



Full Length Article

Relationship between the zeta potential and the chemical agglomeration efficiency of fine particles in flue gas during coal combustion



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ABSTRACT

Fly ash fine particles emitted from flue gas during coal combustion are the primary atmospheric pollutants in China. The purpose of this study was to investigate the characteristics of the zeta potential of fine particle suspensions. The relationship between the zeta potential and the fine particle removal efficiency was also discussed. Batch experiments were conducted to evaluate the zeta potential of fine particle aqueous solutions under various pH, ion concentration, surfactant, polymer, and chemical agglomeration solution conditions. A chemical agglomeration system was designed to simulate the removal process of the fine particles. The test results indicated that the zeta potential absolute value of the solution decreased initially and then increased as the pH increased. As the pH increased from 4 to 12, the zeta potential decreased from $Z_p = 9.4$ mV to $Z_p = -45.4$ mV. The isoelectric point (IEP) was 4.3. Also at the IEP, the highest fine particle removal efficiency of 25.9% was achieved. The zeta potential increased as the metal cation concentration of the solutions increased. The trivalent cation Al^{3+} exhibited the best performance, which increased Z_p from -32.1 mV to -11.2 mV and produced the highest fine particle removal efficiency of 9.2%. Polymers significantly impacted the zeta potential. As the concentration of kappa-carrageenan (CAR) increased from 0.01% to 5%, the zeta potential increased from -30.1 mV to 12.6 mV. The highest fine particle removal efficiency of 41.8% was acquired at a concentration of 0.5%, which had the lowest zeta potential absolute value of 3.5 mV. It can be inferred that the increase in the zeta potential induced the growth of the energy barrier, which prevented particle agglomeration. The suspension with a lower zeta potential exhibited a better fine particle removal efficiency.

1. Introduction

Fine particles with aerodynamic diameters under $2.5 \mu\text{m}$ (termed $PM_{2.5}$) have drawn much attention due to their effect on human health and the environment. Exposure to $PM_{2.5}$ has been associated with increases in mortality and hospital admissions due to respiratory and cardiovascular disease [1–3]. Previous studies [4,5] have shown that coal-fired power plants are predominately responsible for the emission of fine particles in China. Existing dust-removal technologies, including electrostatic precipitators (ESPs) and fabric filters (FFs) can collect coarser particles with diameters larger than $2.5 \mu\text{m}$ [6]. However, these technologies are much less effective for removing $PM_{2.5}$. Therefore, there is a pressing need to improve the fine particle removal efficiency.

Chemical agglomeration has proved its excellent removal efficiency of fine particles [7–9]. It works by spraying a chemical solution into flue gas. Fine particles then agglomerate into larger sizes due to physicochemical interactions with the solution [10–13]. Zeta potential has been widely used to quantify the magnitude of electric charge

distribution that surrounds particles and characterizes the stability of colloidal dispersions [14].

Extensive studies have been conducted to elucidate the relationship between the zeta potential of solutions and the size distribution of particles. The effect of particle size on the zeta potential of a boron powder suspension in acetone with iodine was investigated [15], and the results revealed that the zeta potential increased with increasing particle size. A higher zeta potential value was desirable as it helped stabilize the suspension. Li et al. [16] used chitosan-modified soil to flocculate *Microcystis aeruginosa*, and the results indicated that the zeta potential could be manipulated to improve the flocculation efficiency of *Microcystis aeruginosa*. Barick et al. [17] investigated the effect of the concentration of polyethylenimine and pH value on the zeta potential of silicon carbide (SiC) aqueous dispersions. The zeta potential initially decreased and then increased as the pH rose, which was attributed to the enhanced repulsion between the polymer chains and the SiC surfaces. Carneiro-da-Cunha et al. [18] characterized sodium alginate, kappa-carrageenan, chitosan, and two galactomannans in terms of zeta

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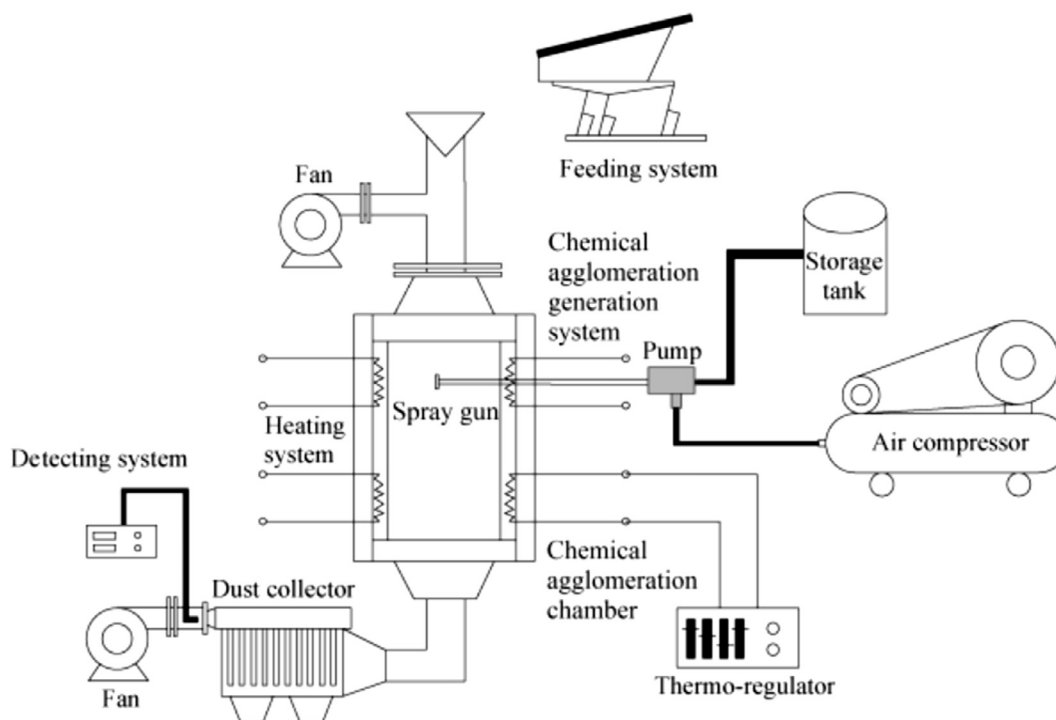


