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Effect of temperature tuning on the aerosol acoustic aggregation process

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ABSTRACT

Diesel exhaust aerosols (DEAs) can absorb and accumulate toxic metal particulates and bacteria suspended in the atmospheric environment, which impact human health and the environment. The use of acoustic standing waves (ASWs) to aggregate DEA is currently considered to be an efficient particle removal method; however, study of the effect of different temperatures on the acoustic aggregation process is scarce. To explore the method and technology to regulate and optimize the aerosol aggregation process through temperature tuning, an acoustic apparatus integrated with a temperature regulation function was constructed. Using this apparatus, the effect of different characteristic temperatures (CTs) on the aerosol aggregation process was investigated experimentally in the ASW environment. Under constant conditions of acoustic frequency 1.286 kHz, voltage amplitude 17 V and input electric power 16.7 W, the study concentrated on temperature effects on the aggregation process in the CT range of 58–72°C. The DEA opacity was used. The results demonstrate that the aggregation process is quite sensitive to the CT, and that the optimal DEA aggregation can be achieved at 66°C. The aggregated particles of 68.17 μm are composed of small nanoparticles of 13.34–62.15 nm. At CTs higher and lower than 66°C, the apparatus in non-resonance mode reduces the DEA aggregation level. For other instruments, the method for obtaining the optimum temperature for acoustic agglomeration is universal. This preliminary demonstration shows that the use of acoustic technology to regulate the aerosol aggregation process through tuning the operating temperature is feasible and convenient.

Introduction

The diesel engine, as a type of combustion engine, is widely used in transportation areas, and has become a troublesome soot emitter for the atmospheric environment. Numerous diesel exhaust aerosols (DEAs), commonly with submicron size, (Guan et al., 2015; Burtscher, 2005; Kittelson, 1998; Harris and Maricq, 2001; Wang et al., 2012) are exhausted into the environment, which exacerbates the atmospheric particle pollution, such as the particulate matter of diameter less than 2.5 μm ($PM_{2.5}$) level. Acoustic removal (Chen et al., 2009, 2015; Gallego-Juarez et al., 1999; González et al., 2003; Guo et al., 2012; Liu et al., 2009, 2011; Noorpoor et al., 2012; Sheng and Shen, 2007; Sun et al., 2013; Yuen et al., 2014) enhances the growth process from small to large aerosol particles by means of acoustic standing waves (ASW) impacts. The process through which the ASW interacts with DEA is generally referred to as acoustic aggregation. Chen et al. (2009) found that the particle size

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distribution of the ultrafine particles in diesel engine exhaust can be markedly changed by ASW at room temperature. Noorpoor et al. (2012) asserted that the ASW field can coagulate nano-particles in diesel exhaust in order to become larger size under any temperature condition. In addition, many researchers, for example, Chen et al. (2015), Sun et al. (2013), Guo et al. (2012), Liu et al. (2009, 2011) and Gallego-Juarez et al. (1999), have verified that coal-fired flue ash can be significantly removed by an enhanced process of acoustic aggregation. Chen et al. (2015) proposed that the coupling of the acoustic and electric environment can efficiently remove fine particles from coal combustion. Yuen et al. (2014) proposed that nonlinear acoustics can act as an energy-efficient technique to enhance the aerosol removal process. Sun et al. (2013) proposed that the coupling effect between a gas jet and acoustic wave can also efficiently remove coal-fired particles. Qiao et al. (2015) proposed that the structural parameters of the acoustic resonant field can enhance the spatial distribution of aerosols and result in the X-pattern distribution phenomenon. In the above studies, temperature is commonly considered as an important factor (Noorpoor et al., 2012; Sheng and Shen, 2007; Liu et al., 2009; González et al., 2003) impacting the effect of aerosol removal in an ASW field, yet relevant experimental studies investigated the removal process under a constant temperature condition. Study on the effect of different temperatures on the removal process is scarce. Considering the importance of the temperature factor on the acoustic aggregation process, it is necessary to study the potential effects of temperature on the aerosol aggregation process in an acoustic field, which is the objective of this paper.

