Optimum Combustion Control by TDLS200 Tunable Diode Laser Gas Analyzer

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The TDLS200 laser gas analyzer, which is based on tunable diode laser spectroscopy, is a new generation of process analyzer. Characterized by high selectivity and long-term stability, it offers fast in-situ analysis of high-temperature or corrosive gas. This paper introduces the TDLS200's real-time measurement of carbon monoxide in a furnace, its application for optimizing combustion control in the furnace, and its contribution to environmental preservation.

INTRODUCTION

Combustion furnaces such as heating furnaces and boilers in plants include various sizes and types, and serve as energy sources, that is, they are cores in all production activities. Because a large amount of fuel such as gas or fuel oil is consumed in plants, their combustion efficiency directly affects the performance and running cost of the plants. Since they generate large amounts of exhaust gas, in recent years it has become important to reduce various greenhouse gases including CO_2 in addition to coping with pollution caused by nitrogen oxide, sulfur oxide, etc.

To minimize environmental burdens such as gas emissions and heat dissipation while maintaining a stable supply of energy (heat) for plant operation, state-of-the-art measurement and control technology is essential. Furnaces are robust facilities, and so they operate for several decades and the usage conditions of each furnace vary with each industry, customer, factory and facility. Consequently, not only proper measurement and control of O_2 and CO but also solving of multi-faceted issues are required. For example, conventional combustion furnaces apply natural air intake and their internal pressures are not uniform. In addition, if air not used for combustion enters the furnace through cracks which old furnaces often have, their combustion efficiency does not increase even if air is controlled by damper.

In order to achieve safe and optimum combustion control of furnaces, it is necessary to work out a strategic plan for comprehensive diagnosis and optimum combustion for the furnaces (furnace wall improvement, damper improvement, control improvement, etc.), execute the strategic plan, and then introduce a laser gas analyzer described in this paper.

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COMBUSTION FURNACE AND AIR-FUEL RATIO CONTROL

Combustion requires fuel and air (oxygen), and insufficient air causes fuel residue, resulting in incomplete combustion with soot and smoke. On the other hand, excessive air causes problems, such as a larger amount of exhaust gas and heating of excessive air, resulting in lower fuel efficiency. Figure 1 shows the principle of the air-fuel ratio and state of combustion. The air-fuel ratio plotted on the horizontal axis shows the ratio of actual supply air to the theoretical amount of air required for fuel combustion (theoretical air amount).

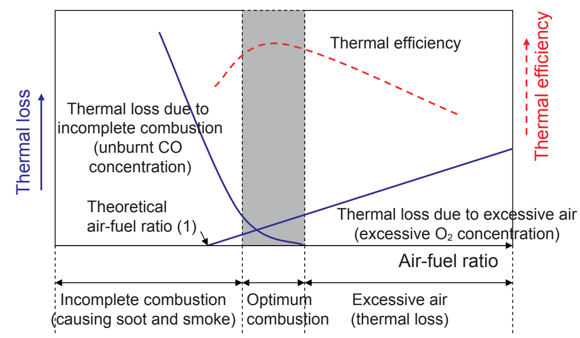

Figure 1 Relationship between Air-fuel Ratio and Heat Efficiency (Combustion)

For combustion furnaces such as heating furnaces and boilers in plants and factories, small-scale controllers such as single loop controllers are employed to optimize the air-fuel control ratio for improving the combustion efficiency. In large combustion furnaces, distributed control systems (DCS) and advanced control (multivariable predictive control, etc.) are used. These mainly control the air-fuel ratio and internal pressure of the furnace to prevent CO, CO_2 and NOx (nitrogen oxide) from being emitted and apply a cross limit circuit to prevent incomplete combustion while controlling combustion to maximize efficiency.

LASER GAS ANALYZER FEATURES AND COMBUSTION FURNACE CONTROL

Overview of the TDLS200 Laser Gas Analyzer

Figure 2 shows the appearance of the TDLS200 laser gas analyzer. This analyzer measures the process gas component concentration using tunable diode laser absorption spectroscopy (TDLAS), which measures molecule-specific optical absorption spectra due to oscillation and rotation energy transitions of molecules in the region ranging from infrared to near-infrared through a semiconductor laser with an extremely narrow oscillation wavelength range. Figure 3 shows an example of using the TDLS200 to measure the concentration of flue gas.

