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SO_2 Concentration retrieval algorithm using EMD and PCA with application in CEMS based on UV-DOAS

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ABSTRACT

A concentration retrieval algorithm is presented, which is applied to in-situ measurement of the concentration of SO_2 based on Ultraviolet-visible Differential Optical Absorption Spectroscopy (UV-DOAS). The algorithm uses the standard deviation of the differential absorbance to represents the gas concentration. Empirical Mode Decomposition (EMD) and Principle Component Analysis (PCA) are used to process the differential absorbance spectrum to improve the SNR. In the algorithm, the basis data for the concentration retrieval of SO_2 is the combination of the EMD & PCA processing result and the standard deviation of the differential absorbance to improve the SNR. The algorithm is applied for a Continuous Emission Monitoring System (CEMS) whose optical path length is 0.3 m. The nonlinear calibration for the system was executed. The relative error of the retrieving concentration is less than 4.68%. The measuring result is −2.05 mg/m^3 during the concentration of SO_2 is zero. For testing the effect of in-situ application, the contrast experiment was implemented in one coil-fired power plant. And the result proof that the algorithm has high stability and durability.

1. Introduction

China has suffered from acid rain and sulfur dioxide (SO_2) pollution since 1980s and is now the world's greatest SO_2 emitter [1]. Since 2002, China has implemented a rigorous policy including a compulsory target to increase energy efficiency and reduce SO_2 emission [2]. Thermal power industry is the biggest SO_2 emitter, being responsible for more than 50% of the total industrial emission. Emission standard of air pollutants for thermal power plants was revised for several times since 1991. The emission concentration limits on SO_2 become stricter. For example, there were only maximum permissible emissions specified without emission concentration limit of SO_2 before 1997. The concentration limit of SO_2 for a coal-fired power plant built after 1997 is 2100 mg/m^3, 400 mg/m^3 and 200 mg/m^3 since the year of 2005, 2010 and 2014, respectively [3–8].

The lower concentration of SO_2 emission put forward requirement on the lower measurement limit while higher measurement accuracy of the continuous emission monitoring system (CEMS). One common in-situ monitoring method for SO_2 in China is the Differential Optical Absorption Spectroscopy (DOAS) [9]. The method has been widely used in fossil fuel power plant flue gas monitoring. This method is first proposed by U. PLAT and D. Perner of University of Heidelberg Institute of

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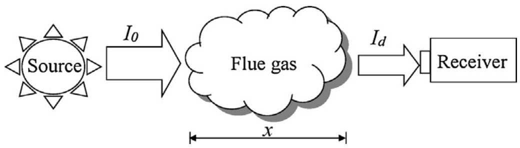

Fig. 1. Principle of DOAS.

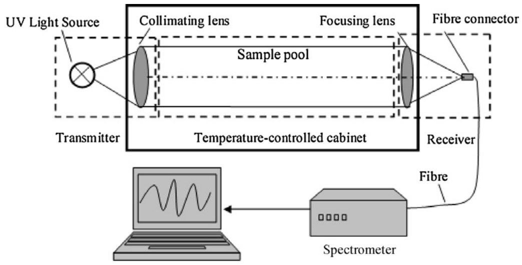

Fig. 2. Diagram of Measurement System.

Environmental Studies, aims to detect trace gases in the atmosphere or SO_2 from vocano [10–12]) using long optical path, usually 200–10,000 m [13]. The DOAS applied to emissions from stationary sources, usually use short optical path. Many kinds of algorithm are introduced to analyze the absorption spectrum to retrieve the concentrations, such as least square of differential absorption and differential absorption cross section [14], neural network [15], Kalman filter [16]. The algorithms has the following disadvantages: First of all, the accuracy of the algorithms depends on the absorption cross section measurement accuracy. Secondly, using reference spectrum in the extraction process of differential absorption make the algorithms depends on the stability of light source output.

Based on UV-DOAS, a new retrieval algorithm for in-situ SO_2 monitoring using Empirical Mode Decomposition (EMD) and Principle Component Analysis (PCA) is proposed. The differential absorption extraction dispense with reference spectrum which make not only the optical design of the CEMS simplified, but also meet the demand on continuous emission monitoring. The proposed algorithm is practically applied in CEMS with 0.3 m optical path. Both the laboratory experiments and in-situ test had been made to verify the algorithm.

2. Measurement and calibration system

Measurement system includes the light source, the collimating lens, the sample pools, focusing lens, the fiber connector, the base, and so on. The UV beam emitted from the light source transmits through the collimating lens to form a uniform beam. After going through the sample pool, the beam accesses to the focusing lens and transferred to the spectrometer by Fibre. The diagram of the system is shown in Fig. 2. All the optical devices have a high UV transmission ability. The optical path is one-way path, which may reduce the unnecessary loss of the light intensity in the transmission process. The focusing lens is used as the aperture to limit the non-paraxial stray light into the detector.

The 0.3 m sample pool is located in the temperature-controlled cabinet which keep the temperature higher than 20 °C to reduce the adsorption quantity of SO_2 gas through the pool. Passing SO_2 gas with different concentrations through the pool would produce corresponding spectroscopic data which can be acquired by the spectrometer and be used to calibrate the system (Fig. 3).

3. Retrieval algorithm for SO_2 concentration using EMD and PCA

3.1. Basic theory of DOAS

The principle of DOAS is that, when the ultra-violet light beam goes through a certain thickness of the gas, its strength will be reduced. This is caused by the gas light absorption characteristic, as shown in Fig. 1. DOAS is based on Lambert-Beer Law, also named the law of light absorption. The ideal intensity change after the light going through the measured gas can be expressed as:

$$A = \log {}^{I_0}\!/_{I_d} = \sigma \cdot x \cdot c \tag{1}$$

In which, A is the absorbance of the measured gas, I_0 is the original light intensity, I_d is the light intensity acquired by the receiver, c is the concentration of the measured gas, x is the thickness of the measured gas, σ is the absorption cross section.