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calculating the heat transfer coefficient.

3.1.3 *incident radiation, $q_{inc,r}$*—the radiation heat flux that is incoming or incident on a surface with units of W/m^2 (BTU/ft^2-s). In general, a portion of the heat flux will be absorbed and some will be reflected from the surface.

3.1.4 *net heat flux, q_{net}*—the heat flux that is into a surface with units of W/m^2 (BTU/ft^2-s). It represents the net of the incoming and outgoing heat flux and is what is transported through a heat flux gage by conduction. It is what is measured by the heat flux gage.

3.1.5 *surface emissivity, (ε)*—the ratio of the emitted thermal radiation from a surface to that of a blackbody at the same temperature. Surfaces are assumed to be gray bodies where the emissivity is equal to the absorptivity.

3.1.6 *thermal resistance, (R_t)*—the ratio of the temperature difference to the heat flux with units of m^2-K/W (ft^2-°F-s/BTU). Consequently, for the same heat flux, a higher thermal resistance gives a larger temperature drop.

3.1.7 *thermal capacitance, (C_t)*—the ratio of the heat transfer to a material to the rate of transient temperature rise. It is proportional to the mass and specific heat of the material with units of J/K (BTU/°F).

4. Summary of Test Method

4.1 A schematic of the sensing technique is illustrated in Fig. 1. Temperature is measured on either side of a thermal resistance layer of thickness, δ. This is the heat-flux sensing mechanism of this test method. The measured heat flux is in the same direction as the temperature difference and is proportional to the temperature gradient through the thermal-resistance layer (TRL). The resistance layer is characterized by its thickness, δ, thermal conductivity, *k*, and thermal diffusivity, α. The properties are generally a weak function of temperature.

$$q = \frac{k}{\delta}(T_1 - T_2) \tag{2}$$

From this point the different gages may vary substantially in how the temperature difference $T_1 - T_2$ is measured and the thickness of the thermal resistance layer used. These aspects of each different type of sensor are discussed along with the implications for measurements.

4.2 Heat-flux gages using this test method generally use either thermocouple elements or resistance-temperature elements to measure the required temperatures.

4.2.1 Resistance temperature detectors (RTDs) generally have greater sensitivity to temperature than thermocouples, but require separate temperature measurements on each side of the thermal-resistance layer. The temperature difference must then be calculated as the small difference between two relatively large values of temperature.

4.2.2 Thermocouples can be arranged in series across the thermal-resistance layer as differential thermocouple pairs that measure the temperature difference directly. The pairs can also be put in series to form a differential thermopile to increase the sensitivity to heat flux.

$$S = \frac{E}{q} = \frac{N\sigma_T\delta}{k} \tag{3}$$

Here *N* represents the number of thermocouple pairs forming the differential thermopile and σ_T is the effective temperature sensitivity (Seebeck coefficient) of the two thermocouple materials. Although the voltage output is directly proportional to the heat flux, the sensitivity may be a function of the gage temperature. The calibrated gage sensitivity in Eq 3 applies only under steady-state conditions.

5. Significance and Use

5.1 This test method will provide guidance for the measurement of the net heat flux to or from a surface location. To determine the radiant energy component the emissivity or absorptivity of the gage surface coating is required and should be matched with the surrounding surface. The potential physical and thermal disruptions of the surface due to the presence of the gage should be minimized and characterized. For the case of convection and low source temperature radiation to or from the surface it is important to consider how the presence of the gage alters the surface heat flux. The desired quantity is usually the heat flux at the surface location without the presence of the gage.

5.1.1 Temperature limitations are determined by the gage material properties and the method of application to the surface. The range of heat flux that can be measured and the time response are limited by the gage design and construction details. Measurements from 10 W/m^2 to above 100 kW/m^2 are easily obtained with current sensors. Time constants as low as 10 ms are possible, while thicker sensors may have response

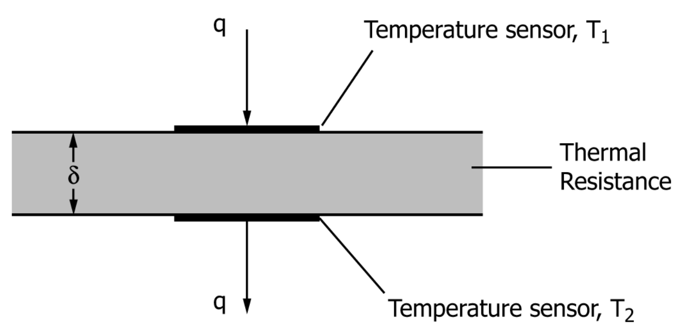

FIG. 1 Layered Heat-Flux Gage