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# Effects of simultaneous acoustic and electric fields on removal of fine particles emitted from coal combustion

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ABSTRACT

Traditional electrostatic precipitation has a relatively low collection efficiency of fine particles emitted from coal combustion due to insufficient particle charging. This paper establishes an experimental system combining travelling sound waves with wire-duct electrostatic precipitation in order to measure the separated and simultaneous effects of an electric and acoustic field on fine particle penetration efficiency. The ranges of the main physical parameters are as follows: discharge voltage, V = 8–12 kV; acoustic frequency, $f$ = 800–2400 Hz; sound pressure level (SPL), SPL = 130–148 dB; residence time, t = 2–6 s; initial fine particle concentration, $N_0 = 6.5 \times 10^5$–$4.99 \times 10^6/cm^3$. The application of acoustic waves in an electric field is proven as an advisable method to remove fine particles with the lowest total penetration efficiency of 4.4%. Although the sound does not change the current–voltage curves of negative corona, it can distort the motion trajectory of the particles leading to a positive result for fine particle removal. The effectiveness of sound on the improvement of fine particle removal diminishes as the voltage increases. For a given discharge voltage, there exists an optimal frequency and SPL. The optimal frequency slightly increases, while the optimal SPL decreases as the applied voltage increases. The influence of residence time and initial fine particle concentration in combined fields are also studied.


## 1. Introduction

Particulate pollution is severely harmful to human health and the environment, and is a major contributor to atmospheric pollution [1,2]. Fine particles with an aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) tend to be higher in enrichment in toxic heavy metals and other pollutants due to the large surface area and strong surface activity [3]. These particles can travel deep into the lungs and can have detrimental effects including lung cancer and other cardiopulmonary diseases [4,5]. Increased levels of fine particles in the air are consistently related to atmospheric visibility because of its higher degree of dispersion, good stability in the air and long-distance transmission [6].

Fossil fuel combustion is recognized as the major source of fine particle emissions [7]. The current conventional particle filters, such as cyclone separators, wet scrubbers, bag houses and electrostatic precipitations, are utilized in many industrial processes to remove particulate matters before the gases are discharged into the atmosphere. Cyclone separators are generally used to collect particles larger than 5 μm in diameter [8]. Venturi scrubbers are the most common scrubbers used for fine particle collection, but the applications in industry are limited due to its high power consumption [9]. Bag houses have high replacement costs, high pressure loss and cannot handle dusts that may corrode or blind the cloth [10]. Electrostatic precipitation (ESP) is the most common and efficient particulate control device worldwide. In ESP, particles are charged by corona discharge and then collected by a strong electric field perpendicular to the gaseous flow. In general, the total mass removal efficiency of a modern, well-designed ESP can approach 99.7% or higher. However, the penetration of fine particles (0.1–1.0 μm) may still be as high as 15% [11] due to their low charging efficiency.

The existing cleaning technology on fine particle removal has a relatively low efficiency. Agglomeration technology has been proposed as a pretreatment method to overcome this problem before the flue gas enters the conventional dust control devices. Electrostatic agglomeration is a process in which aerosol particles are first charged by a corona discharge [12] such as conventional ESP or a bipolar discharge [13,14] and then the particles enter the agglomeration chamber with a DC or AC electric field [15]. Besides electrostatic agglomeration, acoustic agglomeration is as well a highly efficient process in which intense sound waves produce relative motions of particles, causing increased collisions and agglomeration to occur. Fine particles continue to bond together, causing a decrease in fine particles and an increase in larger particles. Acoustic agglomeration has been widely studied in experimental and theoretical investigations [16–22]. The main acoustic agglomeration mechanisms are orthokinetic interaction and hydrodynamic interactions [21]. According to the orthokinetic interaction, different-size particles are entrained at different rates leading to collisions among polydisperse particles [23]. Hydrodynamic interactions produce particle interactions due to nonlinear interaction of scattered waves, which becomes particularly important in monodisperse particles [24]. The

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experimental research mainly focused on aerosol agglomeration prior to aerosol removal in traditional filters. Gallego [25] set up an acoustic agglomeration chamber before a conventional electrostatic precipitation in a circulating fluidized bed combustion plant (0.5 MW). The fine particle number concentration was reduced by ~40%. Another nonlinear acoustic effect (the acoustic wake effect) entrains fine particles towards charged particles, and has been proven to enhance the collision of particles by vibrating the charged particles [26–28]. Wang [29] investigated the combination of acoustic agglomeration and lime seed particles with an agglomeration efficiency enhancement up to 20.04%. Guo [30] studied the combination of acoustic fields and gas–solid jet action on the inhalable particle agglomeration and the removal efficiency was much higher than that for jet action or acoustic agglomeration alone. However, the combination of acoustic field and electric field is currently not reported.

In this paper, the intensive sound that causes coal-fired fly ash particles to agglomerate is combined with a wire-duct electrostatic precipitation to capture particles simultaneously. This experiment aims to investigate the combined intensification effects of acoustic and electric fields on the removal efficiency of fine particles. The influence of discharge voltage, acoustic frequency, sound pressure level (SPL), aerosol number concentration, and aerosol residence time are investigated.

