Thin-Filament Pyrometry Developed for Measuring Temperatures in Flames

Many valuable advances in combustion science have come from observations of microgravity flames. This research is contributing to the improved efficiency and reduced emissions of practical combustors and is benefiting terrestrial and spacecraft fire safety. Unfortunately, difficulties associated with microgravity have prevented many types of measurements in microgravity flames. In particular, temperature measurements in flames are extremely important but have been limited in microgravity. A novel method of measuring temperatures in microgravity flames is being developed in-house at the National Center for Microgravity Research and the NASA Glenn Research Center and is described here. Called thin-filament pyrometry, it involves using a camera to determine the local gas temperature from the intensity of inserted fibers glowing in a flame. It is demonstrated here to provide accurate measurements of gas temperatures in a flame simultaneously at many locations.

This photograph shows the experiment. The flame is a laminar gas jet diffusion flame fueled by methane (CH_4) flowing from a 14-mm round burner at a pressure of 1 atm. A coflowing stream of air is used to prevent flame flicker. Nine glowing fibers are visible. These fibers are made of silicon carbide (SiC) and have a diameter of 15 μm (for comparison, the average human hair is 75 μm in diameter). Because the fibers are so thin, they do little to disturb the flame and their temperature remains close to that of the local gas.

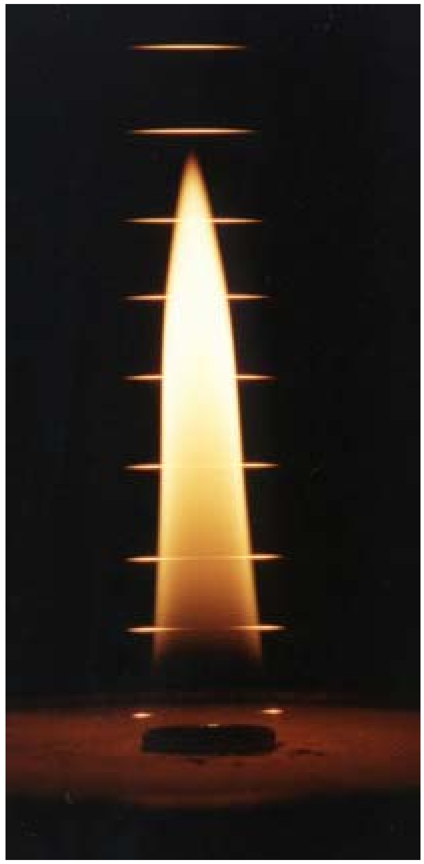
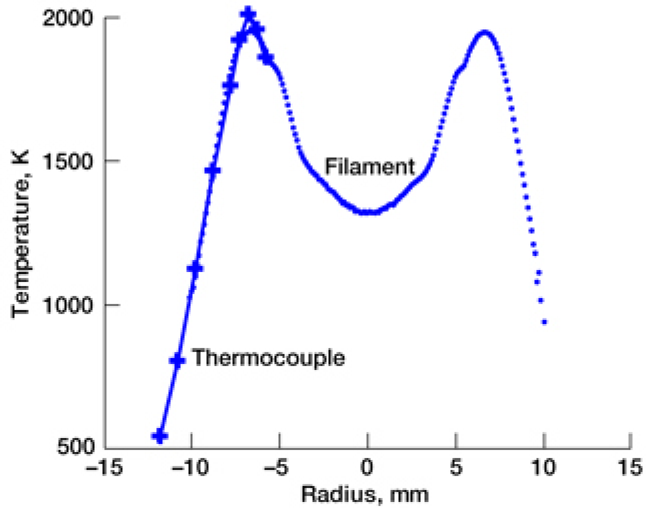


Image of the test flame and glowing fibers. The flame is about 70 mm long. The flame was observed in normal gravity with the flame tip up.

Long description. Color image of the test flame and glowing fibers. The flame is about 70 millimeters long. The flame is yellow and is similar in shape and appearance to a long candle flame. Nine fibers are in place horizontally across the flame and these glow yellow inside and nearby the flame. Low in the flame, the fibers are brighter than the flame, but higher up the flame is brighter than are the fibers.

The flame and glowing filaments were imaged with a digital black-and-white video camera. This camera has an imaging area of 1000 by 1000 pixels and a wide dynamic range of 12 bits. The resolution of the camera and optics was 0.1 mm. Optical filters were placed in front of the camera to limit incoming light to 750, 850, 950, and 1050 nm.

Temperatures were measured in the same flame in the absence of fibers using 50-µm B-type thermocouples. These thermocouples provide very accurate temperatures, but they generally are not useful in microgravity tests because they measure temperature at only one location at a time. Thermocouple measurements at a height of 11 mm above the burner were used to calibrate the thin-filament pyrometry system at all four wavelengths.



Temperature versus radius for the test flame as determined from both thin-filament pyrometry and thermocouples at a height of 21 mm above the burner. This height corresponds to the third fiber above the burner in the photograph.

Long description. Temperature versus radius for the test flame as determined from both filament and thermocouple methods. The *x*-axis (radius) varies from -13 to 13 millimeters. The *y*-axis (temperature) varies from 500 to 2100 K. The filament data are closely spaced, cover the region between -10 and 10 millimeters, and have peaks of about 1950 K at -6 and 6 millimeters. The thermocouple data are less closely spaced and cover the region from -12 to -6 millimeters. These data generally agree with the filament measurements, but they have a sharper peak and a peak temperature of about 2000 K.

This calibration was used to perform thin-filament pyrometry at other heights above the burner. One such profile is shown in this graph; this is for a height of 21 mm. The agreement between the pyrometry measurements and thermocouple results at this height is excellent in the range of 1000 to 2000 K, with an estimated uncertainty of ±50 K and an estimated upper limit of 2500 K. Neither the thermocouple nor the thin-filament pyrometry temperatures have been corrected for radiation, but the correction is expected to be nearly the same for both methods.

We anticipate that thin-filament pyrometry similar to that developed here will become an important diagnostic for studies of microgravity flames owing to its accuracy and its ability to simultaneously measure finely spaced temperatures.

Find out more about this research:
National Center for Microgravity Research at http://www.ncser.net/
Glenn's Microgravity Science Division at http://microgravity.grc.nasa.gov/

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