Fuel 203 (2017) 557–569

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Chemical agglomeration of fine particles in coal combustion flue gas: Experimental evaluation

Guo Yiquan, Zhang Junying *, Zhao Yongchun *, Wang Shaolong, Jiang Cheng, Zheng Chuguang

State Key Laboratory of Coal Combustion, School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, China

HIGHLIGHTS

- Comprehensive experimental parameters in chemical agglomeration were studied.
- High removal efficiency was obtained in iso-electric environment.
- Chemical solution kappa-carrageenan achieved a removal efficiency of 47.1%.
- Synergism showed great advantage: the mixture had a removal efficiency of 59.3%.

ARTICLE INFO

Article history:
Received 20 February 2017
Received in revised form 30 April 2017
Accepted 3 May 2017
Available online 9 May 2017

Keywords:
Fine particles
Chemical agglomeration
Removal efficiency
Coal combustion

ABSTRACT

Fly ash fine particles emitted from coal-fired power plants are the primary atmospheric pollutant in China. The pressure, temperature, and velocity distribution of the flow field in a chamber was simulated to evaluate chemical agglomeration. The effect on the removal efficiency of composition, concentration, pH, K^+ content, and zeta potential of the chemical agglomeration solutions as well as surfactant and flue gas temperature were evaluated. The results suggested that suitable solutions could significantly improve the removal efficiency of fine particles. Among these, kappa-carrageenan performed best and achieved a removal efficiency of 47.1%. Synergism was detected as two different chemical agglomeration solutions were mixed together: a mixture of kappa-carrageenan and konjac glucomannan attained a removal efficiency of 59.3%, higher than their individual values. The efficiency improved initially and then decreased as the solution K^+ concentration increased. Also surfactants affected agglomeration: cationic and non-ionic surfactants enlarged the removal efficiency by 9.0% and 3.7%, respectively, whereas anionic surfactants lessened average removal efficiency by 5.6%. Zeta potential influenced the removal efficiency as well: it peaked as the zeta potential was around 0 mV.

1. Introduction

China is the largest producer and consumer of coal in the world [1]. Previous studies [2,3] have shown that coal-fired power plants are a major emission source of fine particles in China. Fine particles are the particles with diameter less than 2.5 μm. Because of their small size, fine particles can enter the lung and cause various respiratory diseases, such as asthma and lung cancer [4,5]. Besides, they also reduce atmospheric visibility and play a critical role in global climate change [6,7]. Existing dust removal technologies, including electrostatic precipitators (ESPs) and fabric filters (FFs), can remove up to 99% of coarse particles with diameters larger than 2.5 μm [8]. However, these technologies are much less effective for removing fine particles. Therefore, it is essential to improve the fine particle removal efficiency of dust collectors.

Agglomerating fine particles into larger sizes using physical and chemical methods has been shown to be a good approach to improve their removal efficiency. Acoustic [9,10], electrostatic [11,12], heat [13], and heterogeneous-condensation [14,15] agglomeration are effective to varying degrees in accelerating fine particle agglomeration. However, some deficiencies, such as low efficiency and complicated structure, still exist in these methods. Chemical agglomeration works by injecting chemical solutions into flue gas. Physical and chemical processes are used to promote fine particle collision and agglomeration [16,17]. Studies [20,23–26] have indicated that chemical agglomeration significantly enlarged the particle size and presented excellent removal efficiency of fine particles.

Forbes [18] summarized the agglomeration mechanisms and interparticle forces under different circumstances. Particles were

* Corresponding authors.
E-mail addresses: jyzhang@hust.edu.cn (J. Zhang), yczhao@hust.edu.cn (Y. Zhao).

http://dx.doi.org/10.1016/j.fuel.2017.05.008
0016-2361/© 2017 Published by Elsevier Ltd.

