Combustion Research Facility News

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Oxygen-lance-based sensor monitors key steelmaking parameters

Beth Fuchs, Lois Johnston, John Korellis, Dick Roy, and Allen Salmi along with commercialization partner Michel Bonin of Insitec Measurement Systems, Phil Stelts of Bethlehem Steel, Bob Hurt of Brown University, and Gary Hubbard of Hubbard Associates are developing a prototype oxygen-lance-based sensor for monitoring, *in situ* and in real time, critical process control parameters during basic-oxygen-furnace (BOF) steelmaking. This project is one of five activities under the American Iron and Steel Institute's (AISI) Advanced Process Control Program, which is co-sponsored by DOE's Office of Industrial Technologies.

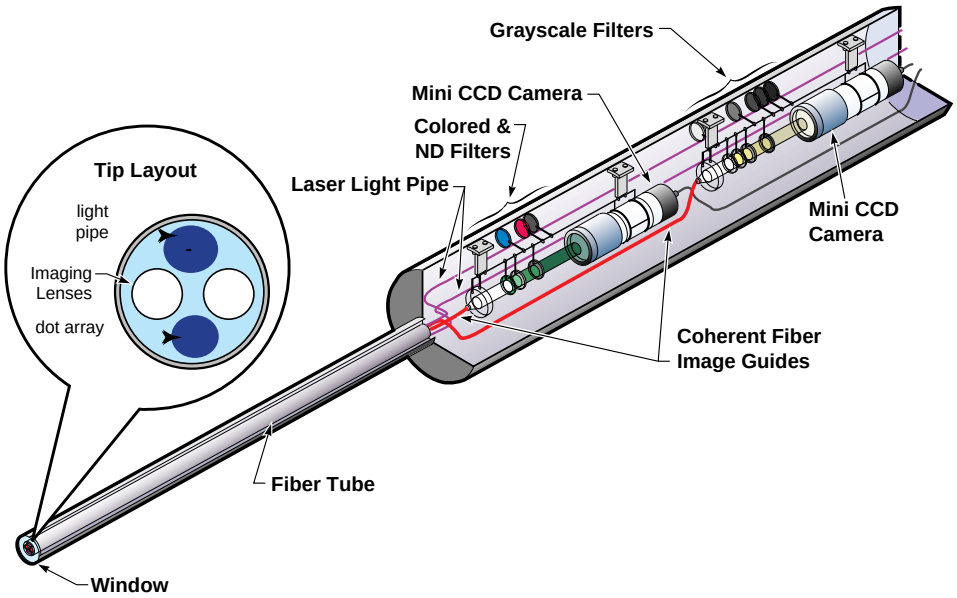
In the BOF process, up to 300 tons of steel are batch processed in individual heats by intensely blowing the high-carbon-content iron melt with oxygen delivered to the melt surface at Mach 2 velocities through a water-cooled lance. The Sandia sensor is located within an oxygen lance that was redesigned by Berry Metal Co.

The Sandia temperature sensor comprises a suite of devices that includes a two-color imaging pyrometry system, which measures hot spot radiance and metal melt temperature, to provide end-of-process carbon content information. Triangulation and pulsed-laser techniques are being developed for use in sensing the position of the surface of the melt. A multiple-laser-dot procedure is being explored for rapid determination of the contour of the ceramic lining of the furnace, thereby providing an indication of refractory wear.

The sensor package, shown in the figure, includes two miniaturized video cameras, various lenses and filters, light pipes, and coherent-fiber image guides positioned within the oxygen lance and coupled to the window and collection lens via fiber optic cables. The real-time output from the video cameras is transmitted to a remotely located control station for data storage and processing.

Following two years of research and development at Sandia and pilot-scale evaluations at Bethlehem Steel's Homer Research Laboratories, field trials of the first prototype were successfully completed at Bethlehem's Sparrows Point plant in Baltimore. Both the sensor and modified lance performed nearly flawlessly. Another set of field trials is planned for December 1995 that will not only incorporate modifications made to the sensor as a result of the first two trials but will also test the new range-finding capabilities from within the oxygen lance.

