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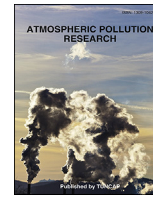

Original article

Measurement of aerosol nanoparticles from a combustion particle generator by using three types of dilutors

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Ultrafine aerosol nanoparticles created from combustion were measured by using three types of dilutors: a simple mixing dilutor, an ejector dilutor, and a rotational disk dilutor. The original particle size distribution from combustion was compared to the estimated distribution from these dilutors. The results showed that ultrafine aerosol nanoparticles maintained their particle size distribution, while particle concentrations decreased 10–20 fold in the dilution processes. Therefore, the dilutors not only diluted the aerosol nanoparticle concentration to the level of the measurement devices, but also helped estimate the shape of aerosol particle size distribution, particularly for ultrafine aerosol nanoparticles from combustion.

1. Introduction

Epidemiological studies have shown an association between particulate matter (PM) and an increase in mortality and morbidity (Dockery et al., 1993). Fine (≤2 μm, Baron and Willeke, 2001) and ultrafine (≤100 nm, Hinds, 1999) aerosol nanoparticles have received scientific and political attention due to claims that they directly affect human health (Li et al., 2003; Fine et al., 2004; Lee et al., 2004a, 2004b; Zhu et al., 2004; Kuklinska et al., 2015). Some ultrafine and fine particles contain hazardous metals such as pure iron and vanadium, which can cause serious diseases (Tolocka et al., 2004). In particular, many of these ultrafine nanoparticles are generated from diesel and gasoline engines, thereby increasing concern about combustion particles (Kittelson et al., 2006; Srivastava et al., 2011; Lu et al., 2012; Arsie et al., 2013; Yoon et al., 2015). To study ultrafine nanoparticles generated from engines, it is essential to correctly measure the nanoparticle concentration and size distribution of exhaust particles. However, these measurements are difficult because the particle concentration from an engine is too high to be measured with standard particle measurement devices. Therefore, in many cases, some kind of dilutor has been used in the measurement process (Burtscher, 2005; Lu et al., 2012; Arsie et al., 2013; Giechaskiel et al., 2014; Li et al., 2015). However, there are questions about the distortions and errors in the particle size distributions obtained from measurements using dilutors, making it necessary to study the performance of dilutors in regard to particle size distributions.

In this study, two dilutors were designed and fabricated: a simple mixing dilutor and an ejector type dilutor. We tested them along with a commercially available dilutor. Ultrafine nanoparticles from a combustion aerosol generator were used as surrogates for engine combustion particles because of their similarity in particle size distribution to particles created by engines (Kittelson et al., 2006; Li et al., 2015). The concentration level of particles from the combustion aerosol generator was within the measurable range of the system without using dilutors. Therefore, a comparison was conducted between the undiluted particle concentration and the estimated particle concentration when using the dilutors.

2. Methods

Fig. 1 shows a schematic diagram of the experimental setup. A combustion aerosol generator (combustion aerosol standard; CAST) was designed and manufactured for this study. This generator

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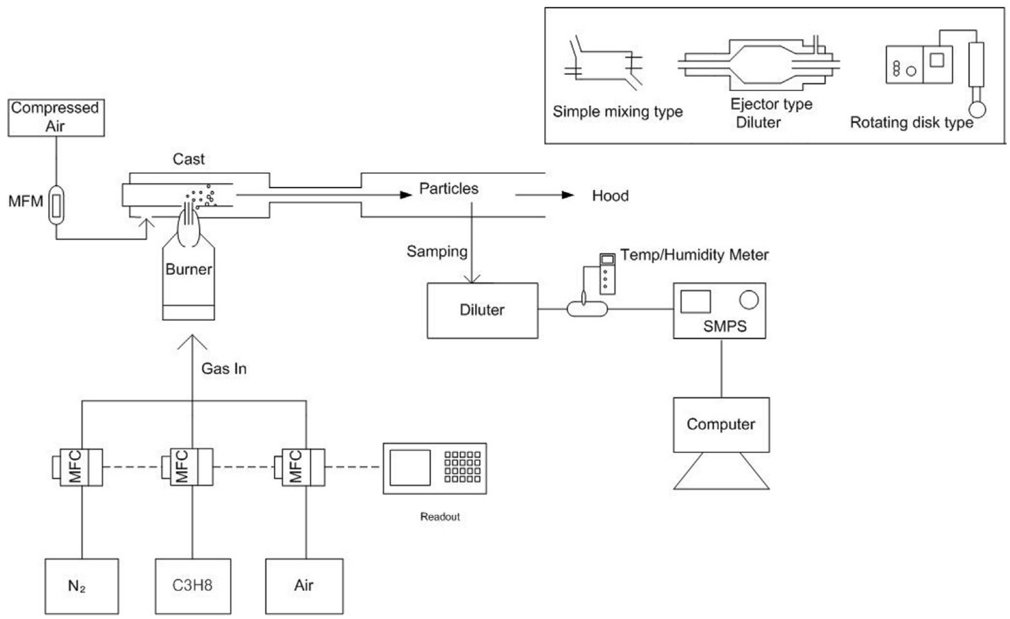

