P2-4 In-situ Measurement of CO by Tunable Diode Laser Absorption Spectroscopy in a Large Scale Waste Test Furnace

Kenji MUTA, Masazumi TANOURA, Hiroki HONDA*
Advanced Technology Research Center, Yokohama R&D center*,
Mitsubishi Heavy Industries, Ltd.
1-8-1, Sachiura, Kanazawa-ku, Yokohama, 236, Japan
Phone: +81-45-771-1223, Fax: +81-45-771-3879, E-mail: muta@atrc.mhi.co.jp

ABSTRACT

A technique for in situ and simultaneous measurement of carbon monoxide (CO) and soot particles by means of near-infrared Tunable Diode Laser Absorption Spectroscopy (TDLAS) was investigated, and the detection limit of CO was found to be 5ppm·m/$Hz^{1/2}$. Furthermore, this technique was applied to analyze combustion gas in a large scale test furnace (waste combustion pilot plant). We confirmed that CO and soot in combustion gas could be directly measured in the furnace, and verified that TDLAS is a powerful tool for real-time measurement of combustion conditions as compared with conventional sensors.

1. INTRODUCTION

In order to realize combustion diagnostics and control of large scale combustion plants, it is necessary to develop in-situ and real-time measurement techniques for gases in combustion processes. Recently, newly developed high-resolution laser spectroscopic techniques, such as LIF,[1, 2] are being used for combustion diagnostics in the laboratory. However, laser spectroscopic techniques have seldom been applied to large scale plants, because these instruments are complex and expensive, difficult to install and operate, and the resulting measurements are frequently affected by coexistence gases.

On the other hand, the performance of visible and near-infrared diode lasers has recently improved, achieving sufficient spectroscopic-quality to be used as light source for high-resolution spectroscopy. The potential of TDLAS has accordingly been recognized, and it is being developed as an in-situ and real-time measurement technique.[5, 6, 7]

The advantages of TDLAS are as follows:

(1) The equipment is compact, relatively inexpensive, and easy to operate.
(2) It is virtually unaffected by interference from other species.
(3) The same instrument can easily be converted from one species to another, simply by changing the laser and calibration cells.
(4) It offers automated, long-lasting and reliable measurements, and it can be applied to outdoor test plants as well as indoor ones.

In our previous paper[3,4], a technique for simultaneous detection of oxygen molecules (O_2) and solid particles by means of visible TDLAS was investigated. The maximum solid particle density was 5.6g/m^3m, allowing measurement of the concentration of O_2 with sufficient precision. We applied this technique to analysis of the exhaust gas from a large-scale test furnace, and verified that O_2 and soot particles in the real exhaust gas can be measured without pretreatment, such as removal of water vapor and soot.

In the research reported here, we first examined the lowest detection limit of carbon monoxide (CO) using a near infrared TDLAS system with the standard gas. We then verified that the TDLAS system can be used to simultaneously measure the concentrations of CO and soot particles in a large scale waste test furnace.

2. MEASUREMENT OF CO BY TDLAS IN THE LABORATORY

2.1 Experiment

Figure 1 shows the schematic diagram of the experimental setup of the TDLAS system used in this standard gas experiment.

The setup consists of the following three sections:

(1) Light Source and Detector

A near-infrared DFB laser diode (Anritsu Corp., 69213) was mounted on a temperature-controlled heat sink (ILX Lightwave Corp., LDM-4412), and was driven by a current supply(ILX Lightwave Corp., LDC-3722). The collimated output beam from the diode laser was split into two beams by a half mirror. One was input to the sample cell for the absorption experiment and the other was input into the reference cell in order to lock the laser wavelength at the absorption center of CO of 1,565.980nm. Each transmitted beam was detected by InGaAs-PIN photo-diodes (Hamamatsu Photonics K.K., G5832-05), followed by a phase-sensitive detector. The laser wavelength was calibrated with a Michelson interferometer wavelength meter (Advantest Ltd., TQ8325).