Use of the sensor package will significantly decrease the time required to process each batch of steel while simultaneously providing an operations monitor of the wear of the BOF ceramic liner. Success of this three-year project will be signaled by AISI commercialization of the Sandia-developed sensor technology and widespread use of the technology by the U.S. steelmaking industry.



Schematic of the temperature sensor. Laser diodes will also be contained within the package for position and contour sensing.

Long-range imaging of gas plumes demonstrated in field trials

A new form of laser remote sensing that allows the real-time imaging of gas plumes is under development in the remote sensing group. The technique, called backscatter absorption gas imaging (BAGI), operates by illuminating a scene with infrared laser radiation as it is being imaged with an infrared camera. When a gas capable of absorbing the laser light enters the camera field-of-view, it attenuates a portion of the laser backscatter and appears as a dark cloud in the video picture. The unique ability of BAGI to remotely generate video images of plumes greatly simplifies the detection and location of gas leak sources.

Recently, Tom Kulp, Randy Kennedy, and Peter Powers completed the field evaluation of a BAGI system that was developed for the US Navy for long-range gas imaging.

The principle of operation is demonstrated in the picture of an earlier system shown in Figure 1. The image is created by simultaneously raster scanning a CO_2 laser beam and the instantaneous field-of-view (IFOV) of a single-element infrared detector across the target at video rates. Operating at a wavelength near 10.6 µm, the laser can be tuned to absorption resonances of many hydrocarbons and other gases of interest for leak detection. Back scattered laser light is collected by optics that are adjusted so that the detector always views the illuminated spot as the scan occurs. The detector output is then amplified and formatted to create the BAGI video image as shown in Figure 1.

Field evaluations of the system were carried out at Sandia and at the Remote Sensor Test Range at the Nevada Test Site (NTS). During the NTS field tests, the imager was used to assess the performance of a plume generating wind tunnel and to demonstrate the ability to visualize gas emissions of sulfur hexafluoride at concentrations as low as 2 ppm and ranges as high as 364 m. This surpasses the 80-m range of the first-generation imager.

Figure 2 contains a processed image from the field trials. It was obtained by applying Beer's law to a pair of digitized frames (one collected with the gas plume on and one with the plume off) to generate a plume optical density map. The data in Figure 2 indicate a noise floor equivalent to an absorption of ~2 ppm-m for sulfur hexafluoride . The data also demonstrate that the images can be processed to generate quantitative plume density distributions.

Current work includes the development of a long-range imager for methane leak detection for the Gas Research Institute. This work will include the testing of differential wavelength imaging for quantitative plume imaging.

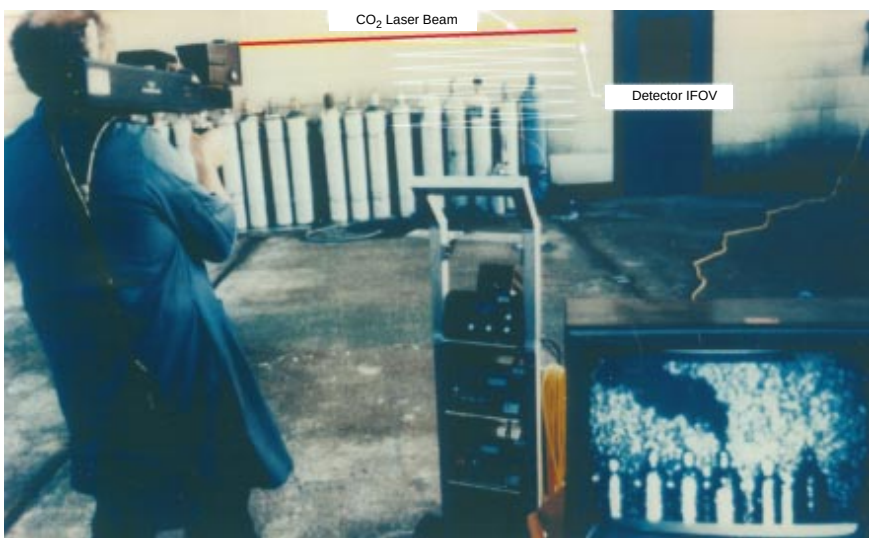


Figure 1. Backscatter gas imaging shown detecting a plume of gas from a leaking cylinder. An indication of the laser and IFOV raster scan pattern that is used to generate the image has been illustrated in the photograph.

