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The R&D of Flue Gas Pollutants Deep-Removal Technology for Coal-fired Power Plants

Abstract The flue gas pollutants deep-removal technology (DRT) focusing on $PM_{2.5}$ removal is the prime method of further reducing pollutants emission from coal-fired power plants. In view of the four key technological challenges in developing the DRT, studies were conducted on a series of purification technologies and the DRT was developed and successfully applied in 660 MW and 1000 MW coal-fired units. This paper analyzes the application results of the demonstration project, and proposes a roadmap for the follow-up researches and optimizations.

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

1 Introduction

In the past few years, the severe smog pollution has seriously impacted air quality and human health. $PM_{2.5}$ caused by fossil fuel combustion is one of the key factors forming and severing smog. However, coal-based primary energy sources in China results in the domination of coal-fired power plants in China's power generation structure, which will long be unchangeable. So improving the efficiency of coal-fired power generation and reducing pollutants emission are the everlasting goals of electric power technological advancement. The expected targets of energy conservation and emission reduction in power industry have been achieved through accelerating the development of coal-fired units with high parameters, large capacity and high efficiency, and strengthening the management of environmental protection and energy conservation for the coal-fired power plants in operation (Zhang, 2004, 2008, 2012). According to the data from China Electricity Council (2013a, 2013b), compared with year 2000, the emission concentration of sulfide and nitrogen oxides (NO_x) has sharply decreased and the total discharge of pollutants has been controlled to year 2000 level although the power generation triples that of year 2000. To meet the updating environmental standards and social development needs, the $PM_{2.5}$ control has turned out to be the primary environ0mental task for China's power industry.

In accordance with *Work Plan for Energy Conservation and Emission Reduction through Renovation and Upgrading of Coal-fired Power Plants* (*2014 — 2020*) (Table 1), by 2020, the pollutants emission concentration of the newly built coal-fired generating units in eastern areas should basically reach the emission limits set for gas-fired generating units and in central areas, it should in principle approach or come up to the limits, while in western areas, it should be encouraged to be as close to the limits as possible.

To achieve the above targets, on the basis of the current flue gas purification technologies, it is necessary to develop a batch of key technologies for deep removal of flue gas pollutants. It is necessary to do system integration and optimization of those technologies and form the flue gas pollutants deep-removal technology (DRT) for coal-fired generating units (also known as "super-clean technology" or "ultra-low emission technology") to thoroughly remove the flue gas pollutants such as $PM_{2.5}$, SO_2, SO_3 and heavy metal, etc. so as to meet the emission standards set for gas-fired generating units and maintain lower system energy consumption simultaneously. Considering regional development needs and the status quo of the existing units, the flue gas pollutants DRT is applicable to the 600 MW and 1000 MW coal-fired generating units as well. It can satisfy different requirements such as system configuration and site conditions (Zhang, 2014) of both the newly built and existing units because of its compatibility and adaptability.

2 The research and development of key technologies

Flue gas pollutants DRT is a complicated multi-process system, so consideration should be given to many factors,

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Table 1

Pollutants Emission Limits for Coal-fired and Gas-fired Generating Units (*Unit: mg/Nm*^{3})

Pollutants	Pollutants emission limits for coal-fired units	Pollutants emission limits for coal-fired units developed in key areas	Pollutants emission limits for gas-fired units
dust	30	20	5
SO_2	100 (newly built) 200 (in operation)	50	35
NO_x	100	100	50

including system performance, emission indicators, system reliability, operation and maintenance costs etc. during system integration and optimization. The four major technical difficulties to be overcome are as follows. The first one is to ensure boiler efficiency so as to realize the stable low NO_x combustion under all loads and load changing conditions, and at the same time, to achieve a best temperature window for selective catalytic reduction (SCR) denitration to solve the catalyst formulation problems caused by a wide temperature window. The second one is to integrate wet desulphurization and wet electrostatic precipitator (WESP) technology so as to obtain deep-removal of SO_2, and dust with lower energy consumption. The third one is to do system optimization and integration for each purification unit so as to achieve a comprehensive optimization of flue gas pollutants deep-removal renovation projects for 600 MW and 1000 MW coal-fired units. The last one is to realize multi-target system integration and optimization in terms of deep removal, system reliability, operation and maintenance cost, etc.

