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Applications of laser diagnostics to thermal power plants and engines

Y. Deguchi [a,*], T. Kamimoto [a], Z.Z. Wang [a,b], J.J. Yan [b], J.P. Liu [b], H. Watanabe [c], R. Kurose [d]

[a] Graduate School of Advanced Technology and Science, The University of Tokushima, Tokushima 770-8501, Japan
[b] State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, China
[c] Energy Engineering Research Laboratory, Central Research Institute of Electric Power Industry, Kanagawa, 240-0196, Japan
[d] Department of Mechanical Engineering and Science, Kyoto University, Nishikyo-ku, Kyoto 615-8540, Japan

HIGHLIGHTS

- Applicability of newly developed laser diagnostics was demonstrated for the improvement of thermal power plants and engines.
- Time resolved 2D temperature and NH_3 distributions were measured in engine exhausts using CT-TDLAS.
- The measurement method of fly ash contents was developed using LIBS for the thermal power plant application.
- The sensitive trace species measurement method was developed using low pressure LIBS and LB-TOFMS.

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ABSTRACT

The demands for lowering the burdens on the environment will continue to grow steadily. It is important to monitor controlling factors in order to improve the operation of industrial thermal systems. In engines, exhaust gas temperature and concentration distributions are important factors in nitrogen oxides (NO_x), total hydrocarbon (THC) and particulate matter (PM) emissions. Coal and fly ash contents are parameters which can be used for the control of coal-fired thermal power plants. Monitoring of heavy metals such as Hg is also important for pollution control. In this study, the improved laser measurement techniques using computed tomography-tunable diode laser absorption spectroscopy (CT-TDLAS), low pressure laser-induced breakdown spectroscopy (LIBS), and laser breakdown time-of-flight mass spectrometry (LB-TOFMS) have been developed and applied to measure 2D temperature and species concentrations in engine exhausts, coal and fly ash contents, and trace species measurement. The 2D temperature and NH_3 concentration distributions in engine exhausts were successfully measured using CT-TDLAS. The elemental contents of size-segregated particles were measured and the signal stability increased using LIBS with the temperature correction method. The detection limit of trace species measurement was enhanced using low pressure LIBS and LB-TOFMS. The detection limit of Hg can be enhanced to 3.5 ppb when employing N_2 as the buffer gas using low pressure LIBS. Hg detection limit was about 0.82 ppb using 35 ps LB-TOFMS. Compared to conventional measurement methods laser diagnostics has high sensitivity, high response and non-contact features for actual industrial systems. With these engineering developments, transient phenomena such as start-ups in thermal systems can be evaluated to improve the efficiency of these thermal processes.

1. Introduction

Recent years have seen tighter regulation of harmful substances such as NO_x, CO, particulates, and heavy metals in several types of commercial plants using combustion processes, including engines, boilers, gas turbines and so on. These pollutants cause the serious problems concerning the environment and human health [1–3]. It is necessary to make efforts to protect natural ecosystems and effectively utilize fossil fuels in various fields. Therefore, the understanding of the reaction mechanism of combustion is becoming more important to minimize environmental disruption and to improve the efficiency of combustors. In particular, detailed measurement techniques for temperature and species concentrations are necessary to elucidate the overall nature of industrial

* Corresponding author. Graduate School of Advanced Technology and Science, The University of Tokushima, 2-1, Minamijyosanjima, Tokushima, 770-8506, Japan. Tel.: +81 88 656 7375; fax: +81 88 656 9082.
E-mail address: ydeguchi@tokushima-u.ac.jp (Y. Deguchi).

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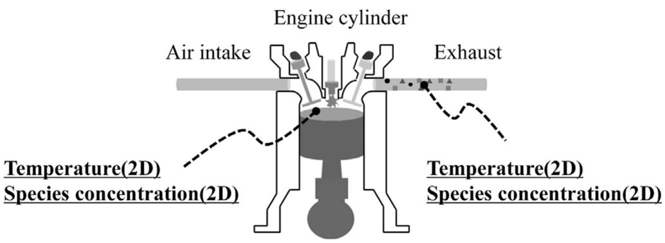

Fig. 1. Engine system.

combustion systems. There are a number of standard methods to detect these parameters, such as well-known "Industrial Standards". These standard methods are well established and easily accessible, although they are limited in terms of meeting the industrial needs described above because of slow response, low sensitivity, complicated pre-concentration, etc. In contrast, laser diagnostics makes it possible to monitor these parameters due to their fast response, high sensitivity, and non-contact features [4]. For example, laser-induced fluorescence (LIF) [5–7], tunable diode laser absorption spectroscopy (TDLAS) [8–10], laser-induced breakdown spectroscopy (LIBS) [11–13], and time-of-flight mass spectrometry (TOFMS) [14–16] have been widely used in various applications to meet the practical industrial requirements noted above.