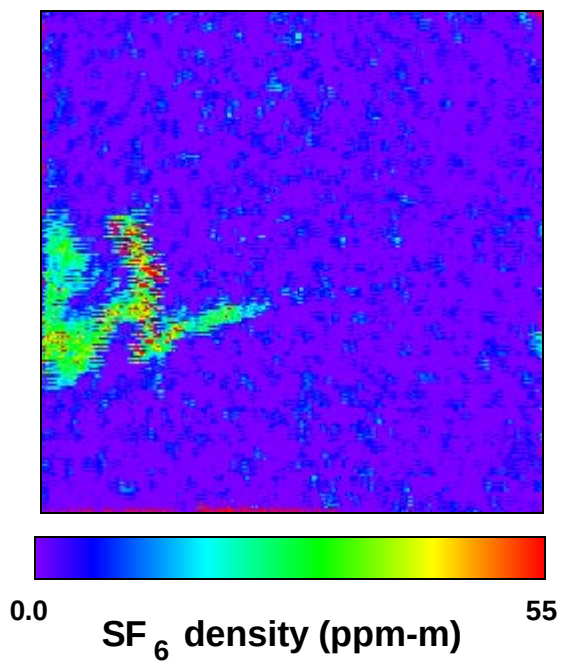


Figure 2. A processed image of a gas plume from the field trials of the long-range imager. The plume originates from a small source near the center of the image and is dispersed by a light wind to the left.

Sandia National Laboratories, a prime contractor to the U.S. Department of Energy, is operated by Sandia Corporation, a wholly owned subsidiary of the Lockheed Martin Corporation.

The CRF Advisory Board met in November to discuss activities, issues, and future directions with emphasis on opportunities related to restarting the CRF Phase II construction project. Seated (l-r) are Pat Flynn (Cummins Engine Company), Jack Matkin (Chevron Research and Technology), and Howard Palmer (Pennsylvania State University, Emeritus). Standing are Bill McLean, Thom Dunning (Pacific Northwest Laboratories), John Maulbetsch (Electric Power Research Institute), Tom Hunter (Sandia/CA's new Vice President), John Crawford (Sandia's new Executive Vice President), and Richard Chang (Yale University). Thom Dunning, Richard Chang, and Jack Matkin joined the Advisory Board this year. Howard Palmer retired from the Board at the conclusion of this year's meeting after serving the CRF in many capacities since its inception.

Inge Gran (bottom left) from the University of Trondheim, Norway, has just concluded a year's visit with several members of the Diagnostics and Reacting Flow department: (back row: Jacqueline Chen, Bill Ashurst, Alan Kerstein, and Bob Schefer; front row right: Tarek Echekki). During his stay Inge collaborated with Jacqueline and Tarek on direct numerical simulation of turbulent premixed methane-air flames modeled with detailed kinetics (*CRF News*, **17**:6) and with Bob on simulation of bluff body stabilized flames.

Albert Heck (right), a visitor from Dr. Richard Zare's laboratory at Stanford University, finished a two-year visit with Dave Chandler (left) where he used the photofragment imaging technique to study the photochemistry of CH_4, H_2, and N_2O. Albert recently returned to a staff research position at Warwick University, England.

Thomas Linsmeyer (center) from the Technical University of Vienna, and Scott Sinquefield (right) from Oregon State University, are working on their Ph.D. research in biomass and black liquor combustion with Larry Baxter.