(2) Data Processing

The diode laser employed is sufficiently narrow in wavelength that it may be considered essentially monochromatic with respect to the gas absorption line shape. In the present experiments we used a wavelength modulation technique for measurement of weak absorption of molecular CO. The modulation of the diode laser injection current results in amplitude and wavelength modulation of the laser. The gas absorption is detected at the modulation frequency or harmonics, using a band-pass filtered, phase-sensitive technique to reject the out-of-band laser amplitude noise; the second harmonic component is directly proportional to the species concentration, which is known as the 2f Detection technique.

On the other hand, the absorption or scattering of solid particles, such as soot, is independent of laser wavelength, within the wavelength range tuned by an individual diode laser. Thus, the solid particles affect transmitted intensity, but have no effect on the harmonic component.

Consequently, if we measure both the modulated component and the DC component of transmitted laser intensity, it is possible to simultaneously detect the gas concentration and the particle density.

Furthermore, the dual modulation technique is useful in removing long-term signal drift. Details are shown in a reference[8] by co-author M.Tanoura.

For the observation of the absorption spectrum, the laser wavelength was slowly swept by a current ramp (0.005Hz, $40mA_{p\text{-}p}$) applied to the injection current, and two sinusoidal modulations (f : 10kHz, $8mA_{p\text{-}p}$, ω: 500Hz, $6mA_{p\text{-}p}$) were superimposed. The laser wavelength was modulated at a frequency of 10kHz and 500Hz, and the resulting signal was demodulated by two phase sensitive detectors at 20kHz (second harmonic of the f-modulation signal) and 1kHz (second harmonic of the ω-modulation signal).

(3) Sample and Reference Gas Cells

In this experiment, the gases in the sample cell and reference cell consisted of a single type of the

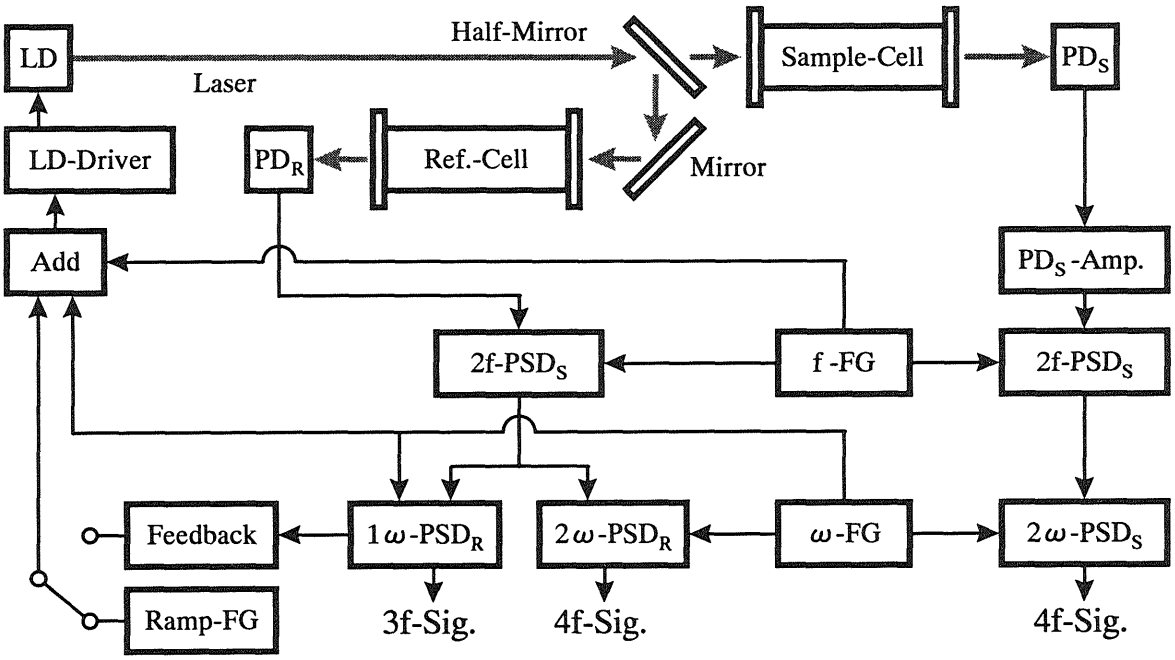
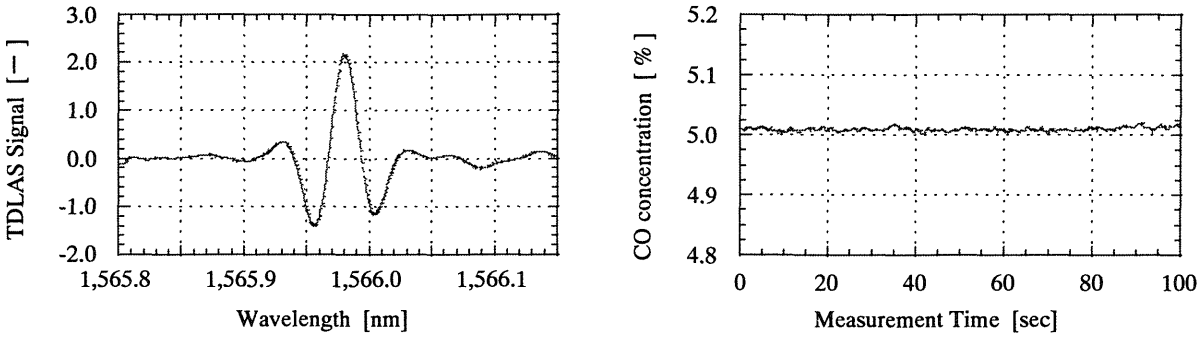


