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Study on the ultra-clean Emission Desulfurization Reconstruction Project of Beilun Power Plant

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Abstract: As the country pays more and more attention to air pollution, the prevention and control of air pollution is increasing year by year, and it has become the only way for the coal-fired power plant to carry out ultra-clean emission reconstruction. This paper studies the ultra-clean emission desulfurization reconstruction project of Beilun Power Plant. The single tower double cycle technology was adopted in the reconstruction of desulfurization project. After the reconstruction of desulfurization system, the performance test and guarantee value condition test were carried out. When the unit load was 600MW, the desulfurization efficiency of flue gas desulfurization system was 99.6% and the dust removal efficiency of desulfurization system was 64.5%. From the performance test results, we can know that all the performance indexes after the reconstruction have reached the agreed guarantee values.

1. Introduction

With the increasing pollution, human beings have repeatedly suffered from the adverse consequences caused by their pollution to the natural environment. In the face of this situation, all countries have to change their development strategies. Instead of developing economy on the basis of environmental pollution, a sustainable development strategy of harmonious coexistence with nature is adopted to achieve a win-win situation. All countries have formulated strict laws and regulations to limit the emission of pollutants during coal combustion, aiming to improve the living environment of human beings. This has greatly promoted the application and development of desulfurization technology in various countries [1]. At present, the commonly used desulfurization technologies can be divided into three categories: pre-combustion desulfurization, in-combustion desulfurization and post-combustion desulfurization, among which post-combustion desulfurization is also called (flue gas desulfurization) [2].

Pre-combustion desulfurization includes gasification, liquefaction, coal washing, and desulfurization of pre-combustion coal by physical technology [3]. Medium combustion desulfurization mainly includes calcium injection in furnace and limestone addition in fluidized bed [4]. In 1980s, the United States developed LIMB process on the basis of calcium injection in furnace, which greatly improved the desulfurization efficiency [5]. Besides, Tampella and IVO in Finland also successfully developed LIFAC process on the basis of the original desulfurization technology [6]. No matter LIMB process or LIFAC process, they have been popularized and applied because of their excellent characteristics in the application process.

Based on the analysis of various technical routes, in the ultra-clean emission desulfurization reconstruction project of 2x600MW units in Beilun Power Plant, on the basis of the existing absorption zone, a high-efficiency absorption tower and a double cycle slurry pool with single tower and double cycle process were built in different places to achieve the purpose of desulfurization reconstruction.

2. Desulfurization Scheme

To achieve the purpose of high-efficiency desulfurization, there are the following main technical schemes, such as double tray wet desulfurization technology, series absorption tower desulfurization technology, single tower double cycle (double loop) desulfurization technology, and additive technology.

Based on the analysis of various technical schemes, and combined with the consultation with several domestic desulfurization companies with excellent performance and advanced desulfurization technologies, a comprehensive comparison of several common high-efficiency desulfurization technologies in China was given, as shown in Table 1 below.

Table 1 Comparison of several high-efficiency desulfurization technologies commonly used in China

Method	Series absorption tower	Double tray wet desulfurization	Single tower double cycle (double loop) absorption tower	Double cycle U-shaped tower (liquid column+spray double tower)
Principle and adaptability	Desulfurization is carried out by classification, so as to increase the liquid-gas ratio and improve the desulfurization efficiency. It is suitable for projects with high sulfur coal and large changes in sulfur content of coal.	Air flow homogenization by double trays; improving the contact effect between flue gas and slurry; increasing the limestone dissolution and enhancing the absorption of sulfur dioxide (SO_2). It can significantly improve the desulfurization efficiency. It is suitable for projects with high and medium sulfur coal types and large changes	Through the liquid collecting hopper, the desulfurization is divided into two loops, and an independent slurry tank is set, so that the PH values of the two loops are different and the desulfurization efficiency is improved. It is equivalent to a series absorption tower. It is suitable for projects with high sulfur coal and large changes in sulfur content of coal.	On the basis of Mitsubishi's liquid column tower, the slurry pool is divided into two paths by a partition plate, and the downstream tower and the countercurrent tower form two independent loops, so as to ensure that the PH values of the two loops are different. Besides, the slurry has twice contact with flue gas, thus achieving the purpose of improving desulfurization efficiency. It is equivalent to a series absorption tower. It is suitable for projects with high sulfur coal and large changes in sulfur content of coal.

