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Analysis of Flue Gas Pollutants Deep-removal Technology in Coal-fired Power Plants

Abstract In recent years, frequent haze has made $PM_{2.5}$ become a public hotspot. $PM_{2.5}$ control has been added to the 2012 release “ambient air quality standard.” Currently flue gas pollutant control technology does not easily remove $PM_{2.5}$. Developing Flue Gas Pollutant Deep-removal Technology (DRT) for coal-fired power plants for deep-removing pollutants such as $PM_{2.5}$, SO_2 , SO_3 , and heavy metals, is an urgent problem. Based on the analysis of the necessity and existing problems of developing DRT suitable for China, this study focused on $PM_{2.5}$ removal technology, low NO_x emission of ultra supercritical boiler under all load conditions, and the adaptability of SCR working temperature. Finally, the flue gas pollutant removal system at a 2×660 MW supercritical power plant was introduced, and the roadmap for developing DRT for 1,000 MW ultra supercritical units was analyzed.

Keywords: Coal-fired power plant, flue gas pollutants, deep-removal, $PM_{2.5}$ removal

1 Preface

$PM_{2.5}$ is one of the factors forming and worsening haze. With China’s rapid economic and social development, activities like thermal power generation, metallurgy, transportation, and heating in industry and people’s daily life is ever-increasing. The main source of $PM_{2.5}$ is soot containing toxic substances like heavy metal from fossil fuel combustion.

Coal-based primary energy sources in China results in the domination of coal-fired power plants in China’s power generation structure. Coal-fired power plants accounts for about 75% of the total installed capacity, and generating 80% or so, of the total which will long be unchangeable. Improving the efficiency of coal-fired power generation

and reducing pollutant emissions are permanent goals of electric power technological advancement and the fundamental guarantee of the sustainable development of power industry and national economy. Energy conservation and emission reduction in the power industry has achieved good results through measures such as shutting down small thermal power generation units of low-efficiency and high-pollution, accelerating the development of those of large-capacity and high-parameter, promoting the R&D of new flue gas purification technology, renovating old units, and, making greater efforts to cure environmental pollution of coal-fired power plants (Zhang, 2004; Zhang, 2008; Zhang, 2012). With rapid economic development, the total discharge of pollutants has been controlled to year 2000 levels.

According to data from China Electricity Council (China Electricity Council, 2013a, 2013b), compared with year 2000, the installed capacity of non-fluidized-bed flue gas desulfurization units increased from 5 GW to 715 GW in 2013. The figure in 2013 has accounted for 91% of the total installed capacity of coal-fired power units in China, and 30% higher than that of the US. Meanwhile, the installed capacity of flue gas de-nitration units reached 430 GW, making up 55% of the nation’s total installed capacity of coal-fired power units which is 5% higher than that of the US. All coal-fired power plants have been equipped with highly efficient dust removal devices. Average coal consumption of electricity supply has fallen by $71 \text{ g}/(\text{kW} \cdot \text{h})$ and increased to $321 \text{ g}/(\text{kW} \cdot \text{h})$. The emission concentration of main pollutants has sharply decreased. For coal-fired power plants, with the power generation tripling that of year 2000, the total emission of SO_2 has been brought down to 8.2 million tons, lower than that in 2000. The total NO_x emission is 8.34 million tons, 78% higher than that of 2000. The total soot emission is 1.420 million tons, much lower than 2000 levels of 3.21 million tons. The key to $PM_{2.5}$ control is soot emission.

There are updated technologies needed for controlling $PM_{2.5}$, SO_3 , and heavy metal like Hg emissions from coal-fired power generation, which the current flue gas purification technology in China cannot cure. Conventional

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electrostatic precipitators (ESP) cannot capture $PM_{2.5}$ effectively. Wet desulfurization absorption towers can remove only a portion of coarser soot particles but cannot remove fine particulate matter such as $PM_{2.5}$ and smaller particles (Wang, Luo, Xu, Ho, Gao, & Cen, 2007; Yao, 2013). To control $PM_{2.5}$ pollution and while controlling emissions of SO_2 , SO_3 , and heavy metals like Hg from coal-fired power plants, the development of flue gas pollutants deep-removal technology (DRT) in coal-fired power is the strategic choice of the sound development of coal-fired power generation.