Fig.1 Schematic Diagram of Experimental Setup for CO Measurement



(a) TDLAS Spectrum of CO

(b) CO Concentraion Measured by TDLAS

Fig.2 Plots of CO measurement

standard gas with CO concentration of 5% (N_2 balance).

The gas was enclosed in single path absorption cells, made of stainless steel with wedged windows. The cells had a pass length of 150mm and an inner diameter of 22mm. The gas was maintained at atmospheric pressure.

2.2 Results and Discussion

Measurement of the absorption spectrum of CO was performed at 1,566nm by TDLAS, and the experimental result obtained is shown in Figure 2(a). The trace in this figure represents the fourth derivative of the absorption line shape, which was obtained by the dual modulation technique. The peak in this spectrum corresponds with the CO absorption center of the wavelength, and the peak height is directly proportional to the CO concentration .

Figure 2(b) shows the CO concentration (5.01%) measured by TDLAS , when the laser wavelength was locked at the CO absorption center. The lowest limit of CO concentration was estimated to be 5ppm · m/$Hz^{1/2}$, from signal intensity and noise level.

3. MEASUREMENT IN A LARGE SCALE WASTE TEST FURNACE

3.1 Experiment

Figure 3 shows the schematic diagram of the experimental setup of the TDLAS system for this experiment. The large scale test furnace for this experiment was a waste combustion furnace. The size was $^{W}2.2m \times ^{D}2.2m \times ^{H}19m$.

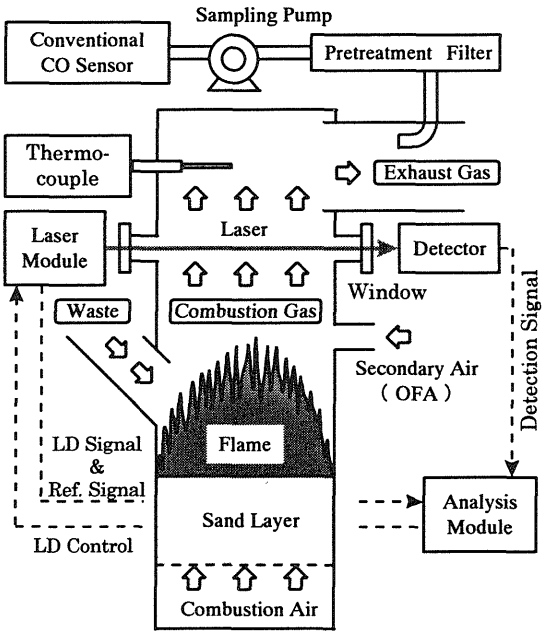
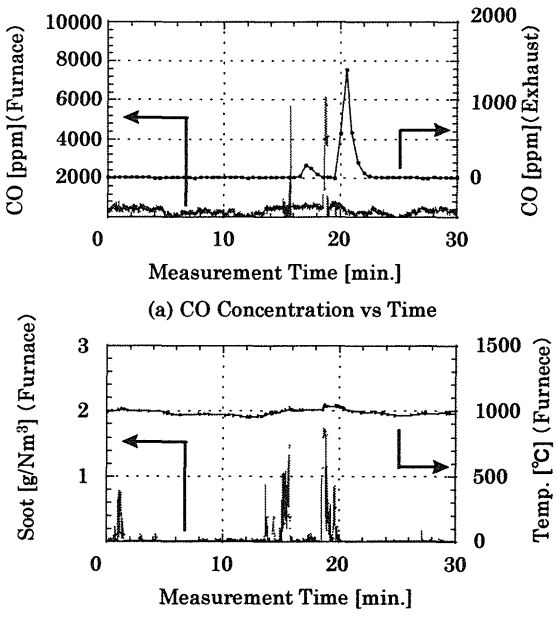