Fig. 1. Schematic diagram of the experimental setup.

consisted of a propane gas burner, a nitrogen gas supplier, and an air supplier. It emitted ultrafine nanoparticles with a concentration of 10^7 particles/cm^3.

Firstly, the emitted ultrafine nanoparticles were measured by a Scanning Mobility Particle Sizer (SMPS 3080, DMA 3081, CPC 3776, TSI, Inc., MN, USA) system without dilutors. Thus, the original values of the particle concentration and size distribution were obtained. Secondly, three dilutor types were employed to measure the particle size distribution and concentration. The original particle size distribution was estimated by multiplying the particle concentration measured with the dilutors by a dilution factor. Thirdly, the original values and the estimated values using dilutors were compared.

In this experimental system, particles larger than 10 nm in diameter were consistently detected by the SMPS system.

The simple mixing dilutor performs like a mixing chamber. The specifications for the tube diameters for the dilution air and aerosol flow were based on isokinetic mixing considerations. The dilutor was designed for a dilution factor of 10; hence, the tube diameter for the dilution air was three times larger than the aerosol flow tube diameter. An image of the simple mixing dilutor is shown in Fig. 2.

A detailed illustration of the ejector dilutor is shown in Fig. 3. As the dilution air passes through the small hole shown in Fig. 3, the flow velocity of the dilution air increases. The pressure drop generated by this increased flow velocity generates suction at the aerosol sampling inlet. So, this system works by creating a low pressure zone simply by blowing the dilution air through the system. In this study, the ejector dilutor operated with a dilution factor of 22.

In addition to the fabricated dilutors, a commercially available rotational disk dilutor (MD19-2E, Matter Engineering AG) was used in this study and is shown in Fig. 4. This dilutor had a rotating disk with cavities, which were connected to both the aerosol flow and the dilution air. The dilution factor could be varied by changing the rotational speed of the disk. In this study, the rotational disk dilutor operated with a dilution factor of 26.

We conducted at least three replications under each dilution condition. The averages and standard deviations were calculated for each condition.

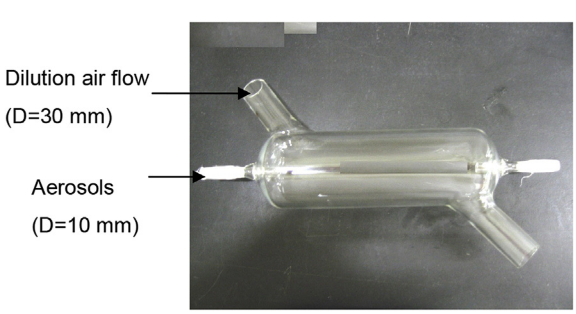

Fig. 2. Photograph of the simple mixing dilutor.

3. Results and discussion

Fig. 5 shows the experimental results. Particle size distribution, with and without dilutors, were obtained, and the original values were estimated by using the dilutors. Figs. 5(a), (b), and (c) show the results of the simple mixing dilutor, ejector dilutor, and rotational disk dilutor, respectively. In these figures, the original value and the estimated value using the dilutors showed good correlation within the particle size range of 30–150 nm. Hence, nanoparticles in this range were diluted, without distortion of the particle size distribution shapes, by these three dilutors. However, each dilutor indicated a different pattern of estimation error in this range. Table 1 shows the estimation error of the dilutors for the combustion nanoparticle concentrations.

The estimation error was calculated by dividing the difference between the undiluted (original) particle concentration and the estimated particle concentration using a dilutor by the undiluted particle concentration. When the simple mixing dilutor was employed, the original particle concentration was underestimated by 37% and 30% for 50 nm and 70 nm particles, respectively. The estimation pattern of the simple mixing dilutor switched from underestimation to overestimation as shown in Fig. 5(a). For