DRT is commonly known as ultra-clean technology in coal-fired power plants. It is the optimization and integration of current removal systems of flue gas pollutants in coal-fired power generation units by adding wet ESP (WESP) device (Mo, Zhu, Wang, & Yi, 2013). Pollutants like $PM_{2.5}$, SO_2 , SO_3 , and heavy metal in flue gas can be thoroughly removed. Consequently, emission standards of gas-fired power plants can be met ($5-10\text{mg}/\text{Nm}^3$, NO_x and $SO_x < 30\text{mg}/\text{Nm}^3$, and lower energy consumption can be achieved.

2 The key technological challenges in developing the DRT

On the basis of system integration of flue gas purification technology, there are four main technological challenges in developing the DRT. The first one is $PM_{2.5}$ removal. The second is the synergy of $PM_{2.5}$ removal systems, desulfurization, denitration, and dust. The third is the low NO_x emission of ultra-supercritical coal-fired power units under all loads and load changing conditions. The fourth are the parameters, equipment and system optimization of DRT.

2.1 $PM_{2.5}$ removal

Presently, the main $PM_{2.5}$ removal technologies for coal-fired power plants are new ESP technologies such as electric coagulation, rotating electrode, and high-frequency impulse power sources. These technologies are effective for $PM_{2.5}$ removal, but are not satisfactory for deep removal. Therefore, it is necessary to install special $PM_{2.5}$ removal devices, such as WESP after wet desulfurization. In China, WESP has been utilized in chemical, metallurgical, and building material industries. There are special requirements and technical difficulties for WESP applicable to coal-fired power plants in China, and it is urgent to develop such $PM_{2.5}$ removal technology and equipment.

2.2 The synergy of removal systems of $PM_{2.5}$, desulfurization, denitration and dust

Flue gas pollutant control in coal-fired power plants has experienced long-term development and research abroad.

The technologies include ESP; baghouse; low-low temperature ESP; WESP; wet limestone-gypsum desulfurization, seawater desulfurization, selective catalytic reduction (SCR) denitration; and, selective non catalytic reduction (SNCR) denitration. The synergistic use of these technologies to thoroughly remove flue gas pollutants is the direction of technology development for foreign coal-fired power plants.

In China, flue gas pollutants control technology for coal-fired power plants has made remarkable progress in its years of development. Currently, ESP is the main method used for dust removal. Baggouse has been applied gradually. For desulfurization, wet limestone-gypsum is the main process. Seawater desulfurization and dry desulfurization have also been used but to a lesser extent. For denitration, low-nitrogen combustion and SCR are widely used. Overall control technology of flue gas pollutants such as dust, SO_2 , and NO_x in China is comparable to that of foreign countries.

In China, common flue gas pollutants control technologies are applied independently or separately, and the systematic research on the interconnection in control of different kinds of pollutants has not been conducted. Some equipment manufacturers have made some research on cleansing units such as WESP, and high-efficiency desulphurization, but comprehensive research on deep removal of multi-pollutant is still absent. DRT and application of flue gas pollutants used in large coal-fired power units is not yet matured. Synergistic DRT of $PM_{2.5}$, SO_x , and NO_x and heavy metal in the flue gas of coal-fired power plants in China is sorely needed.

2.3 Low NO_x emission from ultra-supercritical coal-fired power units under all loads and load changing conditions

Another challenge for DRT is NO_x emission control in ultra-supercritical boilers under all load conditions ranging from low load to full load. When ultra-supercritical coal-fired power units operate under low load ($< 50\%$ BMCR), higher oxygen concentration (air-coal ratio in flue gas) and short residence time (burner tilting up) are required to ensure reheating steam temperature, SCR inlet flue gas temperature and stable combustion, which results in high NO_x emission. However, it is difficult to achieve low NO_x emission under both low load and full load by simply adjusting the layout structure of the boilers, thus there is low NO_x emission under all load conditions. In addition, the working temperature control SCR denitration technology required in ultra-supercritical coal-fired power unit boilers is constrained by the layout of heating surfaces and the insuring safe operation.

