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Experimental study on improving the efficiency of dust removers by using acoustic agglomeration as pretreatment

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ABSTRACT

Fine particles are significantly harmful to the human body and the atmospheric environment. However, the efficiency of current conventional dust removal devices for $PM_{2.5}$ is low. Acoustic agglomeration is a promising pretreatment technology, which uses high-intensity sound wave to induce particles to agglomerate and improves the efficiency of conventional dust removal devices. In this study, an experimental setup of acoustic agglomeration was built and connected to an electrostatic precipitator (ESP) and a bag filter. The influence of acoustic agglomeration on dust removal efficiency was investigated. Results show that acoustic agglomeration has a significant positive effect on improving the dust removal efficiency of the ESP and bag filter. The removal efficiency increases with the increase in sound pressure level. The optimal frequencies or frequency ranges that are best for the combined effect are also obtained. When the combined system is operated at conditions of 1400 Hz and 148 dB, the particle mass concentration removal efficiency of the bag filter can be improved from 91.29% to 99.19% and that of the ESP can be improved from 89.05% to 99.28%. The influence of medium vibration caused by the high-intensity sound wave is also discussed.

1. Introduction

Particulate pollution is currently one of the major types of air pollutions. Particulate pollution is caused by fossil fuel combustion, automobile exhaust, and several other human activities [1]. Inhalable particles, particularly fine particles, can be harmful to the human body and the environment [2,3]. Fine particles can absorb more toxic substances, such as heavy metals and polycyclic aromatic hydrocarbons, and can enter the human alveolus because of its small aerodynamic diameter and large surface area [4]. Fine particles can also cause thick haze, which is a significant concern in many large cities in China [5]. The efficiency of current conventional dust removal devices for $PM_{2.5}$ is low, which is why the study of the pretreatment of fine particle is necessary [6].

Acoustic agglomeration is a promising pretreatment technology. High-intensity sound wave forces particles with different sizes to vibrate with the medium under different amplitudes. Relative movement between particles makes them collide more easily and agglomerate into larger particles. These larger particles keep colliding with other particles. After a certain period of time, the particle size distributions (PSDs) shift toward larger sizes. Consequently, the removal efficiency for fine particles of follow-up dust removal devices is improved.

Various theoretical and experimental works on acoustic agglomeration were conducted [7–14]. However, the results are not completely consistent because of complex mechanisms and different experimental conditions. Orthokinetic interaction is extensively recognized as the primary acoustic mechanism, and hydrodynamic interaction is also considered an important mechanism [8]. In terms of experiments, scientists have conducted many trials to determine the optimal operating conditions for acoustic agglomeration and the influences of several other factors [7,15–17]. Volk [15] used sound wave to stimulate carbon black aerosol and determined that the optimized sound frequency and sound pressure level (SPL) were 3 kHz and 120 dB, respectively. Tiwary [18] reported that 2 kHz sound wave worked best on coal-fired boiler flue gas. Gallego-Juarez at al. [19] compared the effect of 10 and 20 kHz sound waves on flue gas generated by a coal-fired fluidized bed and proved that the 20 kHz sound wave is better than the 10 kHz sound wave for agglomeration. Riera-Franco et al. [10] utilized an agglomeration chamber with four high-power acoustic transducers and determined that an appropriate humidity is better for agglomeration. Wang Jie et al. [16] compared high-frequency (10 and 20 kHz) acoustic waves with low-frequency (0.5–3 kHz) acoustic waves and determined that low-frequency acoustic waves performed better than the high-frequency acoustic waves working on coal-fired flue gas. Although no common view on the optimized conditions existed because of the varied operating conditions [20], overall, the previous studies proved the effect of sound wave. However, only a few studies have been conducted to prove the positive effect of sound wave on conventional dust removal devices, which are closely related to actual industrial applications.

In this study, we combined an acoustic agglomeration system with imitative conventional dust removal devices, including a bag filter and

