Experimental Study on Heat Transfer Performance of White Smoke Reduction Heat Exchange System

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Abstract. In the present study, the white reduction system was designed and manufactured to evaluate the performance of a heat exchange system using a wave heat exchanger. The reducing effect of white smoke and the amount of heat recovered from cooling water were investigated experimentally using the cooling and dehumidifying method. The white smoke reduction system consists of two parts; the generating part and the reducing part of white smoke. When the air-water heat exchanger (A/W) and the supply air (SA) induced draft fan (SA Fan) are simultaneously activated, From the experimental results, we can see that the absolute humidity reduction rate of exhaust air (EA) was 82.9%, and the temperature rate of EA was 68.1%.

1. Introduction

With the implementation of the ultra-low emission reform of coal-fired power plants in China, the wet desulfurization facilities have basically eliminated the rotary GGH. The wet flue gas from the desulfurization outlet is discharged directly into the atmosphere through the chimney and mixed with cold air. During the cooling process, the water vapor contained therein is saturated and condensed. The water droplets formed by condensation will refract and scatter light, making the plume appear white or gray, which is called wet plume, commonly known as white smoke. White smoke refers to a phenomenon in which when the hot and humid air collides with the outside low-temperature dry air, the water vapor is liquefied due to excessive saturation and looks like smoke. Although white smoke does not contain dust such as environmental pollutants, white smoke may still be mistaken for contaminants or fires. What’s more, because of its interference with the line of sight may cause problems, such as aviation and traffic safety. In this way, as the national environmental protection policy becomes more stringent, the requirements for smoke emission policies for coal-fired power plants are also increasing. The elimination of white smoke from chimneys has gradually become a new environmental issue faced by thermal power companies. Therefore, scholars at home and abroad are actively studying the generation mechanism and elimination of white smoke.

At present, they have researched on the elimination of white smoke. Combined with the wet smoke temperature map, the mechanism of white smoke generation and the technology of reducing smoke are analysed, and the technical characteristics and application range of different wet smoke reducing are also compared¹. The generation of white smoke is analysed by numerical simulation. In the meanwhile, the influence of flue gas saturation temperature and atmospheric environment on white smoke is discussed as a practical reference for the study of reducing chimney white smoke [²]. In addition, according to the backflow and cross-flow of the dry heat exchanger, the air heat flow in the cooling
tower is forced to be ventilated, based on which the flow field and the temperature field are numerically studied [3]. In order to prevent the tower from emitting white smoke, the internal circulating water is regenerated by dry air. The best design and performance evaluation of anti-white smoke performance is carried out by discharging it to the outside [4], and the possibility of generation and reduction of white smoke in the cooling tower is studied [5]. By simulating the white smoke generated by large natural ventilation cooling towers, the parameterization of the semi-spectral warm cloud has been studied in the inelastic and non-hydrostatic 3D micro weather codes [6].

In the previous studies, research on reducing white smoke is carried out centering on the cooling tower. Recently, research on the reduction of white smoke equipment has adopted a cooling and dehumidification method. To reduce the temperature and absolute humidity of the exhaust gas outlet, thereby eliminating the generation of white smoke. Consequently, in this paper, under the circumstance of winter external gas with a high possibility of generating white smoke, the cooling, and dehumidification method is used to evaluate the performance of the heat exchange system by a heat exchanger. To this end, a white smoke heat exchange system with the air-to-air and air-to-water heat exchanger is designed and manufactured to study the characteristics of heat transfer.

2. Experimental equipment and methods

2.1. Experimental equipment

As shown in Figure 1 (a, b), a straight AC heat exchanger (3 Air to Air exchangers, 2 Air to Water exchangers) is used in the white smoke reduction heat exchange system. The heat exchanger is made of SUS 304 and has a wall thickness of 0.5 mm. The white smoke reduction heat exchange system consists of a generating part and a reducing part. The generating part is mainly composed of three parts: a boiler, a steam pot, and an exhaust fan. The reducing part is mainly made up of four parts: an induced draft fan, a water pipe, a heat exchanger, and a mixing zone.

Schematic of white smoke reduction heat exchange system and measuring positions (1–11) is shown in Figure 1 c). The supply air (SA) flows into the mixing zone through HX5, 2, 1. That is, the supply air flows into the tubular pipe of the HX 5 through the air supply port 5, and flows into the mixing zone after passing through 6–7–8. The exhaust air (EA) flows into the mixing zone through HXs1–5. That
is, the exhaust air flows into the square pipe of the HX1 through the exhaust port 1, and flows into the mixing zone after passing through ②-③-④. After the SA and the EA exchange heat through the heat exchange unit, the SA(⑧) entering the mixing zone and the EA(④) will flow into the mixing zone to perform final heat exchange. Then, the heat-exchanged EA is discharged to the external environment by mixing zone outlet ⑨ of the white smoke reduction system. The cooling water flows in from HX4 and flows out from the HX3 outlet after heat exchange. Here, EA is for exhaust air, SA for supply air, W for cooling water, and HX for heat exchanger. The subscripts in and out represent the inlet and outlet.

