Improvement of Combustion Efficiency and Reduction of CO_2 by New Laser Gas Analyzer (Probe-type Laser Spectrometer)

Naoto Nakano *[*1]

In order to improve the combustion efficiency of heating furnaces or boilers, it is necessary to measure the O_2 and CO in the exhaust gas and to control the operation of the furnaces. Conventionally, O_2 and CO are measured by using analyzers such as zirconia oxygen analyzer, infrared analyzer, and COe meter. However, there are problems of cost of consumables, maintenance, and responsiveness.

In 2015 Yokogawa released the TDLS8000 tunable diode laser spectrometer that allows the laser to penetrate the furnace and measure O_2 and CO by the amount of laser absorbed, thus solving such problems. In practice, however, the mounting flange of the TDLS8000 must be installed on both sides of the furnace with high positional accuracy.

To eliminate this work, we have developed the TDLS8100 probe-type tunable diode laser spectrometer, which needs to be installed on only one side, thus more than halving the installation cost due to less overhead wiring. This paper describes the features of the TDLS8100 and how it helped us to solve the problems.

INTRODUCTION

Combustion furnaces, including heating furnaces and boilers, of various kinds and sizes are used in plants. Their combustion efficiency directly impacts the operation cost efficiency of the plants, because they consume huge amounts of fuel such as gas, heavy oil, and coal. In addition, large amounts of exhaust gas from such furnaces cause environmental pollution due to nitrogen and sulfur oxides and global warming due to CO_2 and other greenhouse gases. Therefore, such pollutants and greenhouse gas emissions from combustion furnaces must be minimized.

To achieve highly efficient operation of combustion furnaces, combustion control based on precise measurement of O_2 and CO concentrations in the exhaust gas is essential[(1)]. Conventionally, zirconia oxygen analyzers are used to measure O_2 concentrations, while infrared gas analyzers are used to measure CO concentrations in gas samples suctioned by sampling devices. COe meters measure CO and methane concentrations by catalytic sensors and O_2 concentration by zirconia oxygen analyzers, and are often used mainly in North America. However, these conventional measurement methods have several problems. This paper describes the problems in measurements using conventional analyzers, and then introduces the TDLS8000 and TDLS8100 tunable diode laser spectrometers that Yokogawa has developed to solve such problems. Finally, the paper shows how problems are solved by the TDLS8100 probe-type tunable diode laser spectrometer.

*1 Business Planning Sec., Product Analyzer Marketing Department, Analyzer Center, IA Products and Service Business Headquarters

PROBLEMS IN THE CONVENTIONAL MEASUREMENT METHODS

Zirconia oxygen analyzers are used extensively for heating furnaces and boilers, regardless of the furnace size. Zirconia cells must be heated to a high temperature to work as solid electrolytes for measuring O_2 concentration. Some customers are concerned about the possibility of the cells catching fire, because high-temperature zirconia cells come in contact with gases in the process. Another problem in zirconia cells is that they deteriorate quickly in sulfur oxides of very high concentration and so must be replaced frequently, raising the cost of consumables.

Infrared analyzers require gas sampling systems to suction gas samples, regulate their pressure, remove dust from them, and dehumidify them. The sampling process causes a delay in response during measurement, which makes combustion control difficult. In addition, this method requires periodical maintenance including replacing filter elements and pump diaphragms, incurring substantial running costs.

Although COe meters are used in North America and other areas, they are basically a sampling system and suffer from frequent measurement failures due to the insufficient reliability of catalytic sensors.

SOLUTION BY LASER GAS ANALYZERS AND THEIR PROBLEMS

To solve the problems described above, since 2008 Yokogawa has been offering laser gas analyzers that do not require direct contact with gases or sampling system. Figure 1 shows an external view of the TDLS8000 tunable diode laser spectrometer released in 2015.

Figure 1 External view of TDLS8000 tunable diode laser spectrometer

For the TDLS8000, a laser unit (LU) and a sensor control unit (SCU) are mounted on opposite sides of the process to be measured, such as a heating furnace, facing each other. A laser beam passes from the LU to the SCU through the process gas, and the absorption spectrum of the laser light is used to measure the concentrations of various gas components.

However, scaffolds are required for mounting both units on two sides of the process , and a temporary scaffold is also required for the wiring work between the two units. If the units are mounted at high places, additional high-place work is required. The mounting flanges for both units must be positioned accurately, using alignment tools such as a laser aligner, to ensure the laser beam from the LU precisely hits the SCU.

