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Discrimination of particulate matter emission sources using stochastic methods☆

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HIGHLIGHTS

- We presented PM emission source discrimination method based on stochastic analysis.
- Distinction between emission sources was possible based on category of distribution.
- PM emission sources may be distinguished via statistical analysis of measured data.

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ABSTRACT

Particulate matter (PM) is one of the criteria pollutants which has been determined as harmful to public health and the environment. For this reason the ability to recognize its emission sources is very important. There are a number of measurement methods which allow to characterize PM in terms of concentration, particles size distribution, and chemical composition. All these information are useful to establish a link between the dust found in the air, its emission sources and influence on human as well as the environment. However, the methods are typically quite sophisticated and not applicable outside laboratories. In this work, we considered PM emission source discrimination method which is based on continuous measurements of PM concentration with a relatively cheap instrument and stochastic analysis of the obtained data. The stochastic analysis is focused on the temporal variation of PM concentration and it involves two steps: (1) recognition of the category of distribution for the data i.e. stable or the domain of attraction of stable distribution and (2) finding best matching distribution out of Gaussian, stable and normal-inverse Gaussian (NIG). We examined six PM emission sources. They were associated with material processing in industrial environment, namely machining and welding aluminum, forged carbon steel and plastic with various tools. As shown by the obtained results, PM emission sources may be distinguished based on statistical distribution of PM concentration variations. Major factor responsible for the differences detectable with our method was the type of material processing and the tool applied. In case different materials were processed by the same tool the distinction of emission sources was difficult. For successful discrimination it was crucial to consider size-segregated

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mass fraction concentrations. In our opinion the presented approach is very promising. It deserves further study and development.

1. Introduction

Particulate matter (PM) is a general term used for a mixture of solid particles and liquid droplets in the air [1]. These suspended particles vary in size, composition and origin.

PM is one of the criteria pollutants that has been determined to be harmful to public health and the environment. The adverse effects of inhaling dust depend strongly on the chemical composition of particles as well as their specific parameters such as shape, diameter, size, morphology, surface area, structure, electric charge, and solubility. The chemical and physical properties of PM result mainly from its source, mechanism of formation, emission process, distance from the source. Therefore, knowledge about these factors is important for the characterization of dust behavior in air and possible health risks [2,3].

Identifying major pollution sources that contribute to concentration of PM is essential for developing an effective air quality management plan. In practice, there are many methods of deriving information about sources of PM emission. The measurement approach is the most reliable. It involves sampling and laboratory analyses to identify chemical composition and physical properties of collected particles. Both chemical composition and size can provide valuable insights into the source of dust particles. Identifying the composition of the particulate can trace back to the source of pollution.

The characterization of a particular process emissivity must be done using high sensitivity methods. There are several of them. Electron microscopy yields information about particles' shape and diameter. This technique is important for characterization of surface structure and aspherical determination of coarser particles. Computer-controlled electron microscopy is useful for counting, sizing, distribution, and morphology of finer particles. Energy Dispersive X-ray Spectroscopy allows to determine elemental chemical composition. X-ray Fluorescence [4] and Inductively Coupled Plasma Mass Spectroscopy [5] provide information about elemental concentrations. The Scanning Mobility Particle Sizer (SMPS) is one of the most commonly used instruments to measure the aerosol spectra in the size range from 2.5 to 1000 nm [5]. Cascade impactors are used to classify particles according to their size on the substrates placed on different stages of the device [6]. The size of particles in the ultrafine/nano size region is measured using a differential mobility analyzer [7] in the SMPS. The most sophisticated version is capable of counting particles between 1 and 1000 nm in diameter. A Condensation Nucleus Counter [8] can count ultrafine and nano aerosols by a process that involves the condensation of a vapor (usually 1-butanol, 1-propanol or water) onto the surface of the constituent particles to make them large enough to be detected by optical light scattering. Electrical charge measurement can be used to measure the surface area of a particle directly and the diffusion charging type of instrument can be used to measure the active or Fuchs surface area [9].

In contrast to instruments that measure ultrafine particle concentration or number, there are not many instruments available that can be considered as suitable to measure the mass of ultrafine aerosols in real time. Of those that are available there is only one instrument potentially sensitive enough and that can be realistically and conveniently used to perform such measurements. This instrument is based on the principle of a tapered element oscillating microbalance [10,11].

Knowledge about particles' shape, structure, diameter and composition obtained by the analysis of individual particles with an electron microscopy and different spectroscopic methods yield important information for accurate source identification. However, these techniques are expensive, time-consuming and require specialized professional qualifications. Hence, their application field is limited.

The aim of this study is a method that allows to discriminate dust emission sources using relatively simple measurements and stochastic methods of data analysis. We focused attention on this approach, because it is relatively rapid and cost-effective in application.

Our work is based on the assumption that characteristic features of dust sources are reflected in the variability of a PM concentration. This assumption is reasonable, because distribution of emitted aerosol depends on dynamic properties of dust particles which are strongly affected by different phenomena occurring during their formation.

PM may be emitted from a variety of sources. In this study we focused on machining [12–14] and industrial processes involving heat, such as welding and soldering, because each of them may be accompanied by a high dust emission [15].

Machining is a manufacturing process in which a cutting tool removes excess material from a workpiece to produce the desired shape. It was proved that metal machining processes produce broad spectra of particles. Most of the dusts generated during machining consist of very fine particles (diameter smaller than 1 μm). Their numeric concentration is around 10 to 35 times greater than that of the biggest particles (around 5 μm in diameter) and depends on the type of cutting tool used [16]. All machining processes generate aerosols (dry or wet) [17], which can be harmful to health of machine operators and the environment [18]. For the metallic dust emission during machining processes, the following process parameters were found important: cutting conditions (cutting speed, depth of cut and feed rate), tool geometry (rake angle, and lead angle) and workpiece material. These parameters influence the shearing of metal, the friction and the plastic deformation. Friction can thus cause particle detachment by various means [19].