Novel application of PLIF in an operating engine

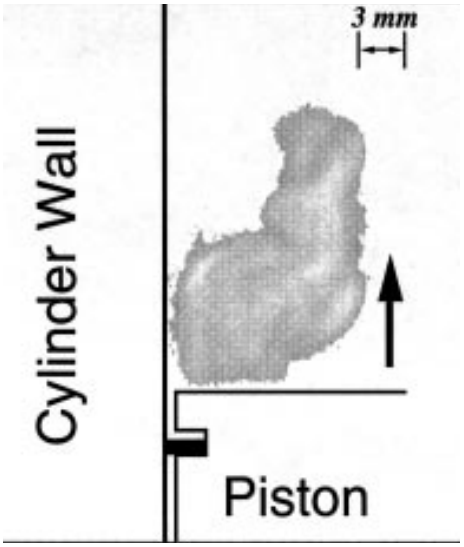
Bob Green has recently applied planar laser induced fluorescence (PLIF) in a new way to observe unburned hydrocarbons (UHC) in an operating engine. The primary source of UHC species emitted from engines is fuel and air trapped in confined volumes in the combustion chamber, particularly the ring-land crevice between the piston and the cylinder wall. Bob is applying PLIF to detect the presence of UHC in the combustion products during the expansion and exhaust strokes.

A Sandia research engine is operated using a gaseous fuel and no lubrication so that the principal source of UHC emissions is combustion chamber crevice volumes. The fuel is "doped" with a marker species that has physical and combustion characteristics similar to the fuel; in this case the fuel is propane and the dopant is acetone. Since the acetone is oxidized by the normal flame in a manner similar to the propane fuel, but will also survive, similar to the fuel, in cooler post-flame environment, it acts as an excellent marker of the UHC in the post-combustion gases.

Optical access is accomplished through a quartz window in the top of the combustion chamber. Both the laser light sheet entering and the fluorescence emission leaving the engine pass through the window. A mirror inclined at an angle of 45˚ is mounted on the top of the piston. If the laser sheet is reflected across the top of the piston by the inclined mirror and the fluorescence emission is collected straight up through the window, the imaging is performed in a horizontal plane. When the fluorescence emission is reflected up by the mirror and the laser sheet simply passes straight down onto the top of the piston, the vertical plane is imaged.

The figure illustrates a vertical-plane image obtained during the exhaust stroke, 40 crank-angle degrees after bottom center. By analyzing additional images recorded at other crank angles, new insight into the evolution and transport of UHC is being obtained. Preliminary analysis has indicated that during the expansion stroke the UHC exits the top ring-land crevice and remains in a thin layer on the cylinder wall until it is "scraped off" by the piston during the exhaust stroke.

This work is a collaborative effort with Lawrence Livermore National Laboratory and the Low Emission Partnership of USCAR.



A vertical-plane image of the UHC in the region of the top ring-land crevice at 40 degrees after bottom center during the exhaust stroke.

Recent meetings

- Larry Baxter chaired the International Engineering Foundation conference on Application of Advanced Technology to Ash-Related Problems in Boilers, held at Waterville Valley, NH, in July. The conference included 67 technical presentations with representatives from 15 countries and featured involvement from both industrial and academic institutions Topics discussed included coal, biomass, black liquor, and other fuel combustion sytems.
- Sandia hosted the 1995 American Flame Research Committee's Fall International Symposium in Monterey, CA, in October. Neal Fornaciari was the conference chair, and Carla Fugazzi and Lori Bradbury were coordinators. The conference featured 49 papers on applied combustion topics and was attended by 109 delegates from the U.S., Canada, Japan, Australia, and Syria.
- Sandia and Ford Motor Company hosted the most recent DOE-sponsored Combustion Technologies working group meeting in Dearborn, MI in October. The meetings are held semi-annually and attract experts from national laboratories, universities, and the auto companies to discuss recent research results on engine combustion issues. The meeting in Dearborn attracted 70 people.
- The 1995 fall meeting of the Western States Section of The Combustion Institute (WSS/CI) was held in October at Stanford University under the direction of Jay Keller, WSS/CI Secretary; Host Reggie Mitchell (Stanford); Program Chairperson Robert Cheng (Lawrence Berkeley Laboratory); and Papers Chairperson Melvyn Branch (University of Colorado at Boulder). Seventy-seven papers were presented during the two-day meeting.

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