

Chapter 39

Basic Research on Elemental and Size Analytical System for Nano-Sized Suspended Particulate Matter Using Contactless Optical Measurement Techniques

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ABSTRACT

A contactless sensing system for nano-sized carbonaceous particulate matter using laser-induced incandescence (LII) and laser-induced breakdown spectroscopy (LIBS) is presented. The LIBS technique allows detecting elemental composition and density of the SPMs, and LII technique allows to measure particulate size. LII technique is temporal resolved method that enables measurement of soot particulate sizes in a combustion process. In the case of the measured material consisting of a carbonaceous element, it is easy to determine the particulate diameter distribution derived from the time-profile of emission attenuation signals during cooling process, because the cooling behaviour is characteristic of the particulate diameter in LII technique. However, in actuality, the SPMs consist of several different types of elements. By using LIBS technique, the elemental analysis is able to conduct easily.

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1. INTRODUCTION

Recent regional atmospheric environment issues in large cities of developing countries are related to rapid industrialization and growth of automobile use. Increasing emission of fossil fuel from factories, power plants, and automobiles is recognized as a serious problem. The beta-ray absorption system is the most typical automatic measuring instrument for suspended particulate matter (SPM) in Japan. The main advantages of the beta-ray absorption method are:

1. The mass absorption coefficient is constant with regard to the particulate composition,
2. It does not require as frequent cleaning as does the piezo-balance type dust monitoring method, and
3. Unlike the light scattering method, it does not require standard calibration steps that use reference material.

However, recently, attention has been focused on designing environmental monitoring systems that can detect particulates smaller than 2.5 μm . It is well known that inhalation of fine particulate matter causes a range of health problems (Brown, Ney, & Hatch, 1950; Kodavanti et al., 2000; Squadrito, Rafael, Dellinger, & Pryor, 2001; Carll et al., 2010). Particulates that are smaller than 2.5 μm in size ($\text{PM}_{2.5}$) can penetrate the gas-exchange region of the lungs. This indicates that information on the size of particulates (e.g. distinguishing particulates based on their sizes) is as important as the information on the elemental components and density of particulates. However, it is difficult to simultaneously obtain real-time information on the size and composition of nanosized SPMs. Laser-induced breakdown spectroscopy (LIBS) is a useful tool to determine the elemental composition of various materials, and it does not require any chemical or physical pre-processing steps. However, because of the breakdown of all particulates, the LIBS technique is not sufficient

for obtaining information on specific particulate sizes. The quantitative values obtained by LIBS only relate to the total volume of particulates per unit volume; in other words, these values relate to the weight/volume density. A particulate counter, based on the laser light scattering method, has been conventionally employed to measure the size and the distribution of suspended particulates. However, this method requires particulate flow path and proper flow control to guide all particulate into the point of measurement. In this article, we apply the laser-induced incandescence (LII) technique along with the LIBS. The average particulate size is determined by using the simulation on the LII technique. The most striking feature of the combined LIBS and LII system is its ability to perform real-time measurements with non-contact and non-guiding particulates into the measurement spot. The simulation method adopted in this research has undergone one of the most detailed studies available, the one provided by H. A. Michelsen (Michelsen, 2003). This calculation approach requires an accurate data or good approximation (Gaussian fit, Voigt fit, etc.) of the laser intensity temporal profile used in the experiment, in order for it to agree with the actual temporal profile of the intensity. The laser intensity profile plays an important role in the theoretical estimation of the energy absorption rate. We demonstrate that an accurate laser intensity profile can be obtained by using a streak camera.

2. EXPERIMENTAL SETUP

Figure 1 shows a schematic of the combined system that consists of LII and LIBS. The optical layout of the system consists of the following devices: a Nd:YAG laser, a spectrograph, a streak camera, and a delay pulse generator. The Nd:YAG laser was operated at 1064 nm to generate a 50 mJ Q-switched pulse with a width of 8 ns (full width at half maximum, FWHM). The emissions from the particulate target were guided into the

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