2.1 The integration technology of wet desulphurization and WESP

High efficiency and low energy consumption desulfurization technologies were researched and developed. The researches were conducted on the even distributions of flue gas and slurry spray, the optimization of the spray layer and the best match way of gas and liquid, the high-efficiency and energy-saving desulfurization technology for slurry circulating system in single column and dual zone, and the impacts of the integration of WESP and wet desulfurization on the desulfurization system to solve even distribution and matching problems of gas and liquid and ensure that desulfurization efficiency exceeds 99%.

To research and develop the large-scale WESP technology, the researches were conducted on electrode configuration optimization, numerical analysis of the gas-solid and gas-liquid flow in WESP tower, layout compactness, and the optimization of WSEP and wet desulfurization integration devices to solve the layout problems for large-scale WESP and wet desulfurization devices with less land occupation and lower energy consumption.

2.2 Low NO_x emission control technologies in boiler under full load conditions

Numerical calculation and optimization of the furnace combustion were performed. In view of the current conditions of full load, varying load and low load, researches were carried out on numerical simulation of denitration system under full load conditions and low NO_x combustion control technology under varying load conditions in order to optimize combustion control strategy and partial chemical equivalent ratio, to control NO_x emissions by increasing the outlet temperature and to create a best operating conditions for SCR denitration under full loads. Besides , the research on the application of high-efficiency SCR denitration catalyst in a wide temperature window was completed as well, as shown in *Figure 1.*

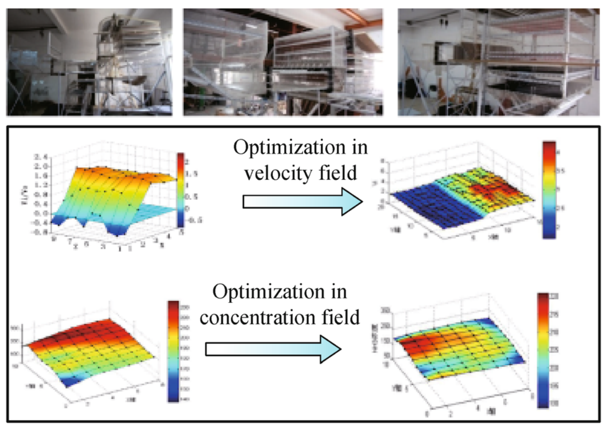

Figure 1. Cold experimental model and numerical simulation.

To do studies on the optimization of SCR flue gas denitration system, studies on the even distribution of flue gas denitration system was done to develop an efficient mixing ammonia injection system and to optimize the nozzle configuration and its specific parameters.

2.3 The integrated optimization and control of flue gas pollutants deep-removal system

The optimization work was conducted through the entire process. Considering flue gas flow process in SCR denitration system, dust removal system, desulfurization system and chimneys, a three-dimensional model of the whole system from economizer outlet to chimney was set up as shown in *Figure 2*. The unit equipment, piping structure and baffle arrangement were optimized, thus to improve equipment energy efficiency and system liquidity, to reduce system pressure loss and pipe wear. In addition, the coupling rule of the flue gas pollutants control system was explored to develop a process configuration optimization technology and to solve the matching problems in the flue gas pollutants deep-removal system.

A smart control station for NO_x & NH_3 optimization was developed. Based on the predictable control of load mode, the optimization control of NO_x & NH_3 was done under varying load conditions so as to solve the problem of high ammonia escape rate caused by NO_x concentration jet lag and excessive ammonia in the frequent load changing procedure. Consequently, the leveling control of SCR ammonia injection was implemented, the ammonia (NH_3) escape rate was reduced, and NO_x removal rate and the equipment economy and reliability were improved, as shown in *Figure 3*.