## 2. Experimental setup

The agglomeration and precipitation chamber is made of a vertical tube with an inside diameter of 99 mm and a length of 1500 mm (Fig. 1). A horn installed on the top of the chamber is used to connect the chamber to a compression driver (YF-513) combined with an amplifier (QSC RMX2450). The driver can provide a maximum input power of 80 W and a frequency range of 180–5500 Hz. The amplifier is controlled by a signal generator (Goodwill SFG-1013). Rubber foam is placed on the bottom of the chamber to prevent sound wave reflections and ensure a relatively homogeneous travelling wave, which can be interpreted as one-dimensional travelling wave. A discharge electrode with diameter of 2 mm and 60 mm in length is properly fixed in the center of the grounded tube serving as a collecting electrode. A negative DC power supply is used to adjust the operation voltage and to record the operational corona current.

The particles used in the experiment were collected from the last ESP field of a coal-fired boiler. The feeding system consists of an electromagnetic vibrating feeding device and a vibration controller [31]. The electromagnetic vibrating feeding device, produced by Hangzhou Feiyu Magnetism & Electricity Equipment Ltd., is controlled by the vibration controller with a maximum feeding dosage of 5 g/min. The device is driven by four springs and an electromagnet, which can be magnetized and demagnetized leading to the spiral base moving down and up. Particles move forward under the vibration of the spiral base and then mix with the air-stream in a Venturi tube through a connecting pipe. The fly ash particles are well-mixed in the buffer tank prior to entering the chamber. The flow rates of the aerosols are adjusted by the blower to ensure a residence time ranging from 2 to 6 s in the chamber. Coarse particles are removed by a cyclone with a cut-diameter of 10 μm before entering a two-stage diluter (DEKATI DI-1000; Dekati type), which can dilute the aerosols at a ratio of 1/64. The diluted aerosols would then enter an electrical, low-pressure impactor (ELPI; Dekati type) at the outlet of the chamber to measure the concentration of particles. Charges captured by the particles are negative due to the negative corona discharge [32], so an electrostatic neutralizer is not used before the ELPI [33]. The results of particles with a diameter of 0.03–2.5 μm are presented in this paper because of its low removal efficiency during electrostatic precipitation. All the experiments were carried out at ambient temperature, i.e. 25 °C, and all the measurements were carried out after the system operated steadily for more than 10 min.

## 3. Theoretical analyses

A charged particle suspended in an acoustic and electric field mainly experiences a drag force and an electric force in the radial direction, and a drag force in axial direction (Fig. 2). The gravitational force, buoyancy force, virtual mass force, Basset history force, pressure gradient force

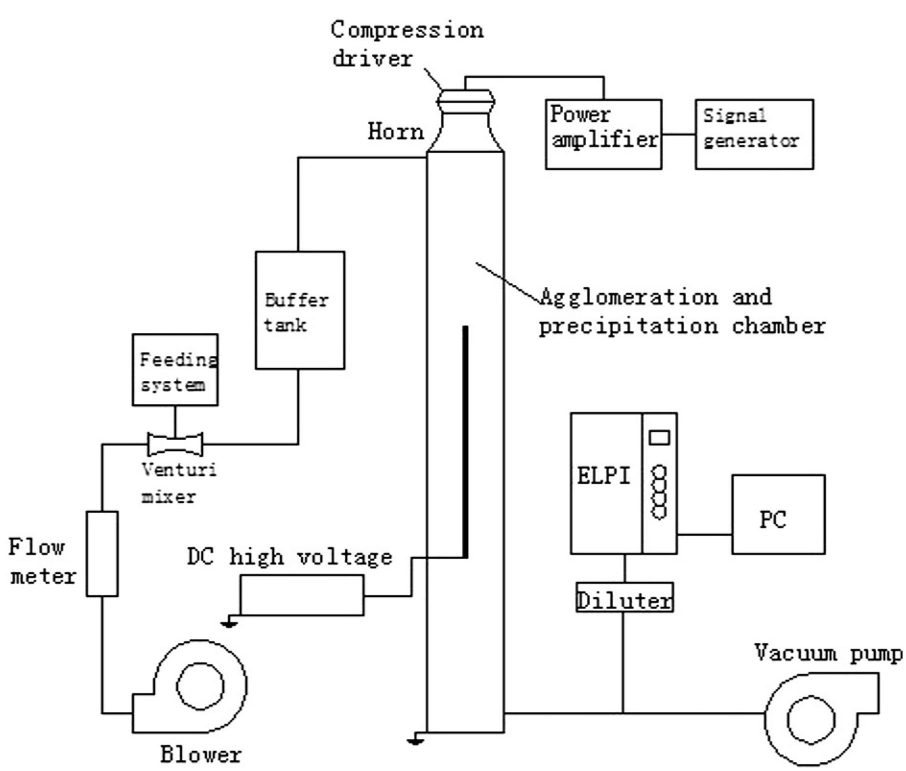


**Fig. 1.** Schematic diagram of experimental facilities.