Analysis of Main Influencing Factors of the Wastewater Evaporation in Flue Duct

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Abstract. Desulfurization wastewater has the characteristics of small discharge and high pollution, and must be strictly treated. To obtain the main factors affecting the evaporation characteristics of desulfurization wastewater in boiler flue, a 600MW unit of a coal-fired power plant in China was taken as an example. According to the theory of fluid mechanics and heat transfer, the numerical simulation method was used. The results show that the way the nozzle is installed on the upper wall of the flue inlet can enhance the evaporation effect of the desulfurization wastewater. It is also revealed that the influence of the flue gas flow rate on the droplet evaporation effect is relatively small. The smaller droplet diameter and the higher flue gas inlet temperature will obviously enhance the evaporation effect of the droplets in the flue. However these two factors will increase the operating cost and reduce the boiler thermal efficiency. Therefore, the values of the droplet diameter and the flue gas inlet temperature need to be further determined by technical and economic comparison.

1 Introduction

Limestone-gypsum wet desulfurization processing has the advantages of high desulfurization efficiency and high technical maturity. Therefore it was widely used in coal-fired power plants around the world.

However, the desulfurization wastewater has high suspended solids, high salt content and strong corrosive properties[1-3]. The sulphate in the desulfurization wastewater is discharged to the surrounding environment, and is reduced by the sulphate-reducing bacteria in an anaerobic environment to produce a foul odour and corrosive hydrogen sulfide, which seriously pollutes the atmosphere[4]. Excessive amounts of sulfate can destroy soil properties and structure, affecting the yield and quality of crops. Soluble heavy metal substances in wastewater will accumulate in the environment and be difficult to remove, posing a potential hazard to the ecological environment, animals and plants and human health[5]. Therefore, although the discharge of desulfurization wastewater is not large, due to its special water quality characteristics, it must be strictly treated, otherwise it will have a serious impact on the surrounding environment of the power plant.

In the current technology for treating desulfurization wastewater, the flue evaporation method has the advantages of the simple system and small secondary pollution[6-8]. The method is that the desulfurization wastewater after the primary sedimentation treatment is sent to the flue between the electric precipitator and the air preheater for atomization, and the residual heat of the flue gas absorbed by the wastewater is quickly evaporated into steam, and enters the condensation tower for condensation recovery. Collection and disposal of the particulate matter, precipitated salt and fly ash in the wastewater is performed by the electrostatic precipitator [9,10].

Due to the differences in operating parameters of coal-fired boilers in different countries and regions, the installation location and parameter setting of the desulfurization wastewater nozzles are also different, which will affect the treatment effect of the desulfurization wastewater. Therefore, to obtain the main factors affecting the evaporation characteristics of desulfurization wastewater in boiler flue, this paper takes a 600MW unit of a coal-fired power plant in China as an example and uses numerical simulation method to study. The conclusions obtained provide a reference for the engineering application of flue gas evaporation mode of desulfurization wastewater.

2 Flue Structure Size and Calculation Parameters

This paper takes a 600MW class unit used in a power plant in China as an example which employed a tail flue of π type boiler, shown in Figure 1. The curved cross-section of the boiler tail is 6.4 meters long, 4.8 meters wide and the total length is about 33 meters. The total flue gas volume is 920000 Nm^3/h, the desulfurization wastewater discharge is 3.7 m^3/h, the air preheater outlet flue gas temperature is 150℃, and the flue gas flow rate is 10 m/s.

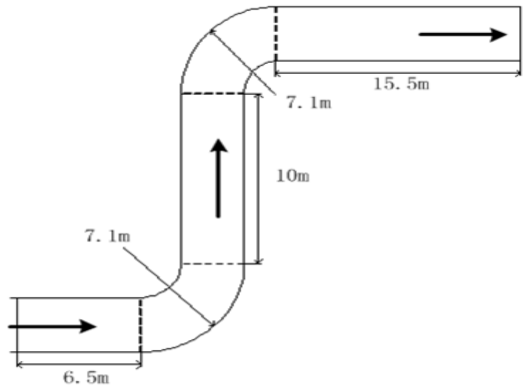


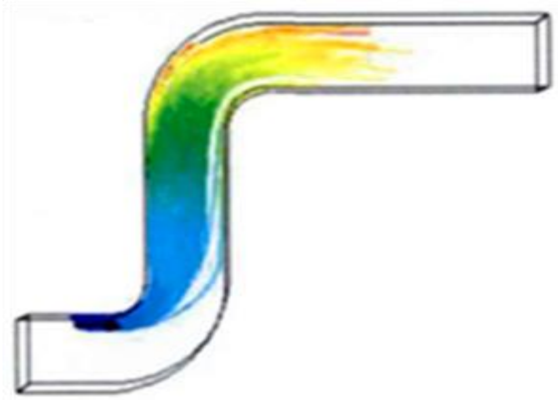
Fig. 1. Structure Size of the Boiler Tail Flue

