Fuel Processing Technology 174 (2018) 9–16

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Research article

Improving the removal of fine particulate matter based on heterogeneous condensation in desulfurized flue gas

Rui Zhang[a], Hao Wu[b,*], Xiaodong Si[a], Lingling Zhao[a], Linjun Yang[a,*]

[a] Key Laboratory of Energy Thermal Conversion and Control, Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, Jiangsu Province, China
[b] School of Energy and Mechanical Engineering, Nanjing Normal University, Nanjing 210042, Jiangsu Province, China

ARTICLE INFO

Keywords:
Fine particulate matter
Heterogeneous vapor condensation
Desulfurized flue gas
Reduction efficiency

ABSTRACT

To reduce the emission of fine particulate matter (PM) in coal-fired power plants, a new method aimed to improve the removal of fine particulate matter based on heterogeneous vapor condensation was investigated. The ideal supersaturation environment, necessary to the occurrence of heterogeneous vapor condensation, was achieved by reducing the initial temperature of limestone-gypsum desulfurization flue gas with a fluorine plastic heat exchanger. The temperature drop, initial relative humidity and initial temperature of desulfurized flue gas have an important influence on the establishment of ideal supersaturation environment and the reduction efficiency of fine particulate matter. Numerical calculation indicates that a higher temperature drop and initial relative humidity of the desulfurized flue gas is beneficial to the establishment of ideal supersaturation environment, while the influence of initial temperature of desulfurized flue gas is unobvious. It has been also experimentally proved that the increase of temperature drop and initial relative humidity have a positive effect to the improvement of the reduction efficiency. However, it can be also found that the reduction efficiency changes slightly with the variation of the initial temperature of desulfurized flue gas. Therefore, this method is suitable for different initial temperatures of desulfurized flue gas and is more applicable for practical industrial applications. Most commonly, the optimal value of temperature drop of desulfurized flue gas is in the range of 4 to 6 °C and the corresponding number concentration of fine particulate matter emission can be reduced as high as about 43%.

1. Introduction

Recently, a lot of research interest has been devoted to human health and environment issues, especially the air pollution [1,2]. Generally, the particulate matters with smaller size always stay in the atmosphere for a long time, easy to carry a large number of poisonous and harmful substances [3,4]. According to earlier studies, the fine particulate matters mainly come from coal-fired power plants [5]. Although the traditional dust separator, such as cyclone system, electrostatic precipitator (ESP), and fiber bag precipitator, has been applied, the removal performance is not ideal for submicron particles [6,7]. Recently, more and more coal-fired power plants have been equipped with the wet flue gas desulfurization (WFGD) system to reduce the emission of SO_2. However, in some situations, it may lead to an increasing concentration of fine particulate matter after limestone-gypsum desulfurization [8,9]. Since conventional dedusting technology cannot remove the fine particulate matter effectively, a new technique of flue gas pretreatment has been proposed. Enlarging the fine particulate matter by physical or chemical condition, and then, applying the conventional dust equipment have been found an effective way to remove the grown fine particulate matter. As expected, the heterogeneous vapor condensation is regarded as one of the most promising preconditioning techniques [10,11]. The fine particulate matters are activated and enlarged to be larger sizes droplets in ideal supersaturation condition, and then be removed easily by downstream equipment. The decisive factor of the heterogeneous vapor condensation is to establish an ideal supersaturation vapor environment that the supersaturation degree exceeds the critical supersaturation degree of the fine particulate matter [12]. In the past years, a series of research projects have been conducted to develop the theoretical model and apply the heterogeneous condensation practically. Yan et al. [13] reported a supersaturated vapor condition could be obtained by adding stream into flue gas at the inlet of the desulfurization tower and then the fine particulate matter can be enlarged and removed effectively in the process of desulfurization. Bao et al. [14] found that the addition of water vapor into desulfurized flue gas will lead a supersaturated vapor environment to

* Corresponding authors.
E-mail addresses: wuhao4617@163.com (H. Wu), ylj@seu.edu.cn (L. Yang).

https://doi.org/10.1016/j.fuproc.2018.01.015
Received 26 October 2017; Received in revised form 13 January 2018; Accepted 14 January 2018

be formed, thus the fine particulate matters in the flue gas can be enlarged by heterogeneous vapor condensation and separated by demister efficiently. Xiong et al. [15] segregated the fine particulate matters by heterogeneous condensation coupling impinging stream, and the removal efficiency is improved significantly. However, there are still many problems that need to be solved in the actual application of these methods. In order to realize heterogeneous condensation in desulfurization tower, adding stream is more suitable for low temperature and high humidity flue gas [16], even as the cost increases. The impinging stream device has a complex structure which is difficult to implement in power plant and the addition of water vapor also increases the cost. Therefore, more experimental investigation would still be needed to enrich this field.

In our previous works [16–18], we have investigated the removal of fine particulate matter based on heterogeneous condensation, and some interesting results have been obtained. Researches show that the desulfurized flue gas approaches saturated phase, and the relative humidity is approximately 95–100% [17]. Thus, a supersaturated vapor environment, necessary for the condensation growth of fine particulate matter, can be easily achieved by a proper temperature lowering. In this paper, a fluorine plastic heat exchanger was adopted after desulfurization process to establish the required ideal supersaturation environment via reducing the temperature of desulfurized flue gas. Meanwhile, the ideal supersaturation degree value of the desulfurized flue gas under different operating conditions was calculated numerically. Furthermore, the influence of some main parameters (temperature drop, initial temperature and relative humidity of the desulfurized flue gas) on the reduction efficiency of fine particulate matter was also investigated. In addition, the effect of the condensable water vapor amount on the reduction efficiency also has been discussed.

