**NISTIR 6242**

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## Book of Abstracts
## November 2-5, 1998

Kellie Ann Beall, Editor

Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

NIST

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**U.S. Department of Commerce**
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**Technology Administration**
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# TEMPERATURE UNCERTAINTIES FOR BARE-BEAD AND ASPIRATED THERMOCOUPLE MEASUREMENTS IN FIRE ENVIRONMENTS

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## 1. INTRODUCTION

Gas-phase temperature is the most ubiquitous measurement recorded in fire environments and plays a central role in understanding of fire behavior. Generally, either bare-bead or sheathed thermocouples are employed. While it is recognized that such thermocouples are subject to significant systematic errors when used in fire environments, e.g., see [1], in most fire studies uncertainties for temperature measurements are not estimated or reported.

The work summarized here has been undertaken to characterize the uncertainties in temperature measurements which can occur when bare-bead thermocouples are used in fire environments and to assess the potential of two approaches--aspirated thermocouples and the use of multiple thermocouples having different diameters--to reduce the uncertainties.

## 2. THERMOCOUPLE RESPONSE

Thermocouples are made from two dissimilar metal wires which are joined to form a junction. When a thermocouple junction is at a different temperature than the ends of the two wires, a potential voltage difference develops across the open ends which is related to the temperature of the junction. In general, the thermocouple junction temperature can be determined with a great deal of accuracy. The difficulty is that the junction temperature is not necessarily equal to the local surrounding gas temperature which is generally the quantity of interest.

For steady-state conditions, differences between the junction temperature and local surroundings can result from 1) radiative heating or cooling of the junction, 2) heat conduction along the wires connected to the junction, 3) catalytic heating of the junction due to radical recombination reactions at the surface, and 4) aerodynamic heating at high velocities. Radiative effects are particularly important in fire environments and are the focus of much of what follows.

## 3. EXPERIMENTAL

A practical approach for characterizing the errors associated with the use of thermocouples for gas measurements in fire environments has been adopted. Measurements using bare-bead thermocouples typical of those employed at NIST for fire tests, several types of aspirated thermocouples, and combinations of thermocouples having different diameters have been recorded at multiple locations in idealized enclosure fires, and the results are compared. Note that a drawback of this approach is that the actual temperatures being measured are not known with certainty.

Tests were performed in a 40%-reduced-scale model of a standard ASTM enclosure used for fire testing. Two fuels--natural gas and heptane--were employed. Temperature measurements for several types of thermocouples were compared at different locations in the upper and lower layers. Additional measurements included heat-release-rate measurements, upper- and lower-layer doorway velocities, and radiative heat flux in the center of the doorway at the floor.

## 4. RESULTS

Figure 1 compares temperature time records for 400 kW natural gas fires, recorded 22 cm above the floor in the doorway, for two types of double-shield aspirated thermocouples and a NIST bare-bead thermocouple. The radiative flux measured by the floor-mounted radiometer is also shown. The actual temperature at the measurement point is unknown, but is expected to be on the order of room temperature or ≈ 25 °C. During the test, the bare-bead thermocouple recorded temperatures approaching a maximum of 250 °C and had a time dependence very similar to that for the radiant flux. For long times the error in the bare-bead temperature measurement due to radiation is on the order of 200 °C or roughly 70% in terms of absolute temperature. The two aspirated probes provide more accurate results than the bare-bead thermocouple, but are still subject to significant error.

Temperature measurements made in the upper layer were also subject to systematic uncertainties, but the errors were generally smaller in absolute terms than those made in the lower layer. Attempts to correct temperature measurements using several variable-diameter bare-bead thermocouples were unsuccessful due to their limited time response and the rapid temperature fluctuations present in the fire environment.

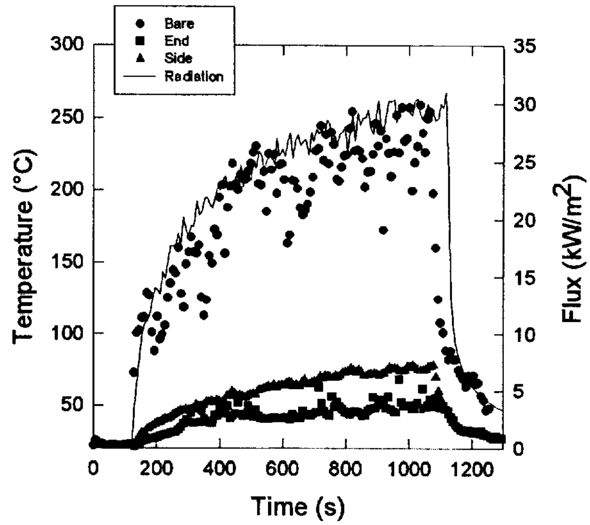


Figure 1. Temperatures measured in the lower layer of the enclosure doorway with end- and side-aspirated thermocouples and a 0.254 mm bare-bead thermocouple are shown for 400 kW natural-gas fires. Radiative flux was measured at the floor.

## 5. DISCUSSION

The findings of this investigation demonstrate that instantaneous and time-averaged temperature measurements recorded in fire environments using bare-bead thermocouples can have significant systematic errors due to both radiative heat transfer and finite time response. In principle, it should be possible to correct for such uncertainties when sufficient knowledge of thermocouple properties and the environment are available. However, such properties as the local radiation environment, the local gas velocity and composition, and the thermocouple surface emissivity are difficult to measure, and, in practice, such correction does not appear to be feasible. Perhaps the best approach is for a researcher to estimate the various properties along with their uncertainty ranges and use error propagation to calculate the resulting uncertainty range for the measurement. It is the responsibility of the researcher to assess whether or not the resulting uncertainty limits meet the requirements of the experimental design.

As part of this study, an idealized model of the relevant heat transfer processes for bare-bead and single- and double-shield thermocouples in typical fire environments has been developed. The calculated behaviors are qualitatively similar to those observed experimentally. The largest calculated relative errors occur for cool gases in highly radiative environments. The calculations show that for certain conditions aspirated-thermocouple measurements are subject to significant uncertainty and that double-shield aspirated thermocouples are predicted to perform significantly better than single-shield versions.

Based on the current results, it is concluded that extrapolation of temperature measurements to zero diameter for close groupings of bare-bead thermocouples having different diameters is not a viable approach for correcting thermocouple results in fire environments due to the strong temperature fluctuations present and the finite time response of the thermocouples.

The findings summarized briefly here are being prepared as a full internal report. [2]

## 6. REFERENCES

1. J. C. Jones, *J. Fire Sci.* **13** (1995) 261.
2. William M. Pitts, Emil Braun, Richard D. Peacock, Henri E. Mitler, Erik L. Johnsson, Paul A. Reneke, and Linda G. Blevins, *Thermocouple Measurement in a Fire Environment*, National Institute of Standards and Technology Internal Report, to appear.