Fig.3 Schematic Diagram of Experimental Setup for Measurement in a Large Scale Test Furnace



(a) CO Concentration vs Time

(b) Soot and Tempurature vs Time

Fig.4 Result of Test Furnace Measurement

The TDLAS system was set below the secondary air (over fire air) port. This system was the same as in Figure 1, except for the sample gas cell. After alignment of the laser axis and the tuning of all circuits, we measured concentrations of both CO and soot in the test furnace by TDLAS, and measured the temperature in the furnace by thermocouple .

In addition to TDLAS, CO concentration was measured by a conventional CO sensor at the exhaust port, which was set downstream from the TDLAS measurement position. For the measurement by CO sensor, it was necessary to set up a gas sampling line and to remove water vapor and soot, known as pretreatment.

3.2 Results and Discussion

Figure 4 (a) and (b) shows the results of TDLAS measurement in the large scale waste test furnace. Figure 4(a) shows CO concentration measured by TDLAS in the furnace (solid line) and the value measured by conventional CO sensor at the exhaust port (closed circle). Figure 4(b) shows soot density measured by TDLAS (solid line) and gas temperature measured by thermocouple (solid line) in the furnace. The following results were obtained from Figure 4.

When combustion fluctuation occurred, the CO concentration and soot density determined by TDLAS increased synchronically. On the other hand, the CO fluctuation observed by conventional sensor was about one hundred seconds late. We demonstrated that real time and simultaneous measurement by TDLAS of CO concentration and soot density is possible in the furnace. In addition, the CO concentration measured by TDLAS is much higher than the value by CO conventional sensor. This is because the combustion reaction continued at the TDLAS measurement position but finished at the CO sensor position, from the viewpoint of gas temperature in the furnace.

Generally, both the concentrations of CO and soot are kept low in large scale waste furnaces. But, when the waste mass into the furnace was varied, the concentration evolution of both CO and soot occurred. At that time, it is possible to watch the combustion conditions in the furnace using a video camera. From this information, we have seen that soot evolution caused by combustion fluctuation in the waste furnace is a fast phenomenon that finished in under half a minute. For real furnaces the feeder is controlled so that the rate of waste feeding into furnaces is constantly maintained.

On the other hand, CO concentration is usually measured by conventional sensor at the exhaust port. Due to the low response of conventional sensors, we have obtained only the information that CO evolution as measured by conventional sensor was a slow phenomenon lasting a few minutes. The actual time scale of CO evolution in the furnace has been unknown, although it is very important for the development of new waste furnaces. In this experiment, we ascertained that the CO evolution in the furnace finished in under half a minute. We verified that the CO evolution in the waste furnace is a fast phenomenon, the same as the soot increment.

4. CONCLUSION

We have verified that TDLAS is a powerful tool for combustion diagnostics in a waste furnace. We measured CO concentration by means of near-infrared TDLAS using a 1,565.980nm wavelength diode laser. The following results were obtained:

1. The detection limit of CO by TDLAS was determined to be $5ppm \cdot m/Hz^{1/2}$.
2. Using TDLAS, the real time measurement of combustion conditions (CO, soot) in a large scale furnace is possible.
3. We verified that the CO evolution in the waste furnace is a fast phenomena, the same as the soot increment.

Research is underway to further develop TDLAS techniques and apply them to the direct measurement and the control of real furnaces and the analysis of phenomena in combustion situations.

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