2.4 The parameters, equipment and system optimization of DRT

Foreign cases and domestic research on control of flue gas

pollutants from coal-fired power plants show that emission levels of $5\text{mg}/\text{Nm}^3$ to $10\text{mg}/\text{Nm}^3$ for dust including $\text{PM}_{2.5}$ and below $30\text{mg}/\text{Nm}^3$ for SO_2 and NO_x is achievable through deep and synergistic removal in coal-fired power plants. At the current stage, high construction investment and operation and maintenance cost, poor adaptability in meeting emission targets under different operation conditions, and the low reliability of long-term stable operations are the main obstacles to technological promotion. The reasons for these are the increase of purification equipment, system complexity, match and synergy of the crafts of different purification units, immaturity of localization for some key technologies and equipment, and the drop in flue gas pollutants removal efficiency under low and varying loads.

3 Key technologies and technology roadmap need to be tackled

To meet the large-scale industrial demand for the deep removal of flue gas pollutants in coal-fired power plants of both 600MW and 1,000MW, system solutions for flue gas pollutants deep removal for $2 \times 660\text{MW}$ supercritical units were chosen for research. Systematic analysis is conducted on key technologies and the technology roadmap for flue gas pollutants deep removal system for 1,000MW ultra-supercritical units.

3.1 Systemic solutions for deep removal of flue gas pollutants from $2 \times 660\text{MW}$ supercritical units

In a power plant, deep removal technology is adopted in the flue gas pollutants control system of $2 \times 660\text{MW}$ supercritical units. When desulfurization and denitration devices are constructed, WESP is installed at the outlet of the desulfurization device to reduce emission of $\text{PM}_{2.5}$ and SO_3 , and solve the problem of gypsum rain. Processed with wet electrostatic absorption for further collection of dust, the desulfurized flue gas will be emitted to the atmosphere through the smoke stack. The maximum soot content at the

outlet of the smoke stack is designed to be $10\text{mg}/\text{Nm}^3$.

Both design coal and check coal are anthracite. The parameters of the main equipment are as follows (Table 1).

Here enters the deep removal system design plan. Low-nitrogen combustion + SCR denitration + ESP (with high-frequency power source) + dual-loop wet desulphurization + WESP. WESP is put at the upper end of the dual-loop wet desulphurization absorption tower to form an integrated device. The overall layout is compact, rational and smooth. It is, economical in land occupation and investment. In this project, WESP is adopted, and the dust removal efficiency will not be lower than 75%. Given the annual utilization hours of 5,000h, the availability rate of the WESP will be 100%, and the lifetime of the device will be 30 years. WESP craft system mainly constitutes of systems of flue gas, dust collection electrode, discharge electrode, and recycle flushing and protection wind.

Design principles of craft system include:

(1) One WESP for each boiler for the WESP device. One WESP can treat all the flue gas from one boiler under 100% BMCR operating condition with certain extra capacity.

(2) Dust concentration at the outlet $\leq 10\text{mg}/\text{Nm}^3$; dust removal efficiency no lower than 75%.

(3) Water from equipment flushing and scrubbing will flow into the absorption tower as make-up water for desulfurization.

There are two main layout plans for the WESP. One is a single plate-type WESP installed between wet desulfurization absorption tower and the smoke stack, or plate-type layout. The other is a tube-type WESP installed on the wet desulfurization absorption tower, or tube-type layout. Both are mature technologies and have applications abroad. Plate-type layout occupies more space due to flue duct interface and flow velocity. Tube-type layout needs less because it utilizes the desulfurization absorption tower itself and the outlet flue duct. Due to the constrained installation space in this project, high-efficiency and energy-saving dual-cycle wet desulfurization integrated with tube-type WESP is adopted. This technology is suitable for both new projects and renovation projects, especially the latter. Whop drawings have been started.

Table 1

Parameters of the $2 \times 660\text{MW}$ Supercritical Units

Main Equipment	Model and Parameters	
Boiler	Sliding-operation once-through boiler of supercritical parameter, "W" flame combustion mode and II-type layout	
	Boiler maximum continuous rating (BMCR)	2,090t/h
	Rated steam parameters	25.4MPa(g)/571°C
Turbine	Supercritical parameter, single-shaft,	
	Rated load	660MW
	Rated admission flow	1,990.3t/h
	Rated initial parameter	24.2MPa(g)/566°C
	Rated back-pressure	5.6kPa(a)

3.2 Technology roadmap of flue gas pollutants deep removal system for 1,000MW ultra-supercritical units

Based on the flue gas pollutants DRT for 600MW supercritical units, and that for 1,000MW ultra-supercritical units is planned to be developed. The main parameters for the units are shown below (Table 2).