agglomerated due to certain forces such as hydrophobic interactions, van der Waals attraction, and electrostatic attraction. The interparticle forces, as described in the Derjaguin–Landau–Verwey–Overbeek (DLVO) theory, were the electrical double layer force and the van der Waals force. The balance between these forces determined the particle dispersion and agglomeration. According to Goldszal and Bousquet [19], four states were observed during the combination of particles and liquid droplets. During agglomeration, liquid bridges were created and these links entirely filled the interparticle space. Johansen and Schæfer [20] used three grades of fine particles having different physical properties to study their effects on binder solution requirements and agglomeration mechanisms. The results elucidated that agglomerate growth mechanisms were highly dependent on physical properties of power particles and binder liquid viscosity. Baldrey [21] developed a chemical solution to improve the particle removal efficiency of ESP. A similar patent [22] was applied for to remove particles by spraying an adhesive into gas stream. An aggregate comprising the adhesive and the particles was then removed from ESP collection zone. This modification improved the ESP efficiency to over 70% when a concentration of 0.05% chemical solution was injected into flue gas. However, the method aimed at coarse particles, whether it worked for fine particles remained unknown. Chemical agglomeration experiments were conducted [23] to investigate the influence of the composition of chemical agglomeration solutions, flue gas flux, and the spray droplet diameter on the fine particle removal efficiency of ESPs. The results showed that particle size could grow more than four times after agglomeration and removal efficiency of fine particles have been increased by approximately 40%. A pilot test was conducted in a coal-fired power plant by spraying water into the flue gas [24]. The particle removal efficiency of the ESPs was improved by approximately 50%, which decreased the particle concentration from 75 $mg \cdot m^{-3}$ to 39 $mg \cdot m^{-3}$. Similar experiments were performed by spraying the desulfurization wastewater into the flue gas [25]. Particle size distribution and its morphological properties were found to affect the removal efficiency. Ridaoui et al. [26] used a cationic surfactant, cetyltrimethylammonium chloride to change the size and to modify the surface charge of carbon black particles in aqueous dispersions. The results suggested that adsorption of cationic surfactant lead to electrostatic repulsion, which increased particle size as well as the removal efficiency. These results demonstrated the advantage of chemical agglomeration over other preconditioning processes. However, the results appeared to be incomprehensive since the test conditions were limited. Some important factors, such as ion concentration and zeta potential of the chemical agglomeration solution as well as the surfactant, were not taken into consideration. In addition, elucidation of the agglomeration mechanism was incomplete.

In this work, simulated and experimental results of chemical agglomeration were presented. The main objective was to understand the agglomeration process and mechanism, as well as the comprehensive experimental parameters that influenced the removal efficiency of fine particles. First, the pressure, temperature, and velocity distribution in an agglomeration chamber were simulated to verify whether the chemical agglomeration had a negative effect on the flow field. Furthermore, the composition, concentration, pH, K^+ content, and zeta potential of the chemical agglomeration solutions as well as surfactant and the flue gas temperature were studied regarding their effect on the removal efficiency of fine particles. Potential synergism when two different chemical agglomeration solutions were mixed together was also investigated.

2. Experiment sections

2.1. Experimental apparatus and procedures

All the tests were performed using the chemical agglomeration experimental system shown schematically in Fig. 1. Specific experiment information including experimental name, test items, experimental materials, and measurement apparatus are illustrated in Table 1.

Briefly, the system was composed of a chemical agglomeration generation system, a chemical agglomeration chamber, a feeding system, and a heating system. The chemical agglomeration generation system consisted of a spray gun (designed in-house), a solution storage tank, an air compressor, and a constant-flow pump. The spray gun was made up of a double-flow atomization nozzle and two pipes. Chemical agglomeration solution and pressurized air were mixed in the nozzle and then sprayed out. The nozzle was made of stainless steel. Two pipes were used to transport the liquid and gas. One pipe was connected to solution storage tank and the other was connected to air compressor. The diameter of liquid tube and gas tube was 10 mm and 30 mm, respectively.

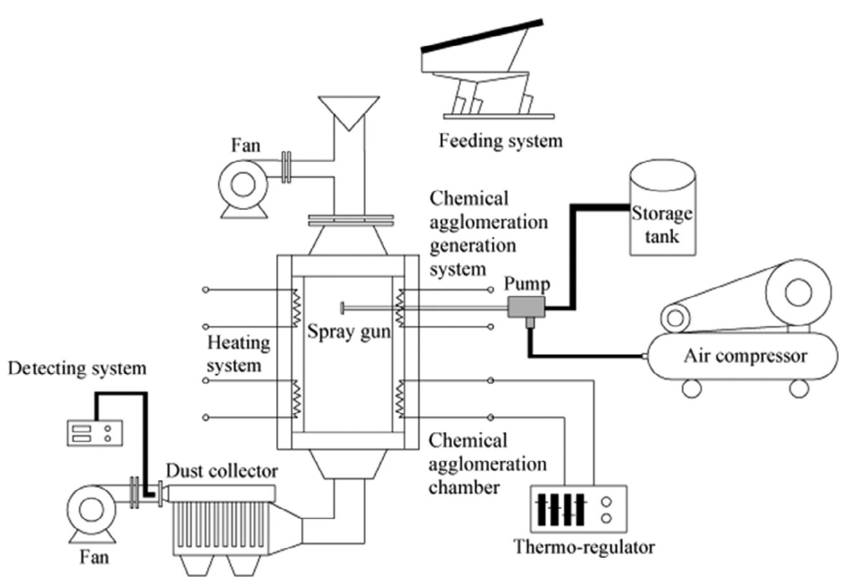

Fig. 1. Schematic diagram of the chemical agglomeration experimental system.