Optical sensors monitor flames

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Optical sensors and signal processing algorithms can analyze the radiation emitted by flames to monitor and control industrial burners.

The permanent optimization of combustion equipment could provide efficiency, reliability, and reduced-pollution benefits. However, current capabilities for monitoring and control of industrial flames are limited; the lack of reliable diagnostic techniques is a major obstacle. The information provided by conventional combustion instruments is clearly insufficient to act on the burner settings, which would be an effective way to optimize the flame (and, for example, reduce emissions of carbon monoxide and/or nitrogen oxides). Novel instrumentation capable of obtaining direct information from the flame is needed to develop reliable monitoring methods before we can implement advanced combustion controls.^{1,2}

Optical sensors could help greatly to fill this gap. Laser-based techniques are an invaluable tool for the investigation of flames or flows, but they are still restricted to research. However, passive sensors offer potential for characterizing a flame's properties from the rich information contained in the flame's spontaneously-emitted radiation. Optical sensors offer the advantages of being selective, fast, and able to gather data even in extremely hostile environments. There are many ways in which they can be used to obtain useful information from combustion systems.

Radiation at some specific wavelengths, associated to the emission of some chemical species, can be used to obtain quantitative results. For example, the emission bands in the range 1–4 μm for HO_2 and CO_2 can be monitored to measure gas composition and temperature.³ Several groups are working on this approach, which is in pre-commercial development.

The most common strategy, however, is to use the radiation signal as a signature of the flame that can be related to some properties or to situations previously characterized.^{4–6} Our group at the Laboratory for Research on Combustion Technologies (LITEC) in Zaragoza, Spain, is investigating different methods along this line.^{7–9}

One possibility is to analyze the average level of radiation and its fluctuations. LITEC has been working with a Si photodiode (sensitive from 190–1100nm) and with a photomultiplier

Figure 1. Emission spectra for premixed flames with different equivalence ratios (*e.r.*), which describe the fuel-air ratios.

tube with a filter at $310 \pm 10\text{nm}$. The first sensor provides a measure of the luminosity of the flame, while the signal obtained by the second sensor is associated with the quantity of excited OH radicals. A strong relationship has been obtained between the average and standard deviation of the radiation signals and the characteristics of the flames in a model of an industrial burner. For example, good estimations of nitrogen oxide (NO_x) emissions have been obtained using the radiation signals as the only input to neural-network models.

Flame-emitted radiation, in general, fluctuates greatly and the frequency content of the fluctuations contains relevant information. The power-spectral-density function of the radiation shows some discrete peaks superimposed over a continuous spectrum. The location and strength of the peaks—as well as the variation of the continuous level with frequency—are modified when burner settings change. These parameters can be related, for example, to the acoustic properties of the combustion chamber. But the spectrum can be also treated as a signature of the flame. This can be used, for example, to identify it with respect to known situations. Remarkably high success rates have been obtained when estimating actual burner settings or NO_x emissions solely from the frequency spectra of the radiation around 310nm.

A different approach is based on the analysis of spectrally-resolved radiation signals.^{10,11} Figure 1 shows the radiation spectra obtained from premixed flames with different equivalence ratios (ERs). The ER is a measure of the fuel-to-air ratio, and is a key parameter in lean premixed combustors, which are in-

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creasingly used in gas turbines and other industrial applications. There is a narrow optimal range for ER: too-high values lead to increased NO_x emissions while too-low ones can result in high carbon-monoxide emissions, pulsations, or flame blow-off. Hence, developing instrumentation to measure ER is an important objective in this area. Several groups have demonstrated that radiation spectra like those shown can be analyzed to obtain reliable estimates of ER. LITEC is working on this approach. We are also applying this method to different fuel compositions, such as those that can appear in biomass gasification or for H_2 -enriched gases, which also affect the radiation spectra.

Optical sensors are a promising method for monitoring and controlling a wide range of combustion applications. LITEC is developing data-interpretation strategies oriented to different cases, such as large pulverised coal burners or lean-premixed combustion of gaseous fuels.

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