



Standard Test Method for Measuring Heat Flux Using Directional Flame Thermometers with Advanced Data Analysis Techniques¹

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INTRODUCTION

This test method describes a technique for measuring the net heat flux to one or both surfaces of a sensor called a Directional Flame Thermometer. The sensor covered by this standard uses measurements of the temperature response of two metal plates along with a thermal model of the sensor to determine the net heat flux. These measurements can be used to estimate the total heat flux (aka thermal exposure) and bi-directional heat fluxes for use in CFD thermal models.

The development of Directional Flame Thermometers (DFTs) as a device for measuring heat flux originated because commercially available, water-cooled heat flux gauges (for example, Gardon and Schmidt-Boelter gauges) did not work as desired in large fire tests. Because the Gardon and Schmidt-Boelter (S-B) gauges are water cooled, condensation and soot deposition can occur during fire testing or in furnaces. Both foul the sensing surface which in turn changes the sensitivity (calibration) of the gauge. This results in an error during data reduction. Therefore, a different type of sensor was needed; one such sensor is a DFT. DFTs are not cooled so condensation and soot deposition are minimized or eliminated.

Additionally, a body of work has shown that for both Gardon and Schmidt-Boelter gauges the sensitivity coefficients determined through the calibration process, which uses a radiative heat source, are not the same as the sensitivity coefficients determined if a purely convective source is used for calibration [Test Method E511-07; Keltner and Wildin, 1975 (**1**, **2**); Borell, G. J., and Diller, T. E., 1987 (**3**); Gifford, A., et al., 2010 (**4**); Gritzo, L. A., et al., 1995 (**5**); Young, M. F., 1984 (**6**); Sobolik, et al., 1987 (**7**); Kuo and Kulkarni, 1991 (**8**); Keltner, 1995 (**9**); Gifford, et al., 2010 (**10**); Nakos, J. T., and Brown, A. L., 2011 (**11**)].² As a result, one can incur significant bias errors when reducing data in tests where there may be a non-negligible convective component because the only sensitivity coefficient available is for a radiation calibration. It was desired to reduce/eliminate these potential source of error by designing a gauge that does not depend on a radiation only calibration. DFTs have this characteristic.

A sensor, also called a Directional Flame Thermometer, was developed to help estimate flame thickness in pool fire tests of hazardous material shipping containers [Burgess, M. H., 1986 (**12**); Fry, C. J., 1989 (**13**); Burgess, M. H., et al., 1990 (**14**); and Fry, C. J., 1992 (**15**)]. As originally designed, DFTs were quasi-equilibrium sensors that used a thin metal plate with a single thermocouple attached and backed by multiple radiation shields. To make a sensor suitable for continuous transient heat flux measurements, this basic design was modified to use two instrumented plates, with a layer of insulation in between.

For the Directional Flame Thermometers described in this standard, the net heat flux is calculated using transient temperature measurements of the two plates and temperature dependent material properties for the plates and the insulation. Three methods are described in this standard to calculate the net heat flux. The most accurate method for calculating the net heat flux is believed to be the 1-dimensional, nonlinear inverse heat conduction analysis, which uses the IHCP1D code. This is based on uncertainty analyses and comparisons with measurements made with Schmidt-Boelter and Gardon gauges, which have NIST traceable calibrations. The second method uses a transient energy balances on the DFT. As will be shown below, the energy balance method compares very well with the inverse method, again based on uncertainty analyses. The third method uses sets of linearized, convolution digital filters based on IHCP1D. These allow a near real-time calculation of the net heat flux [Keltner, N. R., 2007 (**16**); Keltner, N. R., et al., 2010 (**17**)]. See Section 1 for more detailed information on each