Figure 2 Appearance of the TDLS200 Laser Gas Analyzer

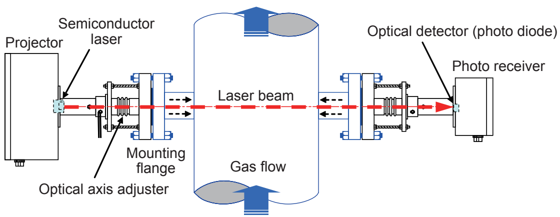

Figure 3 Measurement of Flue Gas Concentration by the TDLS200

To measure spectra, we employ our originally developed peak area method for accurate measurement even in process environments where the composition, pressure and temperature fluctuate simultaneously. Because the TDLS200 analyzer suffers no component interference owing to its high spectrum measurement resolution and is directly installed in a process enabling the laser beam to travel through the process as shown in Figure 3, average concentration in the process can be reliably measured in near real-time and at high speed even in high temperature (Max. 1500 °C) or corrosive environments. This advantage enables analysis signals to be utilized directly for process control and management systems, and the TDLS200 analyzer has been rapidly introduced in various industries such as petroleum, chemistry, iron and steel, and thermal power generation to achieve process improvement and safe operation.

By selecting a suitable semiconductor laser for the intrinsic absorption spectrum wavelength of a target measurement component, various meters for various types of component are available. The O_2 meter and CO meter for combustion gas measurement described in this paper ensure practical measurement performance by measuring absorption spectra of 0.76 µm and 2.3 µm bands respectively.

Measurement of O_2 and CO Concentrations in Combustion Gas by the TDLS200

Figure 4 shows an example of using the TDLS200 analyzer to measure O_2 and CO concentration in a combustion furnace. This example shows the concurrent measurement of O_2 and CO concentration while gradually and manually reducing the amount of air supplied to the burner. This experimental data describes the situation; CO generation begun nearly at the O_2 concentration of 2% and sharply increased at the concentration of almost 1.5%, resulting in incomplete combustion, then by increasing the amount of air supply to avoid incomplete combustion, the O_2 concentration rapidly increased and the CO concentration decreased again, resulting back to complete combustion. This data also indicates that the CO concentration increased from 100 ppm to 4000 ppm in just a few minutes.

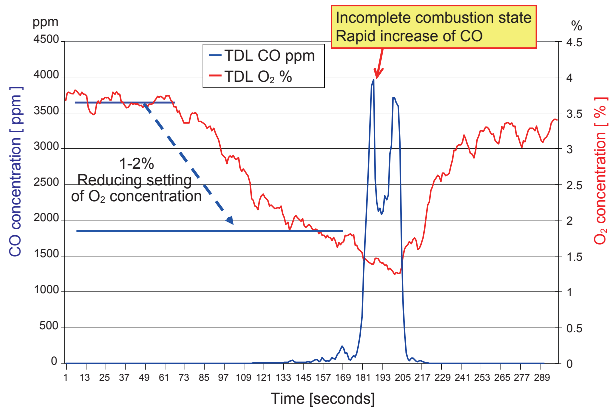

Figure 4 O_2 and CO Concentration Changes in a combustion furnace at Low Oxygen Concentration Operation

Air-Fuel Ratio Control Utilizing CO and O_2 Concentrations

According to Lyman F. Gilbert, the CO concentration in the optimum combustion zone (having the highest heat efficiency per unit amount of fuel) is around 200 ppm irrespective of fuel types and devices. However, CO increases rapidly once it has begun to increase as shown in Figure 4. Thus, either a stable combustion must be kept with sufficient supply of air or a control system must monitor the CO concentration in real-time and keep it constant at a relatively low level.

The amount of air supplied to a burner is controlled by two methods: using a forced draft fan (FDF) and damper as shown in Figure 5, or using natural air intake by controlling the opening degree of the damper of an induced draft fan (IDF). The O_2 and CO concentrations are measured by a concentration meter at the entrance of the flue and then supplied to the control system. The measured CO concentration can be used for combustion control by two methods: controlling O_2 when the O_2 concentration exceeds a prescribed value and overriding to CO control when the O_2 concentration falls below the value, or giving a CO concentration bias (compensation) to the O_2 concentration.