Laser gas analyzers are recognized to be effective and have been introduced to large-scale heating furnaces and boilers. For small- to medium-scale boilers, however, the high installation cost may hinder the introduction of laser gas analyzers, even though their effectiveness is widely recognized.

DEVELOPMENT OF PROBE-TYPE TUNABLE DIODE LASER SPECTROMETER

Configuration

Figure 2 shows an external view of the TDLS8100 probe-type tunable diode laser spectrometer.

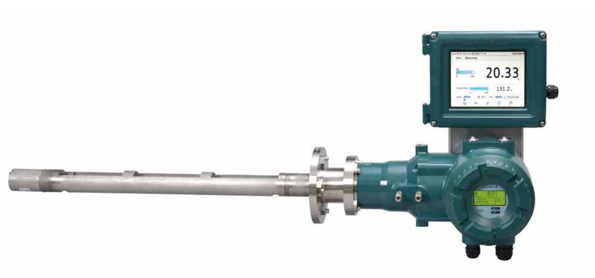

Figure 2 External view of TDLS8100 probe-type tunable diode laser spectrometer

The TDLS8100 consists of three parts: the laser detector module with a laser diode and a photodetector installed, the analyzer with a built-in printed circuit board (PCB) and a display, and the probe with purging section, process gas measurement section, and a reflector to reflect the laser beam. Figure 3 shows the configuration of the TDLS8100.

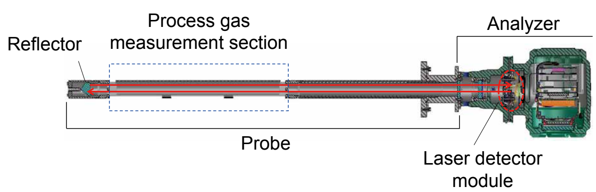

Figure 3 Configuration of TDLS8100

The laser beam emitted by the laser diode in the analyzer travels through the probe, is reflected by the reflector, travels through the probe again, and is detected by the photodetector in the analyzer. Thus, the laser beam travels through the process gas measurement section twice, making the effective optical length for measurement twice the length of the process gas measurement section.

The probe-type analyzer only needs to be inserted into the process from one side, therefore only one scaffold is required for installation. The temporary scaffold for wiring is not required either, because there is no wiring required between units. Thus, the cost of installing the TDLS8100 is less than half of that for the previous model.

Design of the TDLS8100

For measurements with laser gas analyzers, the laser beam must travel through a flow of process gas and hit the photodetector accurately, and the optical length for measurement must be stable enough.

For the TDLS8000 with two units mounted on opposite sides of the process, the laser beam must go through both the process gas and the purge gas that protects the optical windows from dust contained in the process gas. For the TDLS8100, the laser beam also goes through both the process gas flowing in the process gas measurement section and the purge gas. Therefore, process gas must be introduced reliably into the process gas measurement section.

The simplest way to introduce process gas into the measurement section reliably would be through cutting slits on both the upstream and downstream sides of the probe to allow the process gas to flow through these slits. In this case, however, dust would pass through the measurement section together with the process gas, causing scattering of laser light and a consequent decrease in the amount of light detected, as well as deteriorated S/N ratio of the absorption spectra. To prevent this, the probe of the TDLS8100 has a slit cut only on the downstream side, as shown in Figure 4. The process gas enters the measurement section from the downstream side; the probe wall at the upstream side works as a dust guard, reducing the amount of dust entering the measurement section.

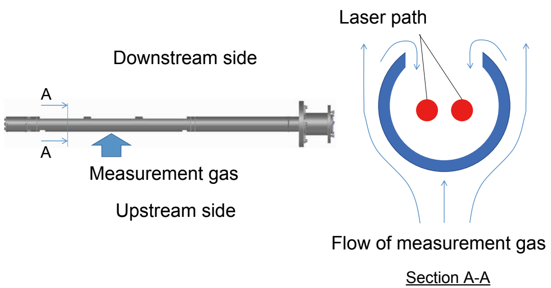

Figure 4 Flow of measurement gas

As it is inserted in the process, the probe of the TDLS8100 may oscillate resonantly with the oscillation of the process flow or furnace body. Therefore, the optimum laser beam size is selected to prevent any unwanted reflection of light by the inner surface of the probe and ensure detection of necessary and sufficient laser light intensity, even if the probe is oscillating. Moreover, the range of the laser beam adjustment is secured taking into account beam misalignment due to structural factors such as probe distortion or changes in ambient conditions. Thanks to its optical adjustment mechanism, the TDLS8100 does not have to be dismounted from the process or disassembled for adjustment even in a hazardous area in terms of explosion. Figure 5 shows that the optical axis of the TDLS8100 is externally adjustable with a screwdriver smoothly and linearly with remarkably reduced hysteresis.

