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Full Length Article

Improving the removal of fine particles from coal combustion in the effect of turbulent agglomeration enhanced by chemical spray

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ABSTRACT

Turbulent agglomeration is a simple and economical method to improve the agglomeration of fine particles from coal combustion, which is beneficial to the particle removal efficiency of conventional equipment. However, the agglomeration efficiency for fine particles is low by single turbulent agglomeration because of the weak adhesion forces between particles, which leads to plenty of ineffective collisions. In this study, a novel technique was presented to improve the effect of fine particles agglomeration in turbulent agglomeration by adding chemical spray. The influence of single turbulent agglomeration and chemical-turbulent agglomeration on fine particle concentrations, particle size distributions, ESP performance, particle removal efficiencies in different stages and total dust concentrations after ESP were investigated respectively. The results showed the chemical-turbulent agglomeration had better effects on the agglomeration and removal of fine particles than single turbulent agglomeration. After chemical-turbulent agglomeration, the PM_{10} number concentration decreased about 34.1% than single turbulent agglomeration, and particle number concentration dropped at each stage under 10 μm, especially at 0.1 μm. Meanwhile, the application of chemical-turbulent agglomeration led to the number removal efficiency of PM_{10} increasing from 82.6% to 89.9%, the mass removal efficiency increasing from 84.5% to 91.8%, and the total dust concentrations after ESP reducing about 638 $mg{\cdot}m^{-3}$ than single turbulent agglomeration, respectively. Furthermore, the enhancement mechanism of chemical-turbulent agglomeration was explored by analyzing adhesion forces between particles and calculating the turbulent agglomeration kernel. In this study, the capillary and solid-bridge forces between particles and the increasing value of K_{TS} after chemical spray were considered as the main reasons for better effects of chemical-turbulent agglomeration.

1. Introduction

Coal is a major kind of energy source worldwide, especially in China, which mainly used coal to generate electricity. However, coal combustion process results in large amounts of ash, which contains much inhalable particles (PM_{10}) [1–4]. The emission of fine particles, especially those with an aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) is harmful to human health because these small particles have large surface area, which is benefit for the enrichment of toxic heavy metals, acid oxides and organic pollutions [5–7]. Therefore, the removal of fine particles is a key problem in the field of environmental protection.

At present, most coal-fired power plants are equipped with electrostatic precipitators (ESPs) or fabric filters (FFs), which can remove up to 99% of coarse particles, but the capture efficiency is low for fine particles because of their small diameters [8–10]. To improve the capture efficiency for fine particles, particle agglomeration was considered as a useful pretreatment technology. Particle agglomeration technology is able to increase the particle size using physical and chemical methods, which could effectively improve the particle removal efficiency of conventional equipment. Common agglomeration methods include condensation-induced agglomeration [11,12], electric agglomeration [13–16], turbulent agglomeration [17–19], acoustic agglomeration [20] and chemical agglomeration [21,22].

Among the above mentioned methods, turbulent agglomeration relies upon fluid flow and inter-particle collision to promote further growth and removal efficiency of fine particles. Turbulent agglomeration has the advantage of simple structures, low cost, reliable operation, easy retrofitting and maintenance [19], so it has shown to be a simple and economical method. But the agglomeration efficiency for fine particles is low by the method of single turbulent agglomeration [17], because successful particle agglomeration contains both collision and adhesion, the way of single turbulent agglomeration only improves the

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collision frequency, and the adhesion was affected by the surface properties of particles [23,24]. Lots of collisions cannot transform to large size aggregates owing to the weak adhesion force between particles. In addition, turbulent agglomeration studies mainly focused on theoretical analysis and numerical simulation at present [25,26].

In this study, to improve the success rate of turbulent agglomeration, an atomizing nozzle was used to spray an chemical agglomeration solution before the turbulent agglomerator, which was prepared by dissolving agglomerants in water. Chemical agglomeration solution droplets adhered on the surface of particles to strengthen the adhesion force between them, and then promote collisions to successful agglomeration. The influence of chemical spray plus turbulent agglomeration (chemical-turbulent agglomeration) and single turbulent agglomeration on fine particle concentrations, particle size distributions, ESP performance, particle removal efficiencies in different stages and total dust concentrations after ESP were investigated respectively. Furthermore, the mechanism of chemical-turbulent agglomeration was studied by analyzing adhesion forces between particles and calculating the turbulent agglomeration kernel.