A coordinated operation guidance system was developed to provide a reference for the best operation. According to experimental and theoretical study results, the mathematical model of pollutants emission system was built. The objective function model with the lowest emissions and unit operating cost and the efficient multi-parameter (operation model) and multi-level optimization algorithm model were built respectively. A coordinated operation guidance system for multi-device and multi-system operations was eventually established to achieve flue gas pollutants deep-removal targets with optimal cost, as

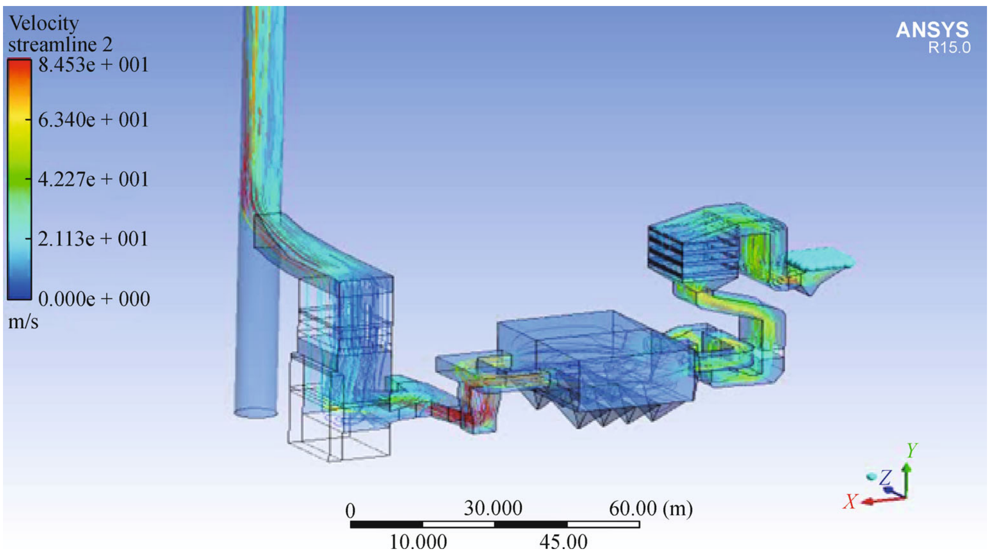

Figure 2. The optimized numerical simulation of flue gas flow process.

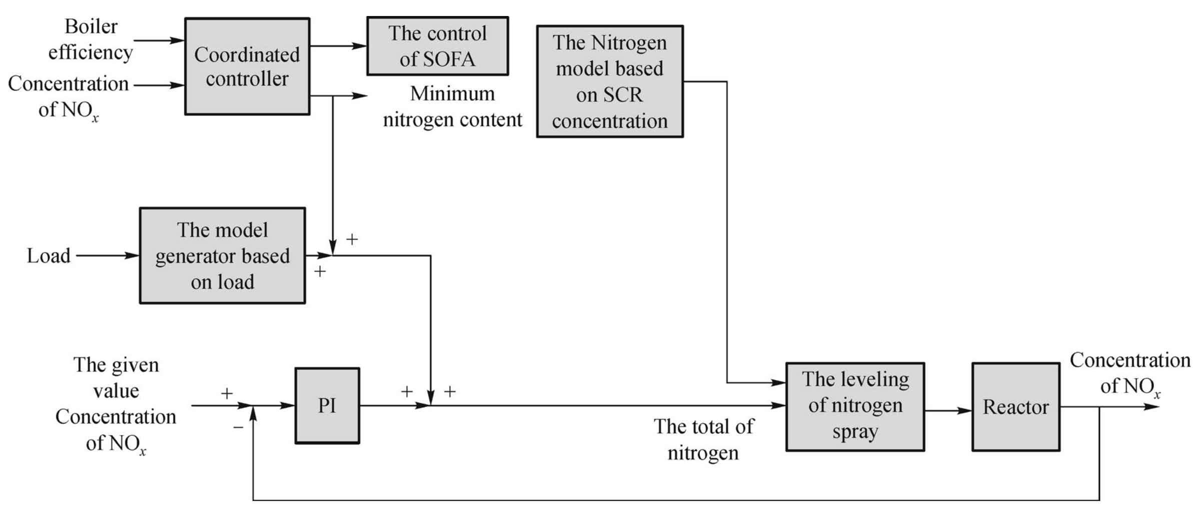

Figure 3. The diagram about the optimization control of NO_x & NH_3.

shown in *Figure. 4*.

