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Numerical Simulation on the Influence of FGD Wastewater Atomized Droplet Particles Parameters on Evaporation Performance

Debo Li[1,2*], Ying Wu[1], Ning Zhao[2], Yongxin Feng[2], Zhiwen Xie[1]

1 Guangdong Electric Power Grid Research Institute, Guangzhou Guangdong, 510080

2 Electric Power Research Institute, Guangdong Electric Power Co., Ltd., Guangzhou Guangdong 510080, China
[*] Corresponding Author. Email: ldbyx@126.com

ABSTRACT

In order to deal with the chloride ions enriched in FGD wastewater which arises from the control of SO_2 emissions, ZLD technology is widely applied in coal-fired power plants. One of the technologies to achieve ZLD is spraying atomized FGD wastewater into the duct between the air preheater and ESP, and the purpose of this study is to figure out the evaporation characteristics of FGD wastewater for greater efficiency. According to the calculating results with variable parameters of atomized droplet particles, it could be concluded that increasing the original temperature, reducing the injection velocity, or reducing the original diameter of the FGD wastewater droplet particles is beneficial to improve evaporation efficiency. Of these three measures, the last one is the most effective due to the quickly-finished preheating process which accelerates the evaporation.

Keywords: FGD wastewater, evaporation efficiency, duct, droplet particles

NONMENCLATURE

Abbreviations	
FGD	flue gas desulfurization
ZLD	zero liquid discharge
ESP	electrostatic precipitator
CFD	computational fluid dynamics

1. INTRODUCTION

The production and consumption of primary energy are based on coal, which is the characteristic of our country's energy reserves for a long time. In order to meet the requirements of environmental protection departments for flue gas emissions from thermal power plants, coal-fired power plants must control SO_2 emissions, and the limestone gypsum flue gas desulfurization (FGD) technology has become a standard configuration. However, the chloride ions in the desulfurization wastewater are continuously enriched when the system works., which is corrosive and causes a decrease in desulfurization efficiency and should be treated before discharge [1, 2].

In this regard, a zero liquid discharge(ZLD) technology of FGD wastewater has been proposed and widely used [3]. The atomized desulfurization wastewater is sprayed into the duct between the air preheater and electrostatic precipitator (ESP) where it could be heated by the flue gas. And then the residual pollutants become solid particles which are collected by ESP.

For this spray evaporation technology, scholars have carried out related research work on the evaporation characteristics of the desulfurization wastewater and the influence of the operating parameters with the help of computational fluid dynamics (CFD) method. Ma et al. [4] used the pure water droplet to simulate the FGD wastewater evaporation, and he drew a conclusion that the flue gas temperature and the atomized particle diameter had a strong influence on evaporation efficiency, while the flue gas velocity was relatively insignificant. However, the research using the pure water

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model is not convincing, because the inorganic ions could affect the gasification rate of water molecules [5]. To improve the accuracy of the simulation, Fu et al. [6] studied FGD wastewater with actual compositions in a 330 MW coal-fired power plant, and the numerical simulation results indicated that the complete evaporation of wastewater droplets was shorter when the temperature and velocity of the flue gas are higher. Besides, some researchers select the saltwater model to represent the FGD wastewater in practical application. Ye et al. [7] adopted the salt-containing droplet evaporation model to explore the real wastewater evaporation characteristics, and found that the increase in jet velocity could improve the droplet evaporation rate not only because droplets were more uniformed in distribution, but also the turbulent kinetic energy of the flue gas was enhanced.

To further reveal the evaporation characteristics and improve the evaporation efficiency of FGD wastewater, the numerical simulations were conducted on a 300 MW coal-fired boiler with different original temperature, original diameter, and injection velocity of atomized droplet particles, and $CaCl_2$ solution instead of pure water used in some researches as the volatile liquid was adopted in this study to make the simulation results closer to the actual situation. It can be expected that the results could provide suggestions for the ZLD evaporation process of FGD wastewater.