2. Experiment sections

2.1. Experimental setup

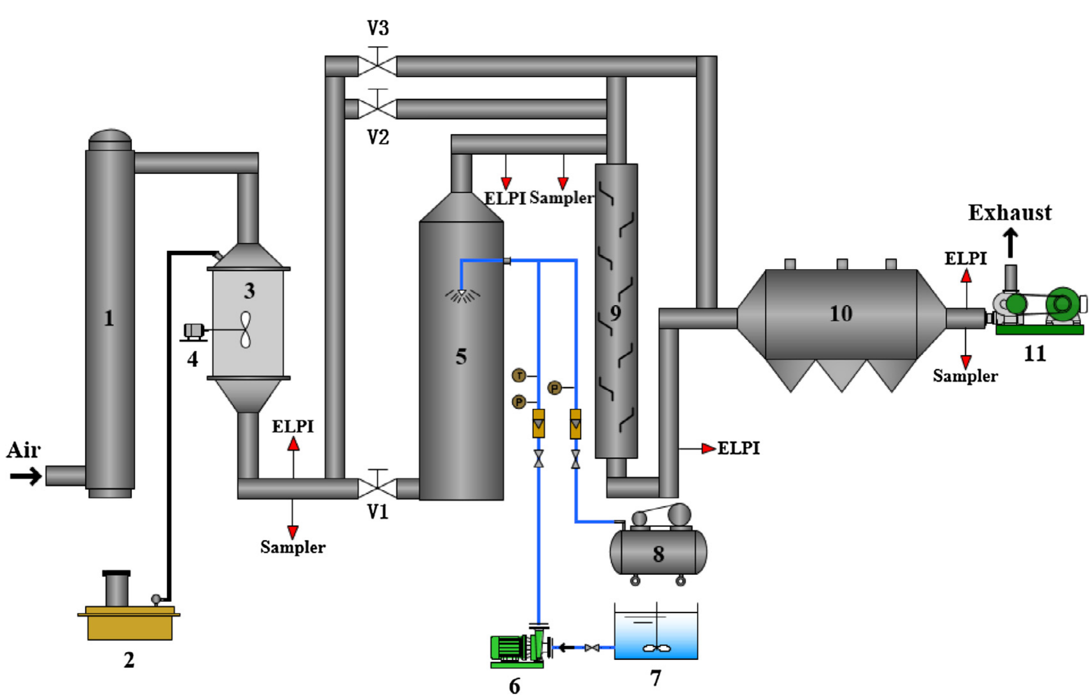
The experimental system comprised a gas heater, a solid aerosol generator, a buffer vessel, a chemical spray system, a turbulent agglomerator, an ESP and an induced draft fan (Fig. 1). The gas heater can heat air up to 250 °C with a flow rate of 300 $Nm^3 \cdot h^{-1}$, and the gas velocity was 10 $m \cdot s^{-1}$ in the pipe by the control of induced draft fan. The coal-fired fly ash particles used in the experiment were sampled from the third ash hopper of ESP in a coal fired power plant. Before experiment, the particles were dried (120 °C) for two hours in the oven and re-dispersed in the flue gas used a solid aerosol generator to keep them from clumping. The chemical composition of fly ash particles was illustrated in Table 1. Besides, a stirrer was installed in the buffer vessel to ensure the steady particle concentration and size distribution so as to keep the particle original state like actual power plant in the flue gas. The chemical spray system consists of an evaporation chamber, an atomizing nozzle, a metering pump, an agglomeration solution tank and an air compressor. The evaporation chamber was formed by a stainless steel tube, which was 4000 mm in height and 377 mm in diameter. The agglomeration solution was sprayed into the flue gas in the evaporation chamber as droplets generated from the atomizing nozzle. The agglomeration solution flow was 10 $L \cdot h^{-1}$, and the average size of droplets was about 20 μm. The turbulent agglomerator was a pipe which had a square cross section, consisted 8 pairs of vortex-generators alternately ranking in 2 columns. The side length of square cross section was 100 mm and the total agglomerator length is 1300 mm. An ESP was settled after turbulent agglomerator as dust removal device, which was a barb-plate tube type ESP and the applied rectifier voltage was −40 kV.

Table 1
Chemical compositions of fine particles used in the experiments.

	Elements (wt%)								
	O	Na	Mg	Al	Si	S	K	Ca	Fe
Particle	52.96	0.32	0.36	12.63	28.45	0.28	0.56	1.23	1.63

2.2. Structure and flow field of turbulent agglomerator

Fig. 2 shows the structure of the turbulence vortex-generator, which had a Z-type section. Each vortex-generator had 4 incisions on the side close to central axis of the pipe, and the depth was 11 mm, the width was 6 mm. The turbulence vortex-generator could generated vortices on y-z plane, and the incisions in the vortex-generator could generated smaller vortices on x-z plane, which was conducive to the turbulent



1-gas heater; 2-solid aerosol generator; 3-buffer vessel; 4-stirrer; 5-evaporation chamber; 6-metering pump; 7-agglomeration solution tank; 8-air compressor; 9-turbulent agglomerator; 10-ESP; 11-induced draft fan.

Fig. 1. Schematic diagram of the experimental system.