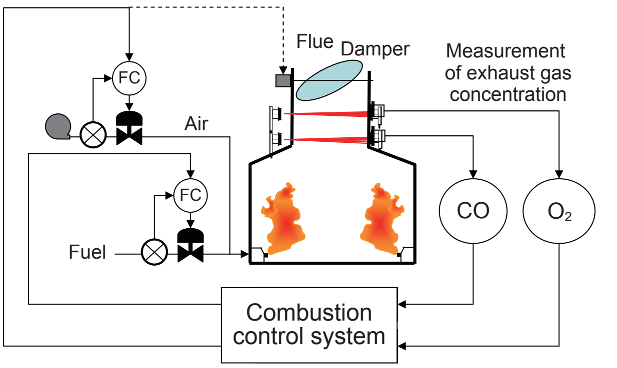

Figure 5 CO and O_2 Control System for Combustion Furnaces

ESTIMATION OF ECONOMIC EFFECTS BY AIR-FUEL RATIO IMPROVEMENT

Because the fuel required for generating the same amount of energy can be saved by lowering the set value of O_2 concentration in exhaust gas when performing air-fuel ratio control, the direct economic effect by the decrease of O_2 concentration in exhaust gas can be estimated. As the economic effects by the improvement, reduction in fuel cost which can be achieved by reducing the excessive O_2 while keeping the furnace temperature constant is calculated. Table 1 summarizes a calculation example. [1]

Table 1 Example of Economic Effect Calculation by Reducing Excessive Oxygen

Item	Symbol	Value	Unit
Prerequisites for fuel oil			
Caloric value per fuel unit weight (LHV: Low Heating Value)	LHV	9800	kcal/kg
Fuel cost per fuel unit	P	40	k¥/kl
Theoretical amount of exhaust gas	G0	11.07	Nm^3/kg
Theoretical amount of air	A0	10.46	Nm^3/kg
Prerequisites for air			
Oxygen-in-air concentration	Or	21	%
Air/exhaust gas specific heat [*1]	SH	0.33	$kcal/Nm^3$ /deg
Operating conditions			
Exhaust gas temperature	Th	400	°C
Ambient temperature	Tl	20	°C
Annual amount of fuel consumed	V	60000	kl
Excessive oxygen concentration	Ox	Before 2.50 After 2.00	% %
Calculation procedure			
1) Exhaust gas air ratio : Or / (Or − Ox)	m	Before 1.14 After 1.11	
2) Actual exhaust gas volume [*2] : G0 + (m − 1) * A0	G	Before 12.48 After 12.17	Nm^3/h Nm^3/h
3) Thermal loss of exhaust gas : G * SH * (Th − Tl)	L	Before 1565.43 After 1526.25	kcal/kg kcal/kg
4) Reduced exhaust gas thermal loss	LD	39.18	kcal/kg
5) Ratio of reduced exhaust gas thermal loss : LD / LHV	q	0.004	
6) Annual amount of fuel saved: q * V	SV	239.89	kl/year
7) Annual money of fuel saved: q * V * P	SC	9595.74	k¥/year

*1: Assume to be constant, though it varies depending on the temperature, CO_2 concentration, etc.
*2: (m-1) * A0 is air volume not used for combustion.

This example shows a trial calculation for 0.5% reduction of excessive oxygen in the heating furnace of a petroleum normal pressure distillation apparatus (topper) which processes oil of 100,000 barrels per day. The result indicates a fuel saving of about 240 kiloliters, worth 9.6 million yen per year assuming a price of 40,000 yen per one kiloliter fuel oil.

Furthermore, by reducing the amount of fuel used, CO_2 emissions can be also reduced. The carbon emission per one kiloliter of fuel oil is about three tons, so CO_2 emissions are reduced by 720 tons per year.

SAFETY CONTROL BY THE TDLS200

A burner management system (BMS) safely controls the burner of the combustion furnace and includes an interlock mechanism and a safety shut-off mechanism to prevent explosion. The BMS must comply with safety standards based on risk assessment such as the international standard (ISO12100) and the EU, USA and Japanese standards (EU standard: EN746, USA standard: NFPA86, Japanese standard: JIS B9700).

Because the TDLS200 analyzer monitors the CO concentration in near real-time and detects the generation of toxic gas due to incomplete combustion, it increases the reliability of the safety system by inputting a signal of the detected CO concentration to the BMS and is expected for implementing the defined safety requirements. Figure 6 shows a typical system configuration in which a CO measurement capability is added to the BMS burner shut-off system. Yokogawa's ProSafe-RS integrated safety instrumented system can be employed as the BMS.