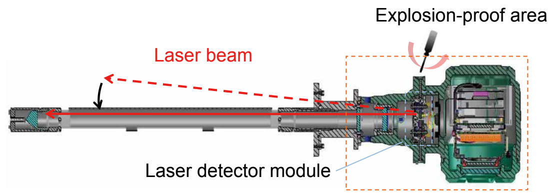

Figure 5 External adjustment function of laser optical axis

In the TDLS8100, the optical window and reflector are purged to prevent dust in the process gas from contacting and depositing on them, similarly to the TDLS8000. However, the ejection area of the purge gas may vary depending on the process conditions such as flow velocity, temperature, and pressure. As a result, the effective length of the measurement section varies, making the measurement unstable. To solve this problem, the TDLS8100 adopts a newly designed purge/measurement gas interface structure, as shown in Figure 6.

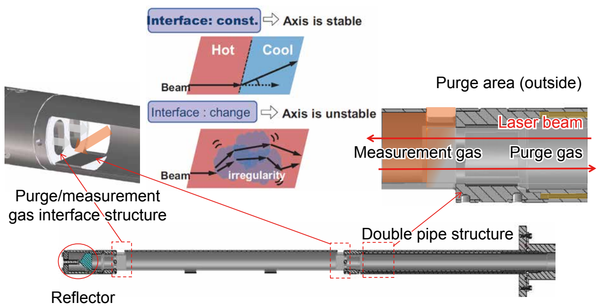

Figure 6 Purge/measurement gas interface structure and double pipe structure

The purge/measurement gas interface structure is achieved by two cutouts on the upstream side of the probe at both ends of the process gas measurement section. The flow of process gas through the cutouts sweeps purge gas downstream, preventing purge gas from flowing into the process gas measurement section. Thus, the interface between process and purge gases is stabilized, and the effective optical path length and the length of the measurement section stay constant. As a result, long-term stable measurements are possible with a very low level of drift, which reduces maintenance costs while ensuring the quality of measurement results.

The double pipe structure is designed to thermally insulate purge gas from the hot process and suppresses spatial variation in purge gas temperature. Gas density varies depending on gas temperature, and light is refracted on passing through gases of different densities. If purge gas is heated by the process nonuniformly resulting in an inhomogeneous temperature distribution, light will be refracted in an unpredictable way, causing measurement errors and failures. In contrast, the double pipe structure keeps the temperature of the purge gas uniform by thermally insulating the purge gas from the hot process. As a result, refraction of the laser beam stays within a predictable range that can be covered by a properly designed reflector. Thus, the laser beam is reflected back to the detector without fail, enabling stable measurements.

As described above, the problems associated with inserting a probe into the process have been solved by optimally designing the optics, hydrodynamics, thermal engineering, and vibrational dynamics of the probe, to stabilize the laser optical axis and the effective length of the optical path over a long period. The design of the TDLS8100 also ensures the robustness of a process analyzer.

CONCLUSION

Taking advantage of its low installation cost, the probe-type tunable diode laser spectrometer can be used in small- to medium-size boilers, for which customers have hesitated to introduce laser gas analyzers. The probe-type laser spectrometer also features less additional installation work and reduced cost of consumables in applications involving replacing the conventional laser gas analyzers and sampling system.

The probe-type tunable diode laser spectrometer is a relatively new process analyzer. Through introducing it in various processes and applications, Yokogawa will continue its development, including refining and improving the probe and preparing a broad range of accessories, aiming for stable measurements over a long period.

Increasing recognition of the effectiveness of laser gas analyzers for boilers of all sizes will encourage the use of combustion control with laser gas analyzers, which has been used only in large-scale heating furnaces and boilers, for a wider range of applications, and enable Yokogawa to offer environmental solutions such as energy saving and CO_2 reduction. As a result, Yokogawa will contribute to achieving Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action) of the Sustainable Development Goals (SDGs)(2).

REFERENCES

(1) Yoshitaka Yuki and Akihiro Murata, “Optimum Combustion Control by TDLS200 Tunable Diode Laser Gas Analyzer,” Yokogawa Technical Report English Edition, Vol. 53, No. 1, 2010, pp. 19-22
(2) United Nations, Sustainable Development Goals, https://sustainabledevelopment.un.org/, (accessed 2019-04-09)