2. Experiment system and measurement technique

2.1. Experimental apparatus

Fig. 1 shows the experimental apparatus, including a full-automatic coal-fired boiler (CZML-0.12), a buffer tank, an ESP system, a WFGD system and a fluorine plastic heat exchanger. The flue gas volume was 350 $Nm^3 h^{-1}$ generated by the boiler. The effect of the buffer tank was to ensure a stabilization of the fine particulate matter concentration and size distribution. Subsequently, the flue gas went through ESP where coarse particulate matters were removed. The flue gas and desulfurization slurry were countercurrent contact in the desulfurization tower that adopts 3 spray levels. Moreover, a high efficient demister was installed on the top of the tower to remove the entrainment droplets and the larger condensable droplets. The height of the desulfurization tower was 5150 mm and the diameter was 200 mm. In addition, there was a fluorine plastic heat exchanger to establish the ideal supersaturation conditions after the wet desulfurization process. The heat exchanger was operated by inletting cold water while the hot flue gas flowing outside the tube. The temperature drop in this paper was an average value, and the regulation of temperature drop was realized by adjusting flow rate of cold water. In the experiment, the amplitude of fluctuation was controlled in ± 10%. The fine particulate matters would grow up to bigger droplets by heterogeneous vapor condensation and then removed easily by the high efficiency demister. Meanwhile, the condensed water was collected into a slurry tank for cyclic utilization. Thus, remove the fine particulate matters and save water could be obtained simultaneously.

2.2. Measuring method

The size distribution and concentration of fine particulate matters before and after heat exchanger were measured by electrical low pressure impactor (ELPI, Dekati Ltd., Finland). The particulate matter aerodynamic diameter ranged from 0.023 μm to 9.314 μm could be detected by ELPI in real time. Due to the highly relative humidity and low temperature of desulfurized flue gas, the vapor would condensate in sampling pipelines and on the impact plate of ELPI easily. In order to ensure the precise measurement of ELPI, the flue gas needs to be pretreated before entering into the ELPI. As shown in Fig. 2, the flue gas went through cyclone separator which can separate the coarse particles, then diluted by the dilute gas in diluter (DI-1000, Finland). The dilution ratio was 67 and the flue gas was heated to 120 °C by the electric heating tape before entering into ELPI. In addition, the flue gas temperature and humidity were obtained by a humiture transmitter (HMT337, Vaisala Ltd., Finland) on line.

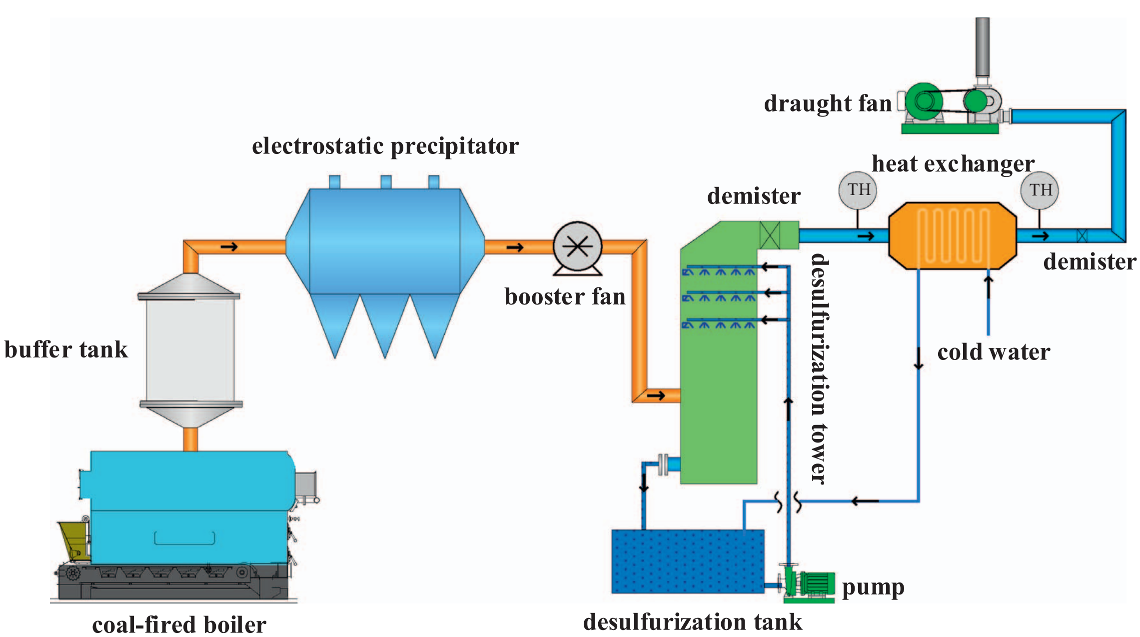

Fig. 1. Schematic diagram of the experimental apparatus.