		in sulfur content of coal types.		
System and equipment	Adding a set of absorption tower system equipment; adding a flue gas system; adding a set of oxidizing air system; adding a set of electrical and control system.	Adding trays.	It is necessary to add a liquid collecting hopper, a slurry pool outside the tower, and a contact pump and slurry circulating pump to maintain the water balance of the two slurry pools.	Adding baffle and slurry circulating pump.
Newly-added land	Maximum	Small	Medium	Medium
Construction difficulty	Maximum	Small	Medium	Medium
Initial cost	Maximum	Small	Medium	Medium
Expected desulfurization efficiency	More than 99%	98%	98%~99%	98%~99%
Operation cost	The largest power consumption, maintenance and comprehensive operation cost	Relatively low	Medium electricity consumption, maintenance, and comprehensive operation cost	Medium electricity consumption, maintenance, and comprehensive operation cost
Operation performance		Unit #3 of Huaneng Power Plant	Units #6 and #7 of Beilun Phase III Project	

In this reconstruction project, considering that the single tower double cycle technology has been successfully applied in units #6 and #7 of Beilun Phase III Project, with good operation effect, the single tower double cycle technology will continue to be adopted.

3. Method and Content of Performance Test after Desulfurization System Reconstruction

At the same time, when conducting the performance test of flue gas desulfurization system, the guarantee value condition test should be carried out to verify whether the SO2 mass concentration, flue gas flow rate, flue gas temperature, limestone quality and flue gas dust mass concentration meet the coal type and flue gas conditions required by the guarantee value. If they deviate from the design conditions, they should be corrected. See Table 2 for main test contents and methods of desulfurization system performance test.

Table 2 Method and content of desulfurization system reconstruction test

No.	Test content		Test load rate%			Test method
			100	75	51.7	
I. Guarantee value condition test						
1	Original flue gas SO_2 mass concentration		√	√	√	Ultraviolet method
2	Original flue gas temperature		√	√	√	Thermal conductivity method
3	Original flue gas flow rate		√	√	√	Differential pressure method
4	Limestone quality analysis	CaO	√	√	√	EDTA titration
		MgO	√	√	√	
5	Original smoke dust concentration		√	√	√	Gravimetric method
II. Performance guarantee value test						
1	Desulfurization efficiency		√	√	√	Ultraviolet method
2	Mass concentration of SO_2 in net flue gas		√	√	√	Ultraviolet method
3	Net flue gas temperature		√	√	√	Thermal conductivity method
4	Moisture content of original and net flue gas		√	√	√	Wet-dry bulb method
5	Limestone consumption		√	√	√	Weighing method
6	Process water consumption		√	—	—	Weighing method
7	Electric energy consumption		√	√	√	Weighing method
8	Net smoke concentration		√	√	√	Gravimetric method
9	Desulfurization system resistance		√	√	√	Differential pressure method
10	Droplet at demister outlet		√	√	√	Mg^{2+} tracer method and atomic absorption method
11	Productive dust emission concentration		√	—	—	Laser method
12	Maximum temperature of thermal insulation surface of equipment		√	—	—	Thermal conductivity method
13	HF removal rate		√	—	—	Chemical method
14	HC1 removal rate		√	—	—	Chemical method
15	Gypsum quality	$CaSO_4 \cdot 2H_2O$	√	√	√	Rapid titration
		Free water	√	√	√	Gravimetric method
		$CaCO_3$	√	√	√	Acid-base titration
		$CaSO_3 \cdot 1/2H_2O$	√	√	√	Iodometric method
		Soluble Cl^-	√	√	√	Silver nitrate titration
III. Other tests						
1	Absorption tower Slurry phase analysis	pH	√	√	√	Glass electrode method
		Slurry density	√	√	√	Capacity method
		Calcium	√	√	√	EDTA titration
		Magnesium	√	√	√	EDTA titration
		Sulphate	√	√	√	Rapid titration
		Chlorine	√	√	√	Silver nitrate titration
		Fluorine	√	√	√	Ion selective electrode method

4. Guarantee Value of Desulfurization System

Design conditions are defined as follows:

The inlet flue gas volume of FGD is: $2.412*10^6 m^3/h$ (standard state, wet basis and actual oxygen content).

The inlet flue gas volume of FGD is: $2.277*10^6$ m^3/h (standard state, dry basis, 6%O_2).

The inlet SO_2 concentration of FGD is: $3.37*10^3 mg/m^3$ (standard state, dry basis, 6%O_2, design coal, 1.4% sulfur).