The key challenges faced to control flue gas pollutants DRT for 1,000MW ultra-supercritical units and the construction of pilot project in China are as follows.

(1) Low NO_x emission from 1,000MW ultra-supercritical boilers under all loads and load changing conditions. Due to the large capacity and high steam parameters of 1,000MW ultra-supercritical boilers, meeting the NO_x emission target and adapting to the SCR denitration working temperature under all load and load changing conditions, call for developing several technologies. The first is the low- NO_x burner and combustion system under all load conditions. The second is the layout optimization design for the heating surface. The third is a low NO_x combustion control strategy and technology under load changing conditions for 1,000MW ultra-supercritical boilers. 1,000MW low- NO_x and ultra-clean-emission boilers under all load conditions need development.

(2) Wet desulfurization integrated with WESP. Under normal conditions, achieving deep removal of SO_2 , desulphurization efficiency must exceed 99%. However, this is difficult to realize using existing flue gas desulphurization technologies with low energy consumption. ESP and flue gas cleaning systems of wet desulfurization integrated with WESP could be used to deeply remove flue gas pollutants like SO_2 , SO_3 , $\text{PM}_{2.5}$, and heavy metal with low energy consumption.

(3) Multi-targets system integration and optimization for 1,000MW ultra-supercritical units. Deep removal system of flue gas pollutants is a complicated multi-process system. During system integration and optimization, consideration needs to be given to many factor including system performance, emission indicators, system reliability, cost of operation and maintenance.

The following is a technological roadmap for the development of a flue gas pollutant deep removal system for 1,000MW ultra-supercritical units and the construction of pilot project. Key deep removal technology will be developed utilizing pilot plant of wet desulfurization

integrated with WESP. Technology and devices of wet desulfurization integrated with WESP will be developed for 1,000MW ultra-supercritical units based on that for 600MW supercritical units. Based on existing technologies at the 1,000MW ultra-supercritical boiler, the low NO_x technology meeting SCR requirement for 1,000MW boilers under all load conditions will be developed, and a low NO_x device suitable for 1,000MW boilers under all load conditions will be designed. After that, the 1,000MW pilot project of pollutant deep removal will be built through integrating and optimizing the pollutant removal system in coal-fired power plants to provide a demonstration of the ultra-clean emission technology in China.

4 Conclusions

In line with the need of haze control of coal-fired power plants in China, this thesis gave an analysis to the key issues faced by DRT, and proposed a technological roadmap and the key technologies to be tackled for developing a DRT suitable for 1,000MW ultra-supercritical units in China. After analytic demonstration, this arrangement is feasible.

In the entire process management of R&D and engineering application, key technologies and crafts of flue gas pollutants deep removal from coal-fired power plants were developed by means of building a pilot plant of wet desulfurization integrated with WESP. On this basis, engineering design and construction of flue gas pollutant deep removal for 600MW supercritical units will develop to verify the key technology and equipment. Flue gas DRT for 1,000MW ultra-supercritical units will be developed and pilot project will be constructed referencing that of 600MW supercritical units. Taking the pilot project as the backing, engineering standard, plant construction and operation standard will be completed, and finally, large-scale implementation of flue gas pollutant deep removal in coal-fired power plants will be realized.

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Table 2

Main Design Parameters of the flue gas pollutants DRT System of 1000MW Ultra-Supercritical Units

Parameter	Value	Parameter	Value
Capacity	1,000MW	NO_x at the boiler outlet	200mg/Nm ³
Availability ratio of units	90%	Soot emission target	4.2mg/Nm ³
Auxiliary power ratio	3.75%	SO_2 emission target	11.9mg/Nm ³
Boiler efficiency	94.65%	NO_x emission target	30mg/Nm ³ (Range of application: 40%–100% BMCR)
Combustion efficiency	99.5%		

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