2.2. Experimental method
According to the experimental test method of CTI-150 [7], the temperature and humidity data are measured at the ①-⑪ measuring points. After the EA and the SA are mixed in the mixing zone, the mixing zone outlet ⑨ uses a camera to detect whether or not white smoke is generated. Under the condition of winter outside air with a high possibility of generating white smoke, an experimental study is conducted on the white smoke reduction heat exchange system. The experimental conditions are that the temperature, absolute humidity and air volume of the EA are 109 °C, 0.0951 kg/kg and 123 m³/min, respectively. The SA temperature, absolute humidity and air volume are 8.5 °C, 0.0025 kg/kg and 290 m³/min. The W temperature is 7 °C and the inlet water supply is 10.5 m³/h. The operating state of the equipment is divided into three phases: the EA Fan start-up state, the air-water heat exchanger start-up state, the simultaneous start-up state of the air-water heat exchanger and the SA Fan. In order to produce a stable EA, it first takes 30 minutes to generate white smoke from the white smoke reduction heat exchange system. If the experimental conditions of the EA and the W are within ±6% of the set value, temperature and humidity data of the EA, SA, and W can be obtained.

3. Experimental results

![Figure 2. Temperature distribution of EA system according to operation condition of white smoke reduction heat exchange system](image)

Temperature distribution of EA system according to the operation condition of white smoke reduction heat exchange system measured through ① ~ ⑪ of HXs1 ~ 5 is shown in Figure 2. ① is the inlet of HX1, ② is the outlet of HX2, ③ is the outlet of HX4, and ④ is the outlet of HX5. When the EA Fan is started, the temperature of the inlet ① of the HX1 is reduced by 10.9%, 35.2%, and 45.9% compared to the temperatures of the outlets ② ~ ④. When the A/W heat exchange is started, the temperature at the inlet ① of the HX1 is reduced by 17.2%, 44.3%, and 59.2% compared to the temperatures at the outlets ② ~ ④. When the A/W heat exchanger and the SA Fan are started at the same time, the temperature of the inlet ① of the HX1 is reduced by 25.8%, 65.4%, and 77.9% compared
to the temperatures of ② ~ ④. In summary, when the A/W heat exchanger and SA fan are started at the same time, after the EA has performed heat exchange through the heat exchange system, the temperature difference at the HX5 outlet ④ is the largest. Moreover, it can be seen that the A/W heat exchanger (② ~ ③) has the largest temperature difference, so it can be judged that the heat exchange efficiency of them both starting up is the highest.

According to different operating conditions, the white smoke situation at the outlet of the mixing zone of the system during the experiment is shown in Figure 4. Figure 4a) shows the starting state of EA Fan. Because EA does not perform any heat exchange through the heat exchanger, the EA after combustion is discharged from the chimney as it is, resulting in a large amount of white smoke. Figure 4 b) shows that when the A/W heat exchange is started, the EA and W are indirectly contacted to reduce the temperature and absolute humidity of the EA. Therefore, about 60% of the white smoke coming from the system outlet is also reduced. Figure 4 c) shows the simultaneous start-up of the A/W heat exchanger and SA Fan. The first heat exchange between the EA and W, and the second heat exchange
between the EA and external air are performed to reduce the temperature and absolute humidity of the EA, so almost no white smoke are observed at the system outlet.

4. Conclusion
This paper applies the white smoke reduction heat exchange system. According to the different operating conditions of the white smoke reduction system, the experimental research on the performance of white smoke reduction and heat recovery of cooling water are carried out.

1) In order to reduce the possibility of white smoke, experimental research has been conducted on the heat and temperature of cooling water recovery and the absolute humidity reduction rate of the white smoke reduction heat exchange system. With the start of the A/W heat exchanger, the temperature at the outlet of the white smoke reduction system decreases by about 65 °C, and the possibility of white smoke reduction is found.

2) When the A/W heat exchanger and SA Fan are simultaneously activated, after EA performs heat exchange through the heat exchange system, the reduction ratios of temperature and absolute humidity at the outlet of the mixing zone of the white smoke reduction system are respectively 68.1% and 82.9%. Therefore, almost no white smoke is observed at the outlet of the mixing zone of the white smoke reduction system. In addition, in order to be able to find the optimal operating conditions of the white smoke heat exchange system in future research, the experimental conditions of adding SA, EA and cooling water will be considered.

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