The inlet temperature of flue gas is: 90℃.

Smoke content: <30mg/m^3 (standard state, dry basis, 6%O_2, design coal, 1.4% sulfur)

Desulfurization system should ensure the design coal for boiler burning; at the same time, it should meet the quality design requirements of limestone; furthermore, the consumption of limestone powder should not exceed the performance guarantee value; in addition, the power consumption cannot exceed the performance guarantee value; moreover, the quality of process water should the design requirements, and the desulfurization efficiency should be ≥ 99.4% under the condition that its consumption does not exceed the performance guarantee value. It should be ensured that the sulfur content of coal is within the range of 0.6%-1.4%, and the desulfurization efficiency is ≥98% during normal operation. Under the condition of inlet SO_2 concentration of 3.37*10^3mg/m^3 (standard state, dry basis, 6%O_2) and BMCR, the SO_2 emission concentration of sulfur dioxide should be ≤20.22mg/m^3 (standard state, dry basis, 6%O_2). Under the condition of boiler BMCR, the dust removal efficiency should be ≥60% and the resistance of desulfurization system should be< 1550Pa. It should be ensured that limestone consumption ≤13.234×2t/h (two FGD units). Besides, the HF removal rate should be ≥ 95% and the HCl removal rate should be ≥ 95%.

5. Test Conditions

The main instruments used in the test included smoke analyzer (NGA2000, Rosemount), automatic smoke (gas) tester (Laoying 3012H, Qingdao), pitot tube (S, Qingdao), electronic balance (BS224S, Beijing), weight (200g), aneroid barometer (DYM3, Shanghai) and infrared radiation thermometer. All instruments used had been calibrated and were within the validity period of calibration. The NGA2000 flue gas analyzer was used to directly detect the mass concentration of sulfur dioxide (SO_2) and the volume fraction of oxygen (O_2) in the flue gas desulfurization system.

The loads of unit 1 were 600MW, 450MW and 310MW respectively, and the unit load rates were 100%, 75.0% and 51.7% respectively. The following conditions were met during the test:

1) During the test period, the maximum fluctuation range of test boiler load in power plant should not exceed 5%.

2) During the test period, the test boiler of the power plant would not have additional oil gun for combustion, and there would be no soot blowing.

3) During the test period, the electric precipitator of the power plant test was guaranteed to be put into normal operation, and the high-voltage power supply system, control system and low-voltage control system could operate normally. Besides, the pneumatic ash conveying system run reliably.

4) During the test period, the flue gas desulfurization system of the power plant had gone through a period of debugging and stable operation before the performance test started, thus ensuring the normal and stable operation of the desulfurization and auxiliary systems.

5) The control system and main instruments of the power plant run normally with correct instructions. Before the performance test started, the equipment supplier had calibrated the online instruments of SO_2 analyzer, thermometer, flue gas flowmeter, oxygen meter and other systems required for the test.

6. Performance Guarantee Value Test and Results

6.1 Desulfurization Efficiency and SO2 Mass Concentration Test of Net Flue Gas

The summary of the test results of the mass concentration of sulfur dioxide (SO_2) and desulfurization efficiency in the flue gas of the flue gas desulfurization system of unit #1 is shown in Table 3 below.

According to the requirements of system test, the guarantee value of desulfurization efficiency should be greater than or equal to 99.4%, and the guarantee value of SO_2 mass concentration at the outlet of flue gas desulfurization system should be less than or equal to 20.22mg/m^3 (standard state, dry basis, 6%O_2).

According to the data in the table, when the unit load was 600MW, the mass concentration of sulfur dioxide (SO_2) at the outlet of the flue gas desulfurization system of the power plant was 10.0mg/m^3 (standard state, dry basis, 6%O_2), which could meet the requirements of the guarantee value; and the desulfurization efficiency was 99.6%, which also met the requirement of guarantee value.