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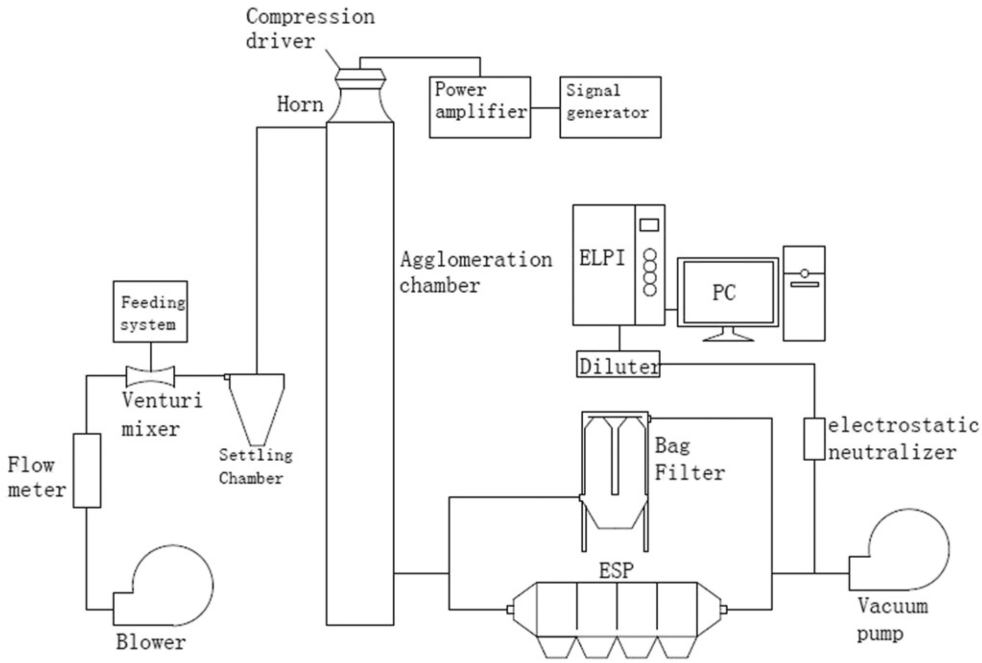

Fig. 1. Diagram of the experimental setup.

an electrostatic precipitator (ESP), to analyze the effects of sound wave on the dust removal efficiency of dust removers. The influences of frequency and SPL were investigated, and several other effects of sound wave on dust removers were also considered.

2. Experimental setup

Fig. 1 shows the experimental setup, which consists of a feeding system, an acoustic source system, an agglomeration chamber, dust removal devices, and an aerosol sampling–measurement system. Fly ash collected from ESP in a coal-fired power plant was used in the feeding system. Particles larger than 10 μm were removed in the settling chamber after the feeding system. The agglomeration chamber was a vertical stainless steel tube with a diameter of 100 mm and length of 1500 mm. Sound-absorbing cotton was placed at the bottom of the tube so that an approximately regular traveling sound wave field could be generated. The acoustic source system was composed of an YF-513 compressor driver, an SFG-1013 signal generator, and a QSC RMX2450 power amplifier, which could generate sound wave with a frequency between 180 Hz and 5500 Hz. In this condition, the SPL in

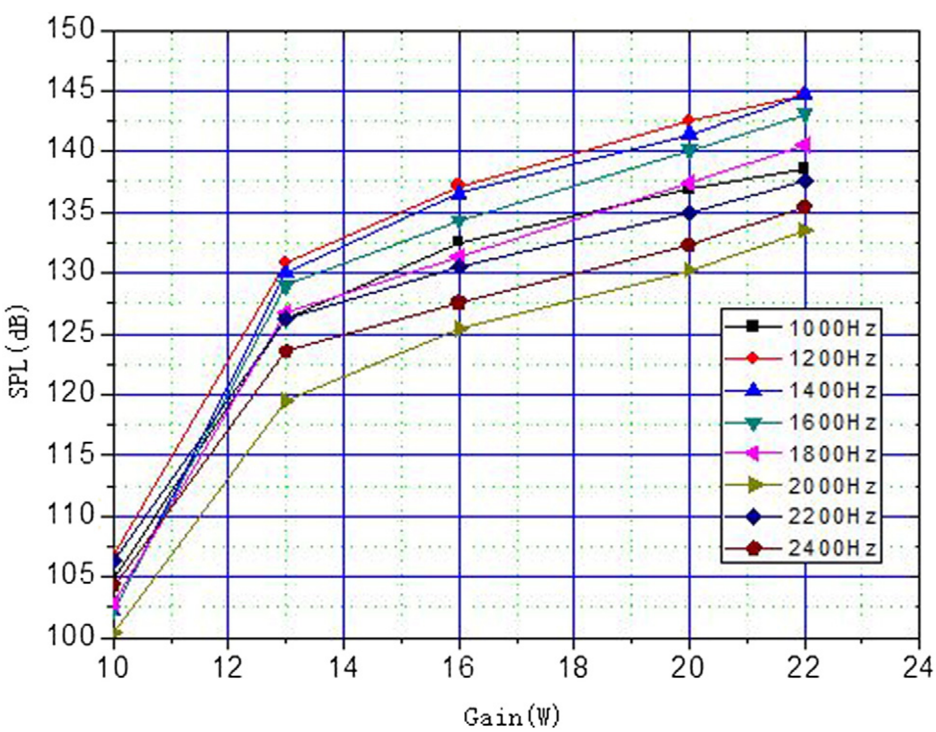

Fig. 2. Relationship between the input power and the SPL in the agglomeration chamber.