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Research article

Chemical agglomeration properties of fine particles immersed in solutions and the reduction in fine particle emission by adding emulsion polymers

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ABSTRACT

To reduce the fine particle concentration in coal-fired flue gas, an emulsion agglomeration agent with excellent atomization performance and low viscosity was applied in a chemical agglomeration experiment. The chemical agglomeration properties of an emulsion polymer and a water-soluble polymer on fine particles were compared and investigated experimentally in this study. In addition, the relationship between the mass concentration and solution viscosity was explored, and the atomization performances of a two-fluid nozzle were also studied. The results showed that when the mass concentration of the agglomeration agent increased, the fly ash particles in the solution became larger; moreover, the final agglomerate diameter and the solution viscosity were related to the polymer molecular weight. According to the phase Doppler anemometry (PDA) experimental results, the median diameter (D_{50}) of the agglomeration solution droplets increased as the mass concentration increased, and the atomization property of the emulsion polymer solution was evidently superior to that of the water-soluble polymer solution. In the experimental facility, chemical agglomeration experiments using four kinds of agglomeration agent were carried out, and they proved that the removal efficiency of fine particles was inversely proportional to the median diameter of the atomized solution droplets. Emulsion polymers can greatly enlarge fine particles and reduce the concentration of the fine particles. The removal efficiency of number concentration was improved by 20–25%.

1. Introduction

Fine particles, especially those with a diameter < 2.5 μm, have caused a series of environmental and health problems [1]. They are considered an important cause of the haze and fog in China, the air quality in haze-fog days was much worse than that in nonhaze-fog days [2,3]. In addition, fine particles are harmful to human health because of their large surface areas, which can be easily enriched by toxic heavy metals and organic pollutants [4,5]. Coal-fired power plants are considered a major source of fine particle emissions. At present, the main dedusting systems of power plants, such as bag filters, electrostatic precipitators (ESPs), and electric-bag dust collectors, can remove coarse particles efficiently [6,7].

With increasing emphasis on energy conservation and environmental protection, China has issued a stricter standard (GB/T13223-2011) for ultra-low emissions, namely, the concentration of particles must be controlled to below 30 mg/m^3. Currently, ESPs are predominantly used as the main particle removal device in coal-fired power plants in China, and their particle removal efficiency approaches 99.5% and even higher [8,9]. The minimum collection efficiency of an ESP appears in the particle size range 0.1–1 μm, with a large portion of fine particles in this range emitted into the atmosphere [7,10,11]. Therefore, many studies on the removal mechanism of fine particles by ESPs have been carried out, and many techniques, such as flow control and optimization [12], energizing with a pulsed or new switching power source [13], fine particle coagulation and growth technology [14], have been proposed to reduce the fine particle emissions. Increasing the size of fine particles at the ESP's inlet has gradually become a research focus among these methods and can be achieved through physical and chemical means, such as acoustic agglomeration [15], turbulent agglomeration [16], chemical agglomeration [17–20], and electro coagulation.

Recently, a large number of studies on chemical agglomeration have been reported, because of its advantage of obvious effect on fine particle growth, lower energy consumption, simple operation, etc. The research by Durham et al. [17] shows that the viscosity and specific resistance of particles can be adjusted by adding a special adhesive solution to the flue gas before it enters the ESP, as the removal

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efficiency of $PM_{2.5}$ was significantly improved. Wei et al. [18] studied the mechanism and influencing factors of chemical agglomeration theoretically. Liu et al. [19] adopted the simulated flue gas system to investigate the removal of fine particles by different chemical agglomeration agents. Bao et al. [20] reported that surfactants can greatly enhance the wetting performance on fine particles and its promotive action for chemical agglomeration. At present, natural polymers (such as xanthan gum, sesbania gum, and guar gum) and synthetic water-soluble polymers (such as polyacrylamide and carboxymethyl cellulose) are mainly used as chemical agglomeration agents in chemical agglomeration experiments. However, these water-soluble polymers are prone to hydrolysis and high viscosity, resulting in a change in the rheological properties of the solutions. The polymer solution, which is sprayed into the flue gas, is atomized into small droplets through a two-fluid nozzle, but the effects of fluid properties on the atomization performance of spray nozzles, such as droplet size distribution, have not been reported.

In this study, emulsion polymers were applied as agglomeration agents in chemical agglomeration experiments, and the agglomeration behaviour of fine particles in the chemical agglomeration solution was investigated experimentally via size distribution analysis. The influence of solution viscosity on droplet size was examined by the PDA system. Based on the results, possible reasons were explored to explain the relationship between the size of droplets and the chemical properties of the agglomeration agent. Furthermore, the changes in fine particle size and concentration before and after the chemical agglomeration process were also studied.