Table 3 Summary of test results of SO2 mass concentration and desulfurization efficiency in flue gas of flue gas desulfurization system of unit 1

Test duration	Unit load MW	Flue gas desulfurization system inlet				Flue gas desulfurization system outlet			Desulfurization efficiency %
		Measure point	O_2 %	SO_2 mg/m^3 SO_2 (Standard state, dry basis) mg/m^3	SO_2 mg/m^3 SO_2 (Standard state, dry basis, 6% O_2) mg/m^3	O_2 %	SO_2 mg/m^3 SO_2 (Standard state, dry basis) mg/m^3	SO_2 mg/m^3 SO_2 (Standard state, dry basis, 6% O_2) mg/m^3	
Average value of 2.20	600	—	5.84	2248.2	2225.5	6.12	10.1	10.2	99.5
Average value of 2.21	600	—	5.75	2497.1	2457.1	6.11	9.7	9.8	99.6
Total average value of 2.20-21	600	—	5.80	2372.7	2341.3	6.12	9.9	10.0	99.6
Average value of 2.16	450	—	6.66	2215.7	2318.1	6.94	8.2	8.8	99.6
Average value of 2.17	310	—	7.46	1632.9	1809.0	8.10	8.2	9.5	99.5

During the test, when the load of unit was 450MW, the mass concentration of SO_2 at the outlet of flue gas desulfurization system of power plant test system was 8.8 mg/m^3 (standard state, dry basis, 6%O_2), and the desulfurization efficiency was 99.6%. when the load of unit was 310MW, the mass concentration of SO2 at the outlet of flue gas desulfurization system of power plant test system was 9.5mg/m^3 (standard state, dry basis, 6%O_2), and the desulfurization efficiency was 99.5%.

6.2 Mass Concentration of Clean Flue Gas and Dust Removal Efficiency Test of Desulfurization System

The test results of the mass concentration and dust removal efficiency of the flue gas desulfurization system of unit #1 are shown in Table 4 below.

In this desulfurization system, the guarantee value of dust removal efficiency should be

≥60%. According to the data in the table, when the load of unit was 600MW, the mass concentration (wet inlet) of flue gas desulfurization system was 9.3mg/m^3 (standard state, dry basis, 6%O_2), and the dust removal efficiency of desulfurization system was 64.5%. At this time, the dust removal efficiency of desulfurization system met the requirements of the guarantee value.

During the test, when the load of unit was 450MW, the mass concentration of smoke dust at the outlet of the flue gas desulfurization system (the inlet of wet dust collector) of the test system was 8.3mg/m^3 (standard state, dry basis, 6%O_2), and the dust removal efficiency of the desulfurization system was 63.2%. When the load of unit was 310MW, the mass concentration (wet inlet) of the flue gas desulfurization system outlet of the test system was 7.9mg/m^3 (standard state, dry basis, 6%O_2), and the dust removal efficiency of the desulfurization system was 61.4%.

Table 4 #1 Test results of net flue gas dust concentration and dust removal efficiency of flue gas desulfurization system of unit

Test duration	Unit load MW	FGD entrance			FGD outlet (wet inlet)			Desulfurization system Efficiency of dust collection %
		O_2 %	mg/m^3 Flue gas (Standard state, dry basis) mg/m^3	mg/m^3 Flue gas (Standard state, dry basis, 6%O_2) mg/m^3	O_2 %	mg/m^3 Flue gas (Standard state, dry basis) mg/m^3	mg/m^3 Flue gas (Standard state, dry basis, 6%O_2) mg/m^3	
2．20	600	5.84	24.8	24.5	6.12	8.9	9.0	63.4
Average value of 2.21	600	5.75	28.2	27.7	6.11	9.5	9.6	65.5
Average value of 2.20-21	600	5.80	26.5	26.2	6.12	9.2	9.3	64.5
2．16	450	6.66	21.6	22.6	6.94	7.8	8.3	63.2
2．17	310	7.46	18.5	20.5	8.10	6.8	7.9	61.4

6.3 Limestone Consumption Test

According to the test requirements, the guarantee value of limestone consumption should be less than or equal to 13.234 t/h. The test results of limestone consumption in flue gas desulfurization system of unit 1 are as follows: the limestone consumption of 600MW unit was 7.9t/h, and the limestone consumption met the requirement of guarantee value. The limestone consumption was 5.8t/h when the load of unit was 450MW. When the load of unit was 310MW, the limestone consumption was 3.3 t/h.

7. Performance Test Conclusion

When the load of unit 1 was 600MW, the desulfurization efficiency of flue gas desulfurization system of unit 1 was 99.6%, and the mass concentration of SO2 at the outlet of flue gas desulfurization system was 10.0mg/m^3 (standard state, dry basis, 6% O_2); the mass concentration of smoke dust at the outlet of flue gas desulfurization system (inlet of wet dust collector) was 9.3mg/m^3 (standard state, dry basis, 6%O_2), and the dust removal efficiency of desulfurization system was 64.5%. The limestone consumption was 7.9t/h. All performance indexes could meet the requirements of guarantee value.

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