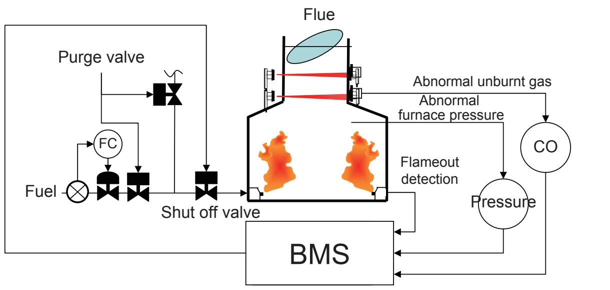

Figure 6 Safety Control in the Burner Control Equipment

OTHER CONSIDERATIONS FOR COMBUSTION OPTIMIZATION

The heat distribution is not uniform within the furnace due to the shape of the combustion furnace, furnace wall condition, burner arrangement, and complicated pipe (pass) arrangement in the combustion furnace. In addition, the control conditions vary dynamically depending on changes of the ambient temperature or fuel composition. In response, comprehensive diagnosis and countermeasures are required for the entire furnace including countermeasures to prevent air intrusion through the furnace walls and adjustment and maintenance of the burner as well as optimization of the combustion control system. Such improvements improve the energy efficiency, reduce the CO_2 emissions and enhance the safety. To achieve this, the followings are typical considerations.

- Confirmation of furnace wall condition
  The furnace walls distort because the external temperature greatly differs from the internal temperature. Usually, the internal pressure of the furnace is lower than atmospheric pressure, so external air penetrates into the furnace via small gaps in the furnace inspection hole, furnace wall joints or through holes for piping. This air intrusion may cause inaccurate measurement of the oxygen concentration in the furnace and thermal loss, so measures must be taken to prevent the intrusion.

- Automatic opening and closing of the duct by a damper
  Most conventional combustion furnaces, especially those outside Japan, employ the natural air intake/exhaust system, so it is necessary to replace the existing duct with an automatic open/close system to control the air-fuel ratio. In addition, the air blower can be used together to greatly improve combustion efficiency.

- Burner improvement and replacement
  For more efficient combustion, the air and fuel must be mixed uniformly before burning. The latest low NOx burner helps achieve a uniform distribution of temperature within the furnace, thus improving heat efficiency and reducing NOx and SOx (sulfur oxides).

- Combustion furnace maintenance
  Because the combustion furnace always operates in a severe environment, carbide corrosion and deterioration and corrosion of the furnace wall, piping and burner occur. Keeping the entire combustion furnace running normally by periodical maintenance secures stable combustion efficiency as well as safety.

FUTURE PERSPECTIVE

The TDLS200 analyzer is attracting considerable attention for many petrochemical plants because it requires little maintenance and can measure the concentrations of O_2 and CO in the furnace in near real-time. In the United States, TDL technology has proven effective for optimizing combustion in the ethylene furnace of the Dow Chemical Company under sponsorship by the Department of Energy (DOE) and its application to combustion furnaces for other than ethylene has been studied. [(2)]

We consider that further CO measurements by the TDLS200 analyzer in actual plants is required to have a good reputation in the market. The TDLS200 analyzer also needs to be made smaller and easier to install to spread in small- to medium-scale combustion furnaces. The optimization solution for the entire combustion furnace requires not only engineering combining CO_2 and O_2 measurements and the control system but also utilization of expert knowledge on combustion furnace diagnosis technology, burners and energy-saving/management. To meet the increasing worldwide demand for energy saving and eco-conscious solutions, Yokogawa should not only develop specialists inside the company but also collaborate with other companies, etc. to deliver comprehensive solutions.

CONCLUSION

The technology for combustion efficiency optimization by measuring O_2 and CO concentrations in this paper was established more than twenty years ago. This paper quotes parts of a Yokogawa Technical Report issued in 1986. However, there were not appropriate means to measure CO directly and accurately in the furnace in real-time, thus application to actual combustion furnaces was difficult and few application examples were seen. The TDLS200 analyzer has established the measuring technology for CO and O_2 concentrations in the furnace, and we believe that it will greatly contribute to practical use of the measurement.

We expect that the TDLS200 analyzer will be introduced to many plants and help create a sustainable society by saving energy and reducing greenhouse gas emissions.

REFERENCES

(1) Tsuneo Hiraoka, “Reduction of Fuel Costs and CO_2 Emissions by O_2 Control for Packaged Boilers,” Yokogawa Technical Report, Vol. 44, No. 2, 2000, pp. 85-86 in Japanese

(2) Energy Efficiency and Renewable Energy, “Advanced Diagnostics and Control for Furnaces, Fired Heaters and Boilers,” US Department of Energy, 2007,
http://www1.eere.energy.gov/industry/combustion/pdfs/advanced_diagnostics.pdf