Grenze International Journal of Engineering and Technology, January Issue

Analysis on the Causes of Abnormal Increase in the Mass Concentration of Smoke Dust in Net Flue Gas from Coal-fired Power Plants

Dr. Nilaykumar A. Patel[1], Khush N. Patel[2], Keya N. Patel[3] and Dr. Yogesh Prajapati[4]
[1,3]Dept. of Electrical Engineering, CSPIT-CHARUSAT UNIVERSITY, Changa, Gujarat, India
Email: nilaypatel.ee@charusat.ac.in, keyap675@gmail.com
[2]Schulich School of Engineering, University of Calgary, Calgary, Canada
Email: Khush.patel1@ucalgary.ca
[4]BVM Engineering College, Gujarat, India
Email: yrprajapati@bvmengineering.ac.in

***Abstract*— The dust mass concentration of the net flue gas at the FGD (Flue Gas Desulfurization) outlet of a power plant increased abnormally. Through comprehensive analysis of the technical route of flue gas collaborative treatment, the laboratory indicators of desulfurization absorption tower slurry and gypsum, and the coal quality indicators of the furnace, it is believed that the reason is that the pollutant content in the original flue gas of the boiler exceeds the design processing capacity of each equipment in the flue gas collaborative treatment system. A large amount of dust enters the absorption tower, causing its slurry to reach a saturated state, and the washing efficiency of the slurry is greatly reduced, which ultimately leads to a decrease in the FGD dust removal efficiency. By replacing the absorption tower slurry, the dust mass concentration of the net flue gas at the FGD outlet is reduced to the normal range, and suggestions for optimized operation and transformation are given.**

***Index Terms*— coal-fired power plant, flue gas collaborative treatment, dust, desulfurization absorption tower, dust collector.**

I. INTRODUCTION

Two units were installed in a cogeneration project of a power plant. The flue gas treatment of the boiler adopted flue gas collaborative treatment technology [1]. The three environmental protection indicators of the clean flue gas [2] were implemented in accordance with the "Emission Standards of Air Pollutants for Coal-fired Power Plants" of Gujarat. In India, emission standards for coal-fired boilers, particularly in thermal power plants, are governed by the Ministry of Environment, Forest and Climate Change (MoEF&CC) under the Environment (Protection) Act, 1986. These standards are periodically updated and include limits for particulate matter, sulfur dioxide (SO2), and oxides of nitrogen (NOx). The dust mass concentration was controlled at <5 mg/m3.

The dust collector was a low-temperature double-chamber five-electric field electrostatic precipitator designed and produced in India. A low-temperature flue gas heat exchanger (LGGH) was set at the inlet, and an LGGH reheater was set at the chimney inlet.

Grenze ID: 01.GIJET.12.1.504_4

LGGH keeps the flue gas temperature entering the electrostatic precipitator at around 90℃ to improve the dust removal efficiency of the electrostatic precipitator and the utilization rate of flue gas waste heat, ensuring that the electrostatic precipitator efficiency is ≥99.95% and the dust mass concentration in the outlet flue gas is ≤20 mg/m3 (the oxygen volume fraction in the dry flue gas under standard conditions is 6%). The schematic diagram of the flue gas collaborative treatment technology process is shown in Figure 1.

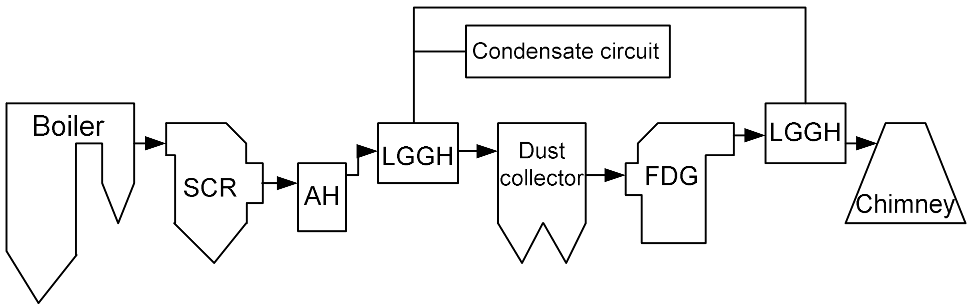