In recent studies on aerosol removal by ASW (Chen et al., 2009, 2015; Gallego-Juarez et al., 1999; Guo et al., 2012; Liu et al., 2009, 2011; Noorpoor et al., 2012; Qiao et al., 2014, 2015; Sheng and Shen, 2007; Sun et al., 2013; Yao et al., 2010; Yuen et al., 2014), the particle size distribution is generally considered an indispensable factor to reflect the change of aerosol behavior characteristics. One important reason is that smaller aerosols (such as those with particle size less than 2.5 μm) cannot be completely removed by the traditional particle removal apparatus (Yao et al., 2010). The second is that the particle size distribution of aerosols can clearly change under the influence of ASW. In addition, aerosol opacity is an important index to determine the concentration of aerosols (Kumar et al., 2005; Zajac, 2008; Czechlowski et al., 2015). The mechanism is based on the light penetrability of smoke with different aerosol concentrations. A higher opacity corresponds to a higher concentration of aerosol. Notably, the aerosol opacity is currently considered as a control index to assess the emission performance of diesel exhaust (Sae, 1996). Accordingly, in this paper we will utilize the opacity to characterize the aerosol concentration variation with different characteristic temperatures (CTs) given by a temperature tuning platform.

In our previous study, we invented a new apparatus for generating an ASW field (Qiao et al., 2014, 2015). The performance in aerosol removal has been tested for tobacco smoke (Qiao et al., 2014). Based on the apparatus, a new apparatus for generating an ASW field with optimal temperature control was constructed to explore the effect of temperature on the acoustic aggregation process for DEA. The DEA aggregation process was investigated at six different CTs in the range of 58–72°C. The corresponding DEA opacity variation was used to evaluate the effect on the DEA aggregation process. Especially, we emphasize the interesting potential of the enhancement of the acoustic aggregation level by means of temperature tuning.

1. Experiment and method

1.1. Experimental apparatus

The laboratory experimental unit was constructed, and the main configuration of the acoustic apparatus with the temperature tuning platform is shown in Fig. 1. The composite image composed of images A, B and C simply represents the apparatus configuration for generating an ASW field with optimal temperature control. The ASW field in the cylindrical aerosol chamber (CAC) is regulated and controlled with a pair of opposing Helmholtz resonant sources (HRS) composed of a Helmholtz resonator (HR) and speaker (Qiao et al., 2014, 2015). The HRS based on acoustic streaming causes a large acoustic pressure. The dashed arrow demonstrates the supply process for the sinusoidal alternating-current (AC) voltage signal from the signal generator and amplifier to the speaker. The temperature tuning platform composed of heating tape, temperature controller and thermocouple has the function of conveniently regulating and controlling the heating temperature. The heating tape is wrapped on the wall of the CAC to form a steady operating temperature environment in it. The heating temperature of the heating tape is regulated by the temperature controller by manipulating the warming-up time. The thermocouple for measuring CT is mounted on the interface between the heating tape and the outside surface of CAC at position D (see image B). The dash dot line demonstrates the process of temperature regulation and control. The double dash line represents the signal wire of the thermocouple. The opacity measurement system consists of a smoke opacity meter (SV-5Y, Tianjin Shi Shengwei Development of Science Company Limited, China) and exhaust gas analyzer (SV-5Q, Tianjin Shi Shengwei Development of Science Company Limited, China). The sampling probe of the smoke opacity meter is inserted into the cushion chamber to extract DEA. The opacity data measured by the smoke opacity meter is analyzed and recorded by the exhaust gas analyzer. The measured precision of the opacity is ±0.2%. The solid line arrow demonstrates the flow direction of diesel exhaust in each component. At the smoke entrance of position F (see image C), the smoke exhausted from diesel is drawn into the CAC by an exhaust separator. After the action of ASW field at a specific temperature condition in CAC, the diesel exhaust is discharged into the cushion chamber. The cushion chamber is used for the DEA sampling of the opacity measurement system. The smoke output of the CAC is arranged at position E (see image A), as the sampling point for the opacity measurement. This point represents the average position between the adjacent nodal point and anti-nodal point of ASW.

For the experiment parameters of the diesel engine, the torsion is 19.9 N/m, and the load is 17%; the engine speed is 1204 r/min; the power is 2.51 kW; the fuel consumption is 403.5 g/kWh. For the experimental parameters of the acoustic sources, the voltage amplitude and the total electrical power input of the signal supplied from the amplifier to the speakers is 17 V and 16.7 W, respectively. During the acoustic aggregation experiment at all CTs, the acoustic frequency is constant, always

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