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Effect of seed nuclei combined with acoustic field on fine particles removal

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ABSTRACT

An effective technique for fine particle removal using the combined effect of acoustic field and seed nuclei was presented. The key operation parameters, such as sound pressure level, initial particle number concentration, seed nuclei and particle properties on the agglomeration and capture performance of fine particles were investigated experimentally. The results showed that the separation of fine particle was improved efficiently with the combined external fields. Fine particle removal efficiencies increased by 25% with the combined effect of acoustic field and droplets at a *SPL* of 153 dB. Removal efficiency increased with the seed nuclei size. The value increased from 20% to 50% as the seed particle size increased from 10 to 30 μm, but removal efficiency showed few changes when seed particle size was larger than 30 μm. Particle removal efficiency correlated well with the initial particle number concentration in the combined effect fields. The removal efficiency with the combined effect of acoustic field and droplets was much higher than those with the combined effect of acoustic field and solid seed particles in high particle loading. Fine particle removal was significantly impacted by the particle wettability, when the combined effect of acoustic field and droplets was used. The removal efficiency of MWI particles was improved by 20% with the combined effect of acoustic field and droplets, comparing to the removal efficiency of BC particles. Fine particle removal efficiency can be highly improved with the combined external fields, especially in low acoustic intensity.

1. Introduction

Fine particles with aerodynamic diameter <2.5 μm ($PM_{2.5}$) are the primary pollutants in the urban atmosphere, which have attracted considerable attention because of their concerns with human health, atmospheric visibility and climate change [1–3]. In recent years, haze events have been observed more and more frequently, since large quantities of particulate matters were emitted into the atmosphere with the increasing of energy consumptions [4–6]. Fine particles are difficult to be collected by current conventional dust removal devices because of their tiny size and special aerodynamic properties. However, fine particle can be separated from gas easily, if they are enlarged by means of physical and chemical preconditioning process firstly. Such preconditioning techniques can be agglomeration, such as acoustic agglomeration, chemical agglomeration, and vapor condensational growth [7–10].

Separation of fine particle using acoustic agglomeration as a preconditioning technique has been investigated experimentally and theoretically [11–15]. Acoustic agglomeration was demonstrated to be a useful and potential pretreatment process for fine particle removal in previous studies [16,17]. The results illustrated that the particle number concentration can be reduced and the particle size can be shifted significantly from small to large one. In acoustic field, collisions between particles were highly promoted by the relative motion among fine particles. However the removal efficiency of fine particles by individual acoustic field was unsatisfied with low intensity acoustic wave [18]. High value of sound pressure level (*SPL*) was needed to achieve considerable removal efficiency [19]. In order to further improve fine particle removal efficiency using acoustic agglomeration, the coupling effect of acoustic wave with other physical and chemical external dynamic field were investigated [20–26]. Studies have found that fine particle removal efficiency was improved by the combined effect of vapor condensation and acoustic wave [20], gas jet and acoustic wave [21]. Hence the coupling effect of acoustic field and other external field was considered to be a novel preconditioning process for fine particle removal. The collision probability can be improved significantly between fine particles and large particles, which was considered as bimodal agglomeration in acoustic wave [25].The agglomeration of submicron or micron particles can be promoted by adding large seed nuclei in acoustic field to form the combined effect of acoustic field and seed nuclei. Generally, such seed nuclei can be solid particles or droplets [22,27]. In acoustic field, the agglomeration between fine particles and seed nuclei was determined by the collisions and adhesion forces, depending on the particle morphology, physical - chemical properties and hydrophobic properties.

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Although the removal of fine particles by adding seed particles has been investigated in previous studies, the data of fine particle properties on the agglomeration process with different types of seed particles were rare. The coagulation and breakage mechanisms between fine particles and different seed nuclei have not been elucidated.

In this study, different types of seed nuclei (solid particles and droplets) were used to investigate the combined effect of acoustic field and seed particles. The bases of acoustic entrainment and force analysis were performed to clarify the coagulation and fragmentation of aggregates. Solid seed particles or droplets were added into the acoustic field individually to form the combined fields. The interaction properties between fine particles and different seed nuclei were carried out experimentally. The aim of this study is to contribute to the fundamental knowledge of the combined effect of acoustic field and solid seed particles (AFSP), the combined effect of acoustic field and seed droplets (AFSD). And to clarify how large seed nuclei interacted with fine particles, performing as agglomeration nuclei. The influences of sound pressure level, seed particle size, initial particle number concentration and particle properties, etc. on fine particle removal efficiencies were demonstrated with the combined external fields.