Based on the structural dimensions of the boiler flue, the fluent software was used to carry out numerical simulation studies under various calculation parameters. The nozzle installation position, droplet particle size, flue gas inlet temperature, and flue gas flow rate all effect the evaporation effect of the desulfurization wastewater. Therefore, in the numerical simulation, the calculation parameters are set such that the average diameter of the droplets is 60 μm to 90 μm, respectively, and the values are taken at intervals of 5 μm; the inlet temperature of the flue gas is 140℃ to 180℃, respectively, and the values are taken at intervals of 10℃; The flow rates are 8 m/s to 12 m/s, respectively, and the values are taken at intervals of 1 m/s. The nozzle installation positions are respectively at the upper wall surface and the lower wall surface of the tail flue inlet section, and the desulfurization wastewater is sprayed in both installation positions. It flows in the same direction as the smoke.

3 Numerical Simulation Results and Analysis

The influence of the nozzle installation position on the droplet evaporation trajectory at the inlet temperature of the flue gas is 150℃, the flue gas flow rate is 10 m/s, the desulfurization wastewater discharge is 3.7 m^3/h, and the droplet diameter of the wastewater is 75 μm, as shown in Figure 2. The way the nozzle is mounted on the upper wall surface is better for the evaporation of the droplets. Most of the droplets can fully contact and evaporate with the flue gas, and only the droplets are close to the wall, as shown in Figure 2(a).

The nozzle is mounted on the lower wall so that most of the droplets are close to the right wall of the flue, as shown in Figure 2(b). Most of the droplets do not have sufficient contact heat exchange with the flue gas, and the degree of diffusion is too low, so that the desulfurization wastewater is not completely evaporated. The nozzles installed at the vertical flue are not completely evaporated due to the short evaporation evaporating flue. At the same time, most of the droplets are adsorbed on the right side wall of the flue, which easily causes corrosion of the desulfurization wastewater on the wall surface of the pipeline, and also causes ash accumulation. By comparison, how the nozzle is mounted on the upper wall of the flue inlet can enhance the effect of evaporation of the desulfurization wastewater. Therefore, this paper selects how the nozzle is installed on the upper wall of the flue for subsequent research.



(a) Nozzle mounted on the upper wall

(b) Nozzle mounted on the lower wall

Fig. 2. Influence of nozzle installation position

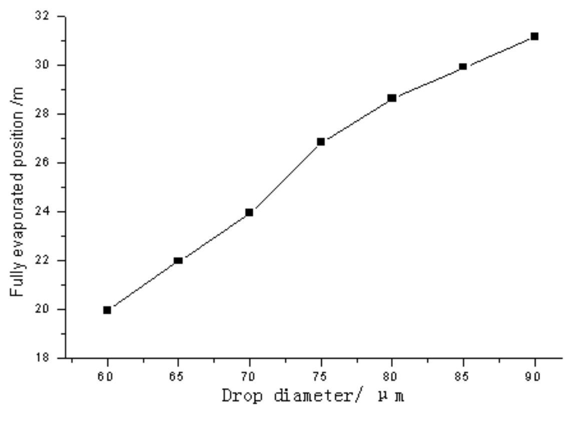


Fig. 3. Relationship between droplet diameter and droplet evaporation trajectory

The relationship between the droplet diameter and the droplet evaporation trajectory is shown in Figure 3 under the condition that the flue gas inlet temperature is 150℃ and the flue gas flow rate is 10 m/s. The larger the droplet diameter, the longer the distance required to evaporate. The reason is that a smaller droplet diameter causes a larger specific surface of the droplet which further causes a larger heat transfer area in contact. Therefore the liquid drops will evaporate in shorter time or longer distance. However, the size of the droplet diameter is related to the amount of work consumed by the atomizing nozzle device. The smaller the droplet diameter, the greater the amount of workload will be. And the operating cost of the device will also increase. Therefore, the value of the droplet diameter should be determined based on the technical and economic comparison.

