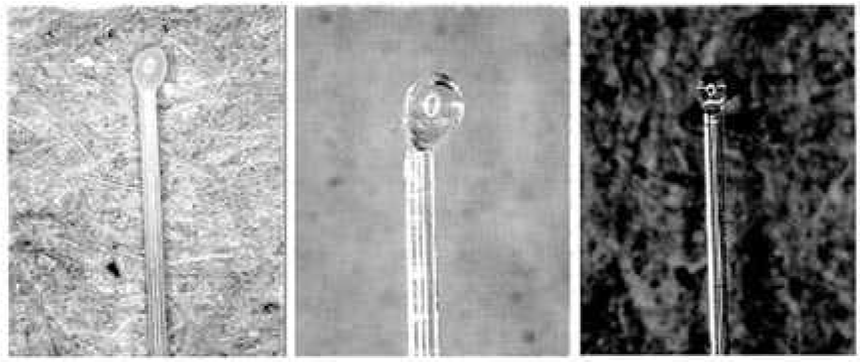
Novel High Gas-Temperature Calibration System Demonstrated

Accurate measurement of high gas temperatures, typically above 1300 K, has always presented challenges to researchers. Thermocouples often perturb the local gas flow and temperature field; they provide indirect information; and at high temperatures, they require large corrections so that actual gas temperatures can be determined. The physical and chemical stability of thermocouples to withstand the thermal loads and reactive environments prevailing at high temperatures naturally limits their life and maximum use temperature. Optical systems have their own drawbacks since accurate results depend on well-characterized emissivity, optical thickness, and gas composition information. These properties are rarely well known, especially in high-temperature, chemically reacting environments. In addition, optical systems usually require independent calibrations, which often involve the use of thermocouples, and hence, suffer from their aforementioned limitations.

A new technique developed by researchers at the NASA Glenn Research Center at Lewis Field exploits an abrupt increase in the emittance of optically thin materials at their unique melting temperatures for a direct determination of gas temperature. Pure metallic-oxide fibers, varying in diameter from 60 to 400 μm, have been used in measurements over a temperature range of 2050 to 2700 K. The accuracy and reproducibility of the technique is estimated to be ±15 K: that is, within the uncertainty in the melting points of the materials. Other fiber materials with different, but unique, melting points could be used to extend the technique over a larger temperature range.

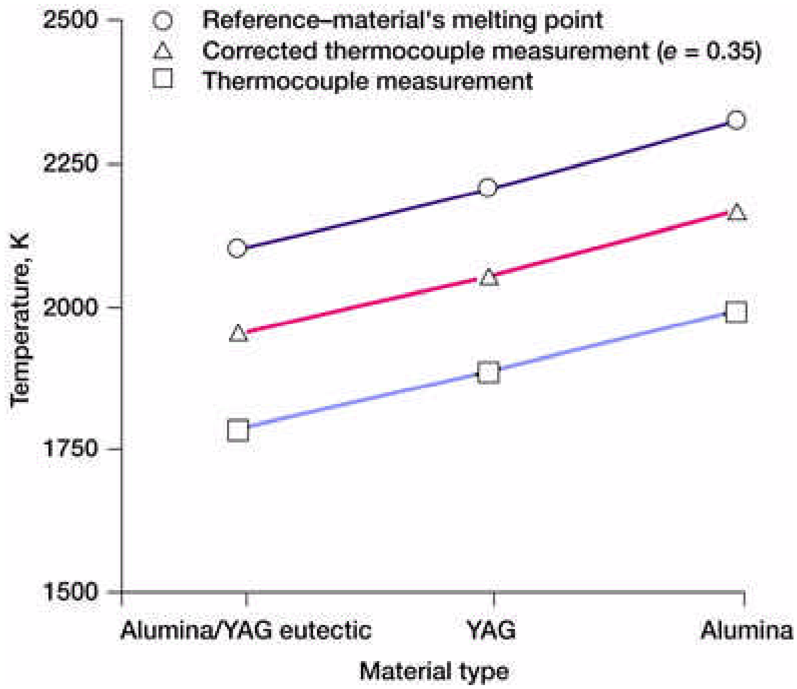
The technique has been demonstrated in hydrogen-air and hydrogen-oxygen flames stabilized on a flat-flame burner. Flame temperatures were varied by adjusting reactant flow rates. Fibers were inserted horizontally, along the fiber axis, into a cross-stream of up-flowing gases at temperatures lower than the gas melting points. Fiber tips were placed at the edge of the uniform-temperature zone of the flame. The flame temperature was increased toward the melting-point temperature by increments controllable to less than 4 K. Small fiber diameters and large length-to-diameter ratios assured rapid thermal equilibration with the surrounding hot gases and minimal conductive heat loss. When the fiber tip melted, a molten droplet was formed and then swept away by the gas stream. Consequently, the fiber was typically shortened by 1 mm. A small, resolidified drop remained on the fiber tip, as shown in the photographs, providing physical evidence of actual melting.



Microscope photographs (30×) of molten fiber tips after resolidification. Left: Alumina/yttrium aluminum garnet (YAG) eutectic; melting point, 2095 K. Center: YAG; melting point, 2200 K. Right: Alumina; melting point, 2320 K.

The reactant flow rates at which the fibers reproducibly reached their melting points in the experiments were also found to be independent of fiber diameters. The calculated emittance values of the fibers, based on published absorption coefficient data of the fiber materials, were around 0.01 at a few degrees below the fibers' melting points. These findings indicate that radiative cooling of the fibers was negligible prior to melting, allowing direct measurement of gas temperature without a radiative correction.

The technique lends itself to gas-temperature measurement under relatively few discrete conditions. Hence, it could most effectively be utilized to calibrate other gas-temperature-measurement devices, improving their accuracy especially at higher temperatures where their reliability becomes increasingly questionable. The technique was applied to assess the accuracy of gas-temperature measurements inferred from thermocouples, and it confirmed that such measurements are typically accompanied by uncertainties larger than 100 K (see the graph). It was also used to calibrate an infrared camera to measure gas temperatures using the band-ratio method.



Gas temperatures measured and inferred from thermocouples versus "reference" melting-point measurements for alumina/yttrium aluminum garnet (YAG) eutectic, YAG, and alumina. (The symbol e refers to the emissivity.)

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