2. Experiment methods

2.1. Experimental set - up

The experimental set - up was shown in Fig. 1. A fluidized bed aerosol generator was employed to generate fine particles in the experiments. Coal combustion fine particle (CC particle), black carbon particle (BC particle) and municipal waste incineration fine particle (MWI particle) were used in this study. Flue gas generated by aerosol generator passed through a buffer vessel and was then into an acoustic agglomeration chamber, where the combined effect of acoustic field and seed nuclei was formed. The acoustic chamber was 1200 mm in length and 100 mm in inner diameter. The standing - acoustic wave was generated by the superposition of original acoustic wave and its reflected wave. A horn (KTD-250) and a baffle - board were equipped at the top and bottom of the acoustic chamber individually to create the original acoustic wave and the reflected wave. The horn was powered by a signal generator (DF1027B) with a power amplifier (DF5883) [20]. Solid seed particles (quartz particles) were added into the agglomeration chamber used a vibrating feeder, while seed droplets were injected into the flue gas by an atomizing nozzle powered by a piston pump. The concentration of the seed nuclei were about (10 ± 0.3) x 10^3 cm^{-3}. Aggregates enlarged in the acoustic chamber were then removed by a sedimentation chamber followed with the acoustic agglomeration chamber. An electrical low pressure impactor (ELPI, Dekati Co. Ltd., Finland) was deployed at the exit of the sedimentation chamber to monitor the variations of fine particle number concentration and size distribution before and after the coupling external fields. The measurement aerodynamic diameter range of ELPI was 0.023–9.314 μm.

2.2. Acoustic intensity distribution in the agglomeration chamber

Large aggregates are formed by the coupling effect of acoustic field and seed nuclei in the acoustic agglomeration chamber. Standing - wave field in the acoustic agglomeration chamber is necessary to generate the coupling fields. In this study, Standing - wave field were formed by the original acoustic wave and its reflected wave. Fig. 2 shows the spatial distribution of acoustic intensity along the agglomeration chamber. The detection location was at the integer multiple of a half wavelength along the axial direction of the agglomeration chamber. The change of acoustic intensity was very tiny along the acoustic chamber with a fluctuation of SPL <0.4%, which made it possible to neglect the attenuation of sound pressure level. That means steady standing - wave field can be formed in the agglomeration chamber.

3. Results and discussion

3.1. Mechanism of fine particle agglomeration with seed nuclei in acoustic field

3.1.1. Acoustic entrainment and relative motion for fine particle and seed nuclei

In acoustic field, the oscillatory motion of fine particles was caused by acoustic waves. According to acoustic vibration theory, the vibration

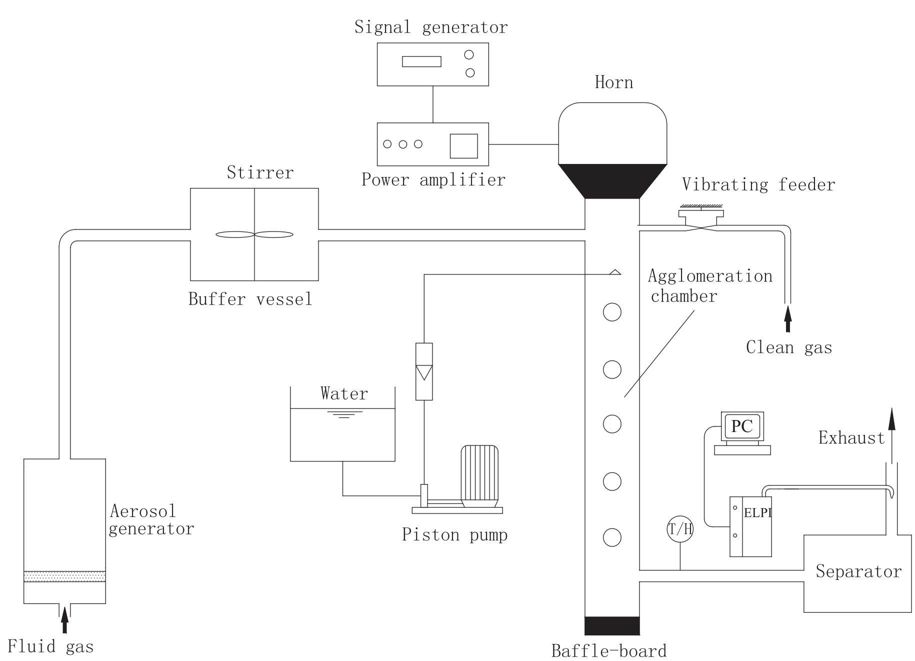

Fig. 1. Schematic diagram of experimental set - up.