Optical sensors monitor flames

Javier Ballester, Ana Sanz, Ricardo Hernández, and Andrzej Smolarz

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.

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 1–4μm for HO2 and CO2 can be monitored to measure gas composition and temperature. 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. Our group at the Laboratory for Research on Combustion Technologies (LITEC) in Zaragoza, Spain, is investigating different methods along this line.

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 tube with a filter at 310 ± 10nm. 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 (NOx) 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 NOx emissions solely from the frequency spectra of the radiation around 310nm.

A different approach is based on the analysis of spectrally-resolved radiation signals. 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-

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

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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\textsubscript{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\textsubscript{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.

**Author Information**

**Javier Ballester**  
Fluid Mechanics Group  
University of Zaragoza  
Laboratory for Research on Combustion Technologies (LITEC)  
Joint Center CSIC-DGA-Univ. Zaragoza  
Zaragoza, Spain  
http://www.unizar.es/lci

Dr. Javier Ballester belongs to the Fluids Mechanics Group at the Centro Politecnico Superior (University of Zaragoza) and is the head of the Industrial Combustion Laboratory of LITEC. He has been involved, in most cases as principal investigator, in many projects related to applied fluid mechanics and combustion, some of them oriented to the advanced monitoring and control of industrial flames.

**Ana Sanz and Ricardo Hernández**  
Laboratory for Research on Combustion Technologies (LITEC)  
Joint Center CSIC-DGA-Univ. Zaragoza  
Zaragoza, Spain  
http://www.pollub.pl  
http://www.unizar.es/lci

Ana Sanz is a graduate student at LITEC, where she has been working in combustion research since 2001. She earned her Industrial Engineering degree from the University of Zaragoza. As a part of her Ph.D. work, she is developing advanced systems of optimization and control for different processes from combustion.

Ricardo Hernández Arrondo graduated in physics in 2003 at the University of Zaragoza and joined LITEC as a member of the LCI workgroup. In 2005 he obtained an FPU scholarship for his doctoral studies. At present he is working on combustion instabilities in lean premixed gas turbines.

**Andrzej Smolarz**  
Dept. of Electronics  
Lublin University of Technology  
Lublin, Poland  
Laboratory for Research on Combustion Technologies (LITEC)  
Joint Center CSIC-DGA-Univ. Zaragoza  
Zaragoza, Spain  
http://www.pollub.pl  
http://www.unizar.es/lci

Andrzej Smolarz was a member of organizing committee of last three Technology and Application of Lightguides conferences in Poland, co-editor of the proceedings volumes, and has authored many papers on optical flame sensing.

**References**