2. NUMERICAL APPROACH

2.1 Physical model

The calculation area and the location of nozzles inside it are shown in Fig. 1. The duct between the air preheater and ESP is in the shape of “Z”, which could be divided into inlet horizontal part, vertical part, and outlet horizontal part. The lengths of these two horizontal part are both 4 m, and the height of the vertical flue is 14 m. The cross-section of the flue is a square with sides of 3 m, and the inner radius of the rounded corner is 0.5 m. Considering that the specific heat capacity of the multi-component solution in the preheating stage of evaporation is smaller than that of the single-component pure water, the former will reach the critical evaporation temperature earlier, which will have a certain impact on the result. Since $CaCl_2$ solution has been proven to be equivalent to FGD wastewater [8], 10% $CaCl_2$ solution was selected to replace the practical wastewater, and it could be discharged from four atomizing nozzles arranged in the vertical flue with a height of 3.5 m.

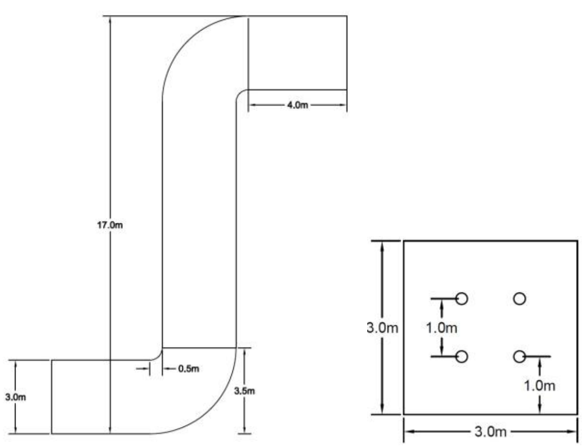

Fig. 1. Schematic of the duct and nozzles arrangement

2.2 Numerical methods

The present study selected Euler-Lagrangian model to simulate the atomized droplets evaporation of FGD wastewater in the flue: the flue gas was regarded as a continuous medium which could be solved by Euler method and the atomized droplets were considered as a discrete phase that could be calculated by Lagrangian method. A pressure-based solver was used, and SIMPLE algorithm was employed for pressure-velocity coupling. Considering the better performance in the cylindrical jets simulation, Realizable *k*-*Ɛ* model was chosen to calculate the gas turbulence. The velocity inlet boundary condition and the pressure outlet condition were adopted. As for the droplets, the solid-cone nozzle model was used to inject the atomized droplet particles into the flue, whose diameter distribution followed Rosin-Rammler function. For simplification of the research, not only the heat transfer between the flue gas and walls was ignored, but also the thermal radiation effect was not considered.

The hexahedral mesh was employed in this model and the grid independency test was carried out before

Table 1. Results of grid independency test

Hexahedral cells number	Average outlet temperautre (K)	Average outlet velocity (m/s)
206,045	380.52	8.87
463,905	380.85	8.59
687,280	379.56	8.57

Table 2. Operating parameters

Parameters	Values
Inlet gas velocity (m/s)	8
Gas temperature (K)	393
Spray cone angle (deg)	45
Mass fraction of water vapor in gas (%)	11
Mass flow rate of wastewater (t/h)	2

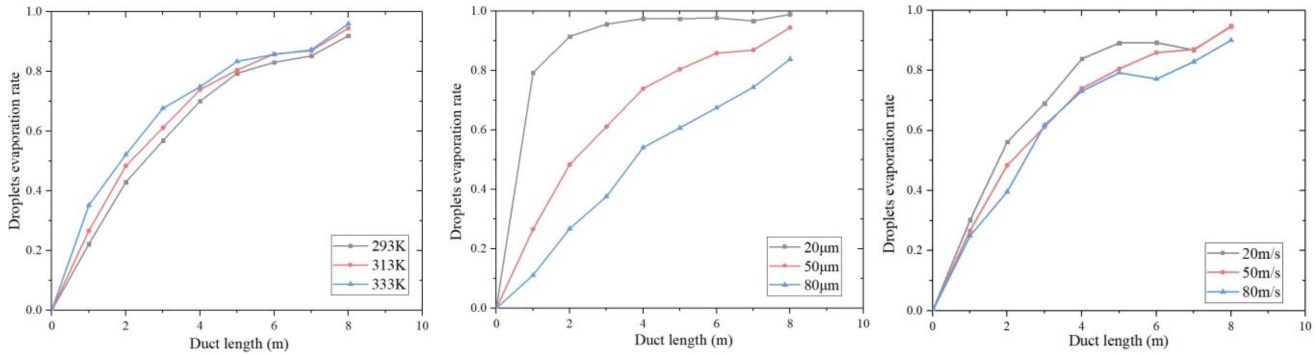

Fig. 2. The evaporation rate of droplets along the duct with different operating parameters: (a) original droplets temperature; (b) original droplets diameter; (c) injection velocity

formal calculation. As the results shown in Table 1, three grid systems were compared and there was no apparent difference in outlet temperature and velocity of the gas. Taking the computer resources, speed, and calculation accuracy into account, the system cell number of 463905 was selected.