2. Experimental section

A flue gas system was designed to simulate the flue gas treatment process in a power plant. The experimental facility mainly consisted of a fully automatic coal-fired boiler (CZML-0.12, LNHDS Ltd., China), a buffer vessel, a selective catalytic reduction (SCR) denitrification system, a chemical agglomeration chamber, an ESP, a WFGD system, and a measurement system.

2.1. Experimental facility

As shown in Fig. 1, the coal-fired boiler could provide approximately 350 Nm^3/h of flue gas for the experimental system. The buffer vessel was used to stabilize the concentration of particles and to regulate the temperature of flue gas via a stirrer and an electric heater. The flue gas passed through the SCR system into the chemical agglomeration chamber, of which the diameter and height were 400 mm and 4000 mm, respectively. The chemical agglomeration solutions were sprayed into the 2-levels agglomeration chamber (height = 4000 mm and diameter = 400 mm) by two-fluid atomizing nozzles; meanwhile the chemical agglomeration process occurred in reverse contact with the flue gas. In addition, the two-fluid nozzles were installed at a distance of 3500 mm and 2500 mm from the bottom of the chamber, respectively. The removal efficiency of fine particles by chemical agglomeration was defined as:

$$\eta = \frac{N_{inlet} - N_{outlet}}{N_{inlet}} \times 100\%, \tag{1}$$

where η is the removal efficiency; and N_{inlet} and N_{outlet} are the concentration of fine particles before and after the agglomeration chamber, respectively.

Then, the flue gas entered the ESP via a booster fan, and the temperature of the ESP inlet was set at 150 °C. The fine particles after agglomeration were collected by the ESP system. Finally, the flue gas was sent into the desulfurization tower in order for the calcium desulfurization process to be carried out.

The flue gas components before the chemical agglomeration chamber are listed in Table 1. In the agglomeration chamber, the agglomeration solution and the flue gas conducted heat exchange in reverse contact. During this process, the solution of the agglomeration agent absorbs heat and evaporates to become part of the flue gas. When the flue gas temperature decreases, SO_X in the flue gas will be combined with water and condense into droplets of sulfuric acid, leading to corrosion of the ESP system and thus possible air leakage. According to previous results [21], the flue gas temperature of the ESP inlet should be controlled to > 140 °C, to avoid the risk of low temperature corrosion. When the temperature of flue gas in the experimental facility drops from 150 °C to 140 °C, the relationship between the flow rate and

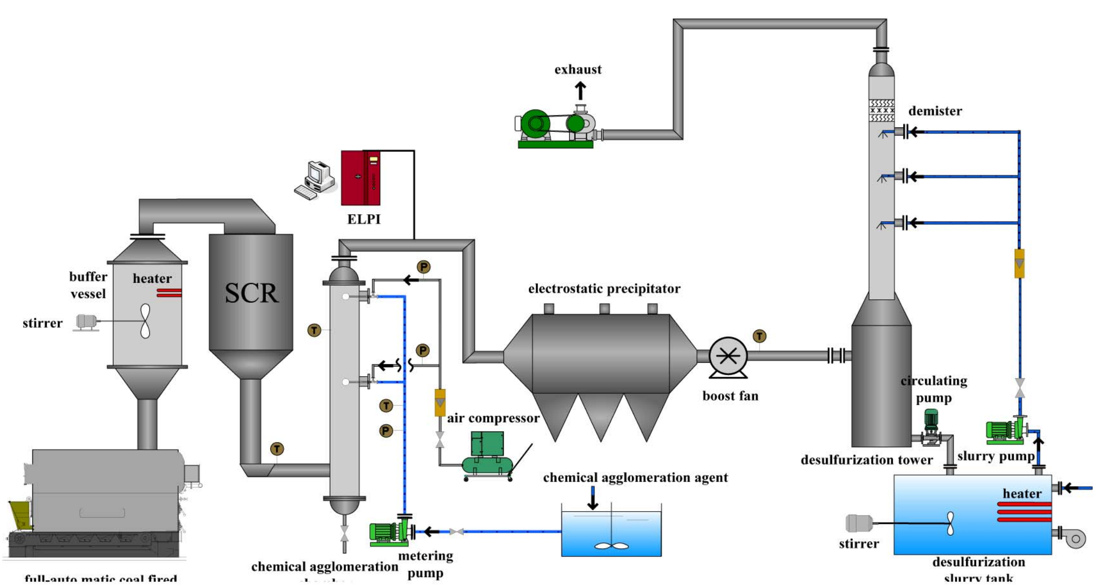

Fig. 1. Schematic diagram of the coal-fired flue gas experimental facility.