2.4 The engineering design, construction and operation technologies for flue gas pollutants deep removal in coal-fired power plants

Engineering design technologies for flue gas pollutants deep-removal were developed for new and in operation 600 MW and 1000 MW generating units. For those new units, the engineering optimization study was carried out by using numerical simulation technology; and the type selection of the boiler and environmental protection device and process parameters were identified in particular. Integrated with the denitration technology under full loads, and the efficient dual-loop wet desulphurization and WESP integration technology, the engineering design of flue gas pollutants deep-removal system was successfully completed. For those units in operation, great attention was attached to the efficiency improving design for desulfurization absorption tower to complete the renovation project design based on the integration of wet desulfurization, WESP, and denitration technology under full loads.

Renovation construction technology for the units in operation was developed. The key point was to conduct research on a construction plan, installation process and quality control methods for the installation of desulfurization absorption tower and WESP device.

Renovation commissioning technology for the units in operation was developed. The key point was to conduct commissioning work for desulfurization absorption tower and WESP device to complete the overall system commissioning work of the boiler, low temperature electrostatic precipitator, fan, the integrated device of wet desulphurization and WESP, water-gas gas-heat device, etc.

Operation technology for the units in operation was developed. System operation procedures were made up and performance tests were carried out.

3 Engineering applications

A 2 × 1000 MW ultra-supercritical coal-fired power plant in eastern China, as one of the first batch of million-kilowatt-class domestic plants in China, has won great honors such as Gold Award of National Excellent Engineering Project, Classic Project since the inception of National Excellent Engineering Project Award. The advanced construction technology and environmental protection technology were adopted and De-SO_x and De-NO_x facilities were equipped from the very beginning. The average coal consumption was only 277.8 g/kWh, and the main technical and economic indicators were at the advanced level compared with similar units in China. Therefore, unit 2 of this power plant was chosen to be the