3. RESULTS AND DISCUSSION

This study mainly explores the influence of the following parameters of atomized droplet particles on the evaporation effect of FGD wastewater droplets: original temperature (293 K, 313 K, 333 K), original diameter (20 μm, 50 μm, 80 μm), and injection velocity (20 m/s, 50 m/s, 80 m/s). And it is worth mentioning that other operating parameters of all the conditions keep consistent as shown in Table 2. Effects of the variable factors on the evaporation efficiency would be presented by the relationship between the duct length and evaporation rate of droplets.

3.1 Effect of original temperature of droplets

Fig. 2(a) shows the change of evaporation mass of droplets along the duct when the original temperature of droplets varies. It could be concluded that the higher the temperature of the original droplets, the faster the evaporation rate with the constant inlet gas velocity. This is not only because the heat that droplets need to achieve complete evaporation decreases when the original temperature increases, but also the surface tension and viscosity of droplet particles are reduced. On this condition, the droplet particles are more liable to break up again in the duct, which is beneficial for the reinforcement of the turbulence of the liquid phase. However, the temperature difference between the flue gas and the droplet decreases when the original temperature rises leading to the decrease of heat transfer rate, and the heat required for droplets evaporation is small compared with the heat carried by the flue gas which means that the effect of original temperature of droplets is insignificant relatively [9]. Therefore, increasing the temperature of the original droplets can speed up the evaporation rate, but does not bring much improvement especially in the later stage of evaporation.

3.2 Effect of original diameter of droplets

The effect of original droplets diameter on droplets evaporation mass is displayed in Fig. 2(b), and it can be found that there are obvious differences among the three curves. About 79.3% of droplet particles are evaporated with the original diameter of 20 µm when they are sprayed 2 m away from the nozzles, whereas the ratios are only 26.6% and 11.1% respectively with the original diameter of 50 µm and 80 µm. When the gas and liquid phases move in the duct, the smaller the diameter of the droplets, the larger the specific surface area, and the more intensive the convection heat transfer. During the preheating phase, the heat absorbed by the droplet particles is used to raise their temperature. As a result, the preheating process would be finished quickly with the small particle diameter, which facilitates the evaporation time reduction and evaporation efficiency improvement.

3.3 Effect of injection velocity of droplets

Under the condition of constant original temperature and diameter, it can be seen from Fig. 2(c) that the evaporation rate of droplets decreases when the velocity of the droplet particles ejected from the nozzle increases. This is because that increasing the injection velocity of the droplets will enhance the diffusion of the droplets in the duct, thereby increasing the probability of droplets colliding and merging. At the same time that droplet particles with low injection velocity are relatively uniformly distributed and have a long residence time in the gas environment, and it is in favor of evaporation. It is worth noting, however, that the atomized droplets are easier to move with the gas under the action of external forces on account of the small diameter. Due to the effects of gravity and drag, the droplets could easily reach the same speed as the gas. In summary, reducing the injection speed to increase the evaporation efficiency is effective, but the effect is limited.

4. CONCLUSION

In the present study, the numerical simulation model of the duct between the air preheater and ESP in a 300 MW boiler was established to analyze the FGD wastewater evaporation characteristics, and 10% $CaCl_2$ solution was adopted in the study instead of pure water to obtain more rigorous results. Three kinds of operating parameters about atomized droplet particles were discussed and the effects on evaporation efficiency were compared.

To increase the original temperature or reduce the injection velocity of the FGD wastewater droplet particles could improve evaporation performance, yet the effect is not apparent. Reducing the original diameter of the FGD wastewater droplet particles has a significant positive impact on the evaporation efficiency, which is attributed to the greatly increased surface area which helps the preheating process of the droplet evaporation to be completed as soon as possible.

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