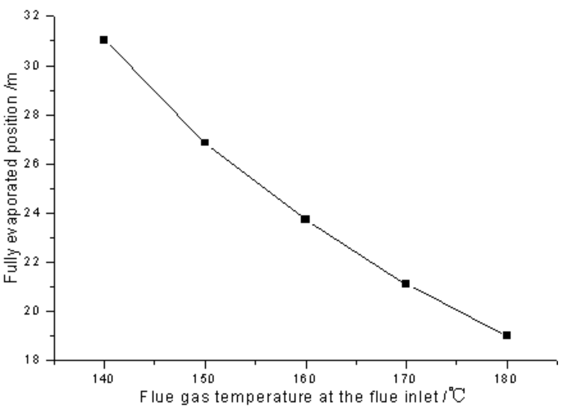


Fig. 4. Relationship between flue gas inlet temperature and droplet evaporation trajectory

The relationship between the inlet temperature of the flue gas and the evaporating trajectory of the droplet is shown in Figure 4. Under the condition, the flue gas flow rate is 10 m/s and the wastewater droplet diameter is 75 μm. When the inlet temperature of the flue gas is 140℃, the distance required for the complete evaporation of the droplet is 31.04 meters; when the inlet temperature of the flue gas is 180°C, the distance required for the complete evaporation of the droplet is 19.11 meters, which is the inlet temperature of the flue gas. The distance of 140℃ is nearly 12 meters shorter. As the inlet temperature of the flue gas increases, the distance required for complete evaporation of the droplets is shortened. The reason is that a higher inlet temperature of the flue gas causes a larger temperature difference between the droplet which further leads to a better heat transfer effect. Therefore the droplets can completely evaporate in less time, i.e. a shorter distance. The effect of complete evaporation of the droplets is inversely proportional to the inlet temperature of the flue gas. However, the higher the inlet temperature of the flue gas, the greater the heat loss of the flue gas of the boiler, which will reduce the efficiency of the boiler. Therefore, it is not appropriate to enhance the evaporation of droplets by increasing the temperature of the flue gas

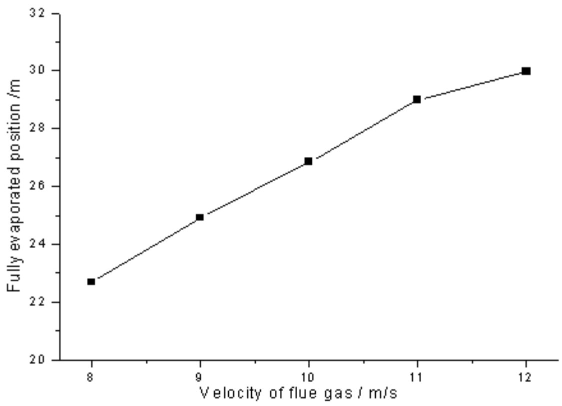


Fig. 5. Relationship between smoke flow velocity and droplet evaporation trajectory

The relationship between the flue gas flow rate and the droplet evaporation trajectory is shown in Figure 5 under the condition that the flue gas inlet temperature is 150℃ and the wastewater droplet diameter is 75 μm. As the flow rate of the flue gas increases, the distance required for the droplet to completely evaporate increases. According to the theory of heat transfer, an increase in the flow velocity of the flue gas can increase the convective heat transfer coefficient, but it also increases the flow velocity of the droplets carried by the flue gas, resulting in an increasing in the distance required for complete evaporation of the droplets. When the flue gas flow rate is greater than 10 m/s, the increase in the distance required for complete evaporation of the droplets will decrease as the flue gas flow rate increases. The complete evaporation distance corresponding to the flow rate of the flue gas of 12 m/s is only 1.3 meters longer than the distance when the flow rate of the flue gas is 11 m/s. Overall, the complete evaporation distance of the droplets at a flue gas flow rate of 8 m/s and 12 m/s, respectively, differs by only about 7 meters. Therefore, the increase of the flue gas flow rate is not conducive to the complete evaporation of the droplets in a short distance; compared with the droplet diameter and the flue gas inlet temperature, the influence of the flue gas flow rate on the droplet evaporation effect is relatively small.

4 Conclusion

Taking the 600MW unit of a coal-fired power plant in China as an example, this paper analyzes the main factors affecting the evaporation characteristics of the flue gas in the boiler flue by numerical simulation. The way that the nozzle is installed on the upper wall of the flue inlet can enhance the evaporation effect of the desulfurization wastewater, the influence of the flue gas flow rate on the evaporation effect of the droplet is relatively small; the smaller droplet diameter and the higher flue gas inlet temperature are significantly enhanced. The evaporation effect of droplets in the flue, but these two factors will increase operating costs and reduce boiler thermal efficiency, respectively. Therefore, the values of droplet diameter and flue gas inlet temperature need to be further determined by technical and economic comparison.

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