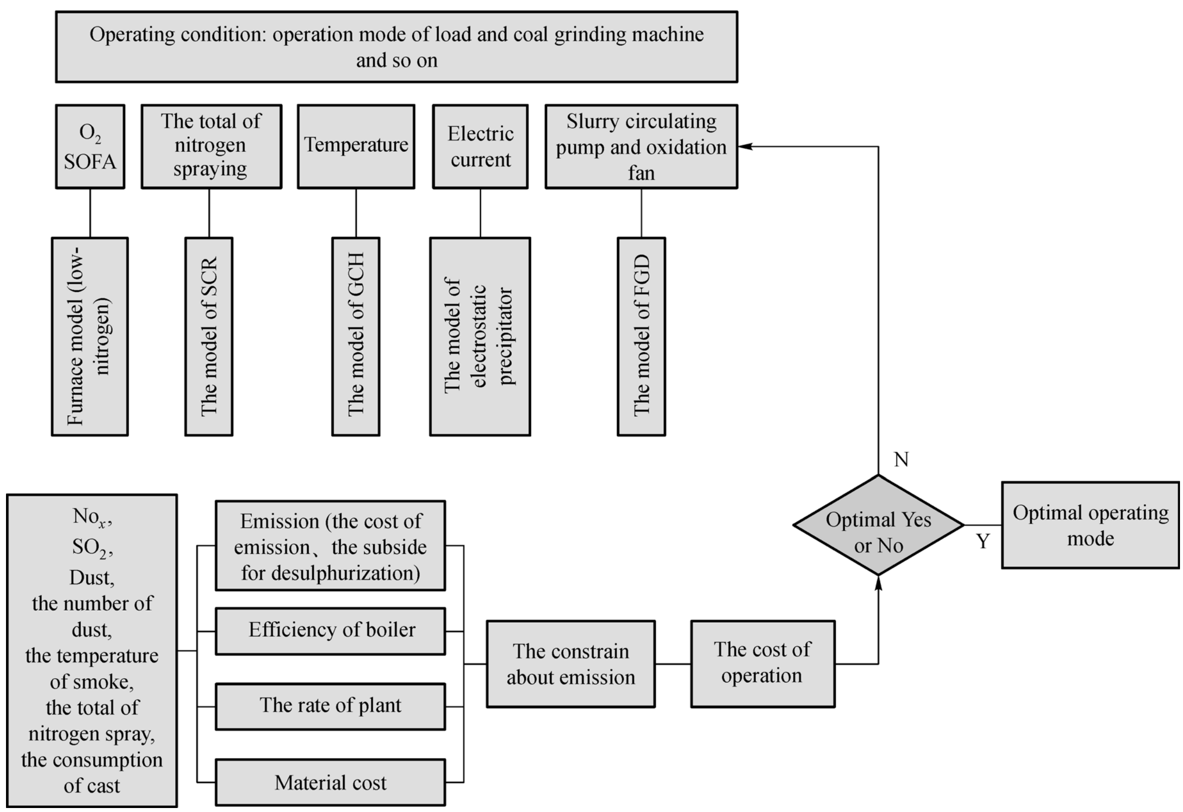

Figure 4. The logic diagram of the coordinated operation guidance system for flue gas pollutants deep-removal.

Table 2

Performance Indicators Comparison before and after Renovation (*unit: mg/Nm^3*)

Pollutants	After renovation	Before renovation	Pollutants emission limits set for gas-fired generating units	Comparison before and after renovation	Comparison with pollutants emission limits after renovation
Dust	1.41	17.5	5	–16.09	–3.59
SO_2	9	28.2	35	–19.2	–26
NO_x	21	31.9	50	–10.9	–29

demonstration project for flue gas pollutants deep-removal technology as the ecological environment in the area was getting vulnerable.

3.1 Renovation project

Taking all factors such as design coal, check coal, the original flue gas purification system configuration, site layout conditions, renovation investment, and operating costs into consideration, after technical and economic comparison, the renovation project was involved in a) improving the capacity and efficiency of desulfurization system, increasing the number of slurry tank tower, keeping the same level of the tower, extending the reaction time and raising the liquid-gas ratio; b) installing an additional two-phase rectifier in absorption tower, and a wall-ring between spray layers to improve desulfurization efficiency; c) extending the third and fourth spray layers and making room for the fifth one; d) moving the original defoggers of the second layer to the smokestack connections, and adding another defogger to ensure a at least 98.2% desulfurization efficiency; e) installing a wet electrostatic precipitator after the wet flue gas desulfurization (FGD) system to keep the dedusting efficiency reaching 75% or above; f) installing a tube-type flue gas heater to heat the flue gas to 75°C or above to eliminate white plume; g) upgrading booster fan due to the increased system resistance.

3.2 Performance indicators after renovation

The renovation project started on June 15, and was synchronized into the system on November 20, 2014. The targets were achieved with all performance indicators meeting the designed standards and the phenomena of "white plume" and "gypsum rain" no longer occurred, as shown in Table 2.

3.3 Economical analysis

188×10^6 CNY in total was invested in the renovation project and another 57×10^6 CNY will be paid for post-operation and financial cost, so the direct cost of unit electricity is increased by 0.014 CNY/kWh given the annual utilization hours of 5000 h.

4 Conclusions

(1) The system integration and optimization of the deep-removal technology was done for the 1000 MW demonstration project. Measured results demonstrate that the indicators have reached the design requirements, dramatically reducing the pollutants emission of $PM_{2.5}$, SO_2, SO_3, heavy metals, etc.

2) The economical analysis of the renovated 1000 MW unit indicates that the direct cost of unit electricity is increased by 0.014CNY/ kWh given 5000 h annual utilization. It is economically feasible on the basis of guaranteed unit operation hours and subsidized environmental price.

3) It is suggested to continue researches on system adaptability and machability to promote the modularization, serialization, and standardization of flue gas pollutants deep-removal technology. It is better to accumulate experience in its applications and to improve its availability and operation economy to meet the deep-removal requirements of flue gas pollutants for both new and existing units.

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