Temperature and concentration distributions play an important role for the combustion structure and the combustor efficiency in engines, burners, gas turbines and so on. In engines, exhaust gas temperature distribution and species concentrations are important factors in NO_x, THC and PM emissions, as Fig. 1 shows. They are also catalytically important parameters in both gasoline and diesel engines. 2D temperature distribution plays an important role for the catalytic efficiency. A thermocouple, which has been widely used as a temperature measurement device, is intrinsically a point measurement method. Non-contact 2D temperature distribution cannot be attained by thermocouples. The development of these methods is important to meet the needs of these applications.

In thermal power plants, the boiler-control system is important for the adjustment of combustion process, as shown in Fig. 2. 2D temperature and concentration distributions also play an important role for the efficiency. The coal and fly ash contents, especially unburned carbon in fly ash, are important factors for efficient combustion. As is well-known, fly ash produced during coal combustion is one of the sources of fine particles. The compositions of fly ash, which contains Si, Al, Fe, Ca, unburned carbon and other materials, are complex and highly depending on the coal quality and combustion procedure. Recently, LIBS technique has been applied to coal combustion and other industrial fields because of the fast response, high sensitivity, real-time and non-contact features. LIBS has been applied to the detection of unburned carbon in fly ash, char and pulverized coal under high pressure and high temperature conditions. This automated LIBS apparatus were also applied in a boiler-control system of a power plant with the objective of achieving optimal and stable combustion [17,18], which enabled real-time measurement of unburned carbon in fly ash as

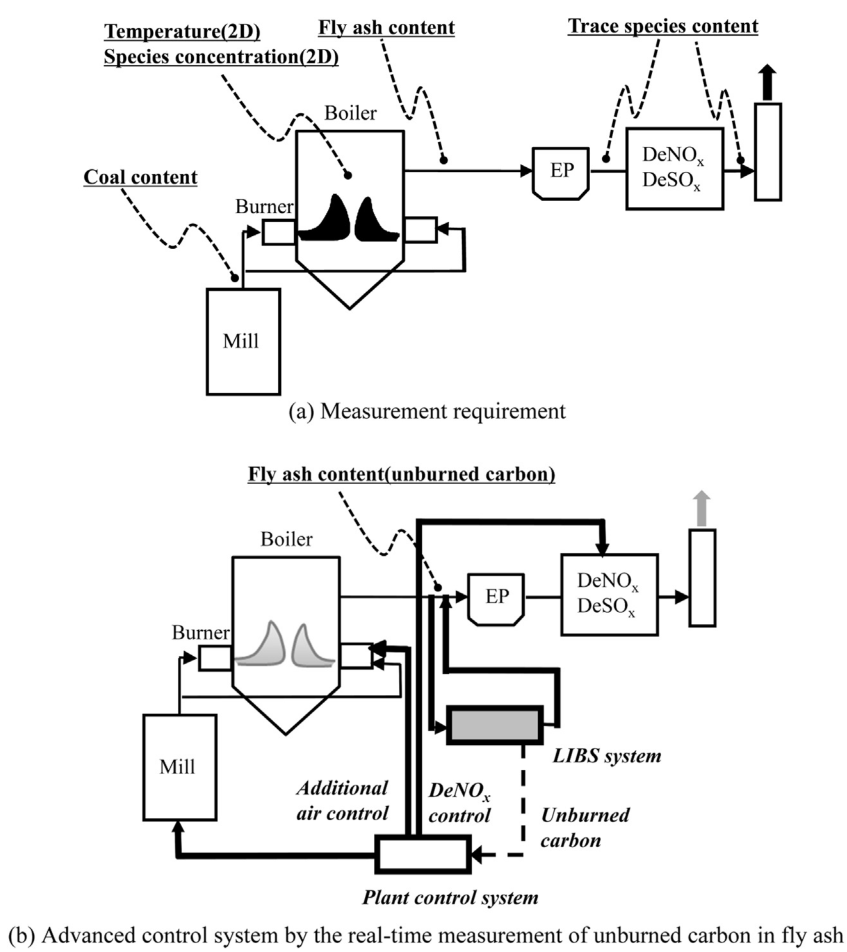

Fig. 2. System of coal-fired power plant.