Phosphor Thermography Measures Transient Temperature Distribution

Fuels, Engines, and Emissions

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Oak Ridge National Laboratory

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Transportation

FOR THE 21ST CENTURY

Background

Through programs sponsored by the U.S. Department of Energy FreedomCAR and Vehicle Technologies Program, the Oak Ridge National Laboratory is developing and applying unique measurement capabilities. These new tools are providing critical insights into several performance barriers of diesel emissions control strategies.

Significant insights into catalyst performance have been realized via the Spatially Resolved Capillary Inlet Mass Spectrometer (SpaciMS). This instrument characterizes the spatial and temporal gas-phase species distributions throughout an operating catalyst. Similar measurements of temperature distributions are needed to better specify the controlling catalyst chemistry. An instrument based on phosphor thermography is providing this information.

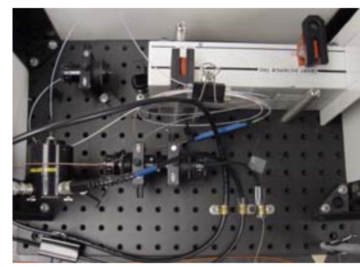
The Technology

The phosphor thermography instrument is based on the temperature-dependent phosphorescence lifetime of rare-earth-doped ceramic phosphors. A 337-nm laser is injected into one (pump) leg of a fiber coupler to excite the phosphor, which is deposited on the tip of a gold-coated bare fiber. The gold coating allows for high-temperature applications up to 750ºC. The phosphor is excited by the laser to long-lived excited states which decay via phosphorescence in the 650-nm range. Some of the phosphorescence is captured by the same optical fiber used to deliver the pump light, and is directed to a second (detection) leg of the fiber coupler. The light emitted from the fiber coupler's detection leg is filtered to reject pump light at 337 nm, and detected via a photomultiplier tube (PMT). The phosphorescence signal displays an exponential decay with a time constant proportional to temperature. The PMT signal waveform is monitored at 400 kHz and analyzed to actively determine the phosphorescence time constant. A calibration curve is used to convert the phosphorescence time constant to temperature. Temperature gradients are resolved by translating the phosphor tip.

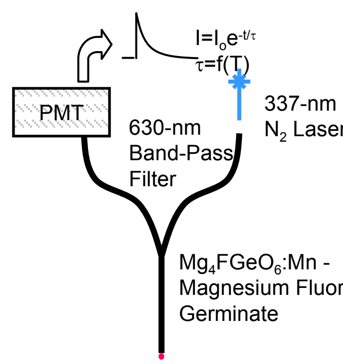
The instrument has been applied to quantify spatio-temporal temperature distributions throughout an EmeraChem NOx adsorber catalyst during regeneration. An approximately 1-inch-diameter catalyst core (200 cells/in.^{2}) was housed in a quartz tube and heated to about 250ºC. The catalyst was exposed to mixture of approximately 11% oxygen in nitrogen at a space velocity of about 25,000 exchanges/hour. A reductant was injected for a 12-s duration on a 125-s period. Temperature measurements were made every 0.3 in-throughout the 3-in.-long catalyst core, by translating a phosphor-tipped optical fiber through one of the central channels. The catalyst channel to optical fiber area ratio was about 210, to mitigate flow occlusion associated with the fiber. Temperatures were measured throughout the catalyst as well as 0.3 inches upstream and downstream of the catalyst. The results indicate noticeable cooling, on the order of 50ºC in the region of the catalyst entrance face associated with the unheated reductant injection. There is some gradual gas heating up to 1.8 inches into the catalyst, likely due to heat transfer from the bulk monolith. Catalyst light-off occurs around 2 inches into the core, as inferred by dramatic temperature increases in the back third of the core. Peak temperatures of ca. 450ºC are reached at the back end of the catalyst. Such temperature data is invaluable to the detailed understanding and modeling catalyst processes.

Benefits

- Minimally invasive
- High temporal resolution
- Transportable
- Quantifies intra-catalyst-channel transient temperature distributions



Photograph of the LIP instrument showing the nitrogen laser, fiber coupler, and PMT



Schematic of the LIP instrument

For more information on how ORNL is helping America remain Competitive in the 21st century, please contact:

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Success Story