Fig. 1. Schematic diagram of the chemical agglomeration experimental system.

potential as a function of ionic concentration and pH of polysaccharide solution. An increase in the ionic concentration led to a decrease in the zeta potential as a result of the reduction in the repulsive potential, which was favored by the interaction between the charged groups and the anion Cl^- . Hashiba et al. [19] studied the influence of polyelectrolyte ammonium polyacrylate (PAA) on ZrO_2 aqueous suspensions. The addition of PAA resulted in an increase in the zeta potential and therefore a decrease in the viscosity of the suspension. Sedimentation tests also exhibited satisfactory dispersion corresponding to the high zeta potential and low viscosity. Marsalek [20] studied the effect of the surfactants sodium dodecyl sulfate, cetyltrimethylammonium bromide, and sodium carboxymethyl cellulose on the stability of ZnO suspensions. The maximum particle size was found near the isoelectric point (IEP). Cationic and anionic surfactants changed the zeta potential of ZnO suspensions and thus affected their stability. Similar results were acquired by Ridaoui et al. [21], who used cationic surfactant cetyltrimethylammonium chloride (CTAC) and amphiphilic polymer polystyrene-polyethylene oxide to modify the surface charge of carbon black suspensions and change the particle size. An increase in the CTAC concentration led to a decrease in the particle size. The zeta potential of the colloidal suspension varied correspondingly. Duan et al. [22] studied the zeta potential and diameter of aluminum salt precipitates. The zeta potential decreased sharply as the salt concentration was increased. Mehdilo et al. [23] measured the zeta potential of three different ilmenite suspensions. The zeta potential was found to be strongly dependent on the contents of the mineral chemical compositions, crystal forms, and crystal surface structure. These results demonstrate the relationship between the zeta potential and particle size. However, the zeta potential of a coal-fired fly ash particle suspension has not yet been investigated. In addition, the results appear uncomprehensive since the test conditions were limited. Certain important factors, such as the composition and concentration of polymers were not considered.

In the present study, the characteristics of the zeta potential of suspensions of fly ash fine particles from flue gas during coal combustion was evaluated under various conditions, such as varying pH and ion concentrations of the colloidal suspension and the addition of polymers, surfactants, and chemical agglomeration solutions. Further,

chemical agglomeration experiments were conducted to investigate the relationship between the zeta potential of the colloidal suspensions and the removal efficiency of fine particles.

2. Experimental protocols

2.1. Zeta potential experiments

The zeta potential is used extensively in the liquid phase to quantify the magnitude of the charge [14]. Batch zeta potential experiments were conducted by testing the zeta potential of the particle suspensions containing various metal ions, surfactants, polymers, and chemical agglomeration reagents. The influence of the pH value on the zeta potential was also investigated. The particles were dried at 110°C for 1 h prior to the experiments. A certain amount of the particle sample was mixed with 100 mL of deionized water in a polyethylene bottle to obtain a particle suspension with a mass ratio of 1%. The pH of the suspension was adjusted in the range of 4–12, and the suspension was then stored at ambient temperature for 1 h until the pH had stabilized. Metal ions were added to the suspensions to create mass concentrations of 0.1%, 0.2%, 0.5%, and 1%. Surfactants, polymers, and chemical agglomeration reagents were added to the suspensions to create mass concentrations of 0.01%, 0.02%, 0.05%, 0.1%, 0.2%, 0.5%, and 1%. The bottles were then agitated for 2 h to achieve complete mixing. Finally, the bottles were placed in a zeta meter for testing.

2.2. Chemical agglomeration experiments

All tests were performed using the chemical agglomeration experimental system shown schematically in Fig. 1. Specific details of this agglomeration system were described in our previous report [24]. Chemical solutions were sprayed into the chemical agglomeration chamber under the force of pressurized air (0.8 MPa). The atomization diameter and flux of the solutions were 15 mm and $4\text{--}7\text{ ml}\cdot\text{min}^{-1}$, respectively. The total transfer rate of the solutions was $0.005\text{ m}^3\cdot\text{s}^{-1}$. Flue gas modulated by a fan was injected into the chemical agglomeration chamber. The velocity and flux of the gas were $0.25\text{--}0.5\text{ m}\cdot\text{s}^{-1}$

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