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The abatement of fine particles from desulfurized flue gas by heterogeneous vapor condensation coupling two impinging streams

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ABSTRACT

A novel process was proposed for fine particles abatement via heterogeneous vapor condensation coupling two impinging steams (TIS) technique in this paper. The essential supersaturation was established by adding steam or humid air into desulfurized flue gas, and the application of TIS technique in this process made the mixture of desulfurized flue gas and humid air or steam more sufficient. The fine particles were enlarged by the heterogeneous vapor condensation and the collision-coalescence in two impinging steams condensational growth chamber (TISCGC), then the enlarged fine particles were intercepted by a wire mesh demister at the top of TISCGC. The results indicated that the enlargement of fine particles in TISCGC was more significant than that of conventional condensational growth chamber (CCGC), thus the fine particle removal performance of wire mesh demister was better. The removal performance of fine particles by this process was influenced by many factors, such as flue gas velocity of opposing jets in TISCGC, additive amount of steam or humid air and the desulfurized flue gas temperature. Under the optimum conditions, the removal efficiency of TISCGC could be increased to 50–60% by using this process.

1. Introduction

Fine particles in the atmosphere have caused many problems for environment and human health due to the enrichment of volatile organics, bacteria, and viruses [1]. At present, coal fired power plants are considered as one of the major source of particulate pollution in the ambient atmosphere [2,3]. However, although the conventional precipitators in power plant have a good performance for the removal of coarse particles, the removal efficiencies for fine particles are inefficient [4,5]. In recent years, the great majority of coal-fired power plants have installed wet flue gas desulfurization (WFGD) systems for SO_2 emission abatement. It has been reported that the number concentration of fine particles would be increased in desulfurized flue gas, which led the emission of fine particles to be further increased [6]. For the fine particles, the reason for the inefficient removal performance of conventional abatement system is the existence of Greenfield Gap [7]. Especially for the particles with the size range from 0.1 to 1 μm, the removal efficiency is far less efficient. The reason for this phenomenon is that in this size range the particles are too large for Brownian diffusion to be effective and too small for inertial impaction to be significant [7]. Nevertheless, it is believed that if the fine particles could be enlarged before entering into conventional precipitator or demister, the removal performance would be greatly improved. Hence, many novel processes based on heterogeneous vapor condensation was proposed [8–11]. In these processes, the essential supersaturation for heterogeneous vapor condensation was established by adding steam or humid air into flue gas and then the fine particles would become larger droplets by vapor condensing on the particle surface spontaneously [12–14].

Since the process based on the heterogeneous vapor condensation is closely relevant to the relative humidity of flue gas, it has been usually applied in the desulfurized flue gas with high humidity. Bao [9] reported that the necessary supersaturation could be formed in desulfurized flue gas after the addition of steam and most of fine particles in desulfurized flue gas could be activated and grow up to droplets in supersaturation environment. Then these droplets could be intercepted by a mesh wire demister at the top of condensational growth chamber. However, the addition of steam made the operating cost increase which limited

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its application scope. Especially for the desulfurized flue gas with relatively high temperature, the additive amount of steam increased significantly. Jiang [15] investigated the supersaturation that formed via adding humid air into desulfurized flue gas and found that the supersaturation, which satisfied the particle nucleation, could be established in condensational growth chamber. Since the humid air was relatively easy to be obtained, the operating cost was decreased significantly.

According to the previous researches, the growth of fine particles usually took place in an empty chamber, which was named as conventional condensational growth chamber (CCGC) [9,13]. However, the mixture of vapor and flue gas was not sufficient, partial flue gas containing vapor and fine particles would flow out of the CCGC without vapor condensing on the fine particle surfaces. Furthermore, the homogeneous vapor condensation even occurred in some places of CCGC due to the higher local supersaturation degree, which was unfavourable for the formation of condensational-grown droplets. These causes made it difficult for many submicron particles to be activated and grow up to micro-sized droplets.

Nowadays, the technique of two impinging streams (TIS) becomes mature gradually and it has been regarded as one of the most efficient methods to intensify interfacial transfer and commixture (especially micromixing). Meanwhile, the opposing jets of flue gas also cause the intense collision among fine particles, and then the fine particles will be enlarged by coalescence. Wu [16] found that micro-sized droplets were inclined to agglomerate by collision and the droplets with diameters of tens to hundreds micrometers tended to split up, which narrowed the size distribution of droplets. Therefore, it can be inferred that the diameter of fine particles or droplets could be further increased by the application of TIS technique, and then the removal performance of wire mesh demister for these further enlarged particles and droplets would be improved.

The objectives of this work were to investigate the fine particle removal performance by heterogeneous vapor condensation coupling TIS technique after wet limestone-gypsum desulfurization process. The essential supersaturation was established by adding steam (105 °C, 0.1 MPa) or humid air (20 °C, 90%RH) into desulfurized flue gas in TISCGC. The removal performance of fine particles by this process was performed. The results could provide theoretical and experimental basis for fine particle abatement in desulfurized flue gas by using this novel process.

2. Experimental details

2.1. Experimental facility

The experimental facility was shown in Fig. 1. A self-sustained coal-fired boiler (CZML-0.12), a buffer vessel, an electrostatic precipitator (ESP), a desulfurization scrubber, a condensational growth chamber and measurement systems were included in the experimental facility. Fig. 2 showed two different structure types of condensational growth chamber, which can be named as CCGC and TISCGC. In experimental system, the flue gas with volume flux 350 $Nm^3 h^{-1}$ was generated by a self-sustained coal-fired boiler. Before entering the ESP system, the flue gas passed through a buffer vessel to make the particle size distribution and concentration remain stable. In the ESP system, coarse particles were collected. After leaving the ESP system, the flue gas entered into desulfurization scrubber, where used limestone as SO_2 absorbent. Then, the desulfurized flue gas with high relative humidity went directly to CCGC or was divided into two streams to flow into TISCGC. In both condensational growth chambers, the desulfurized

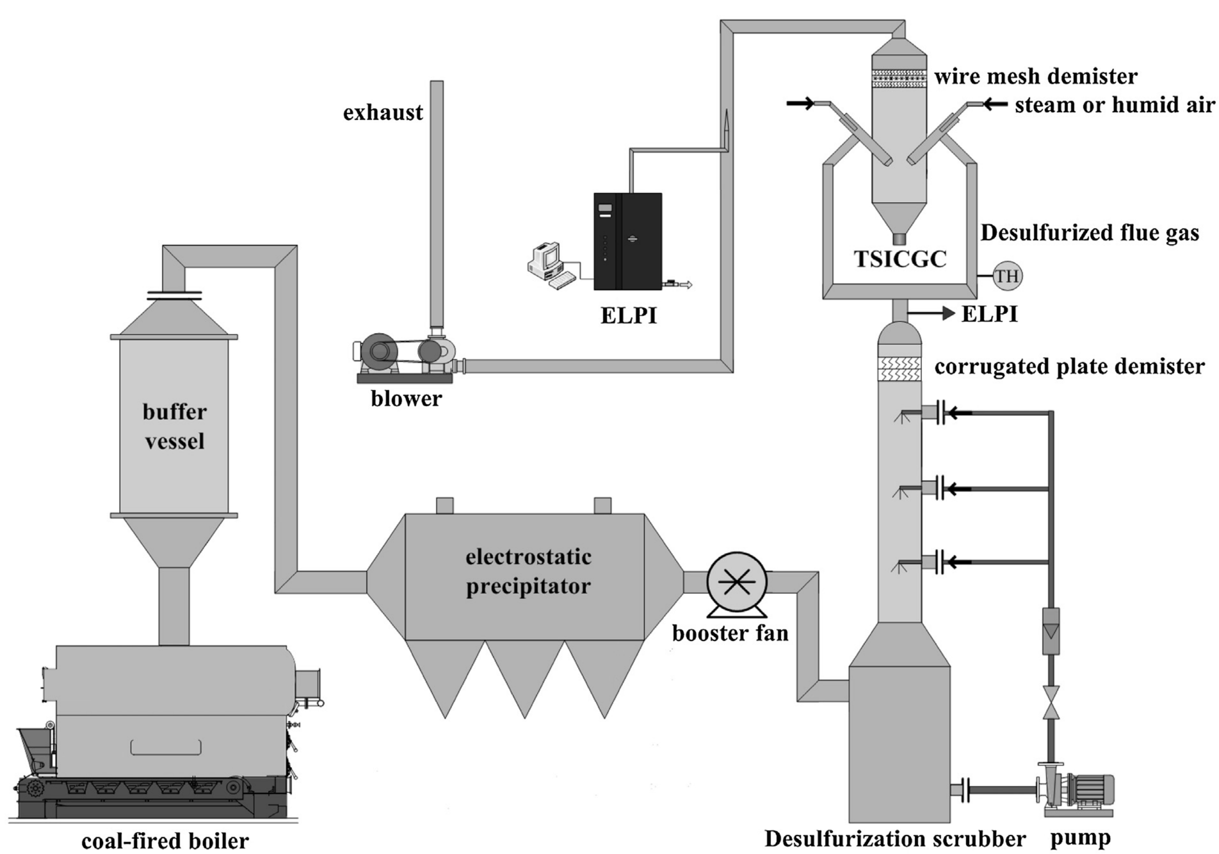

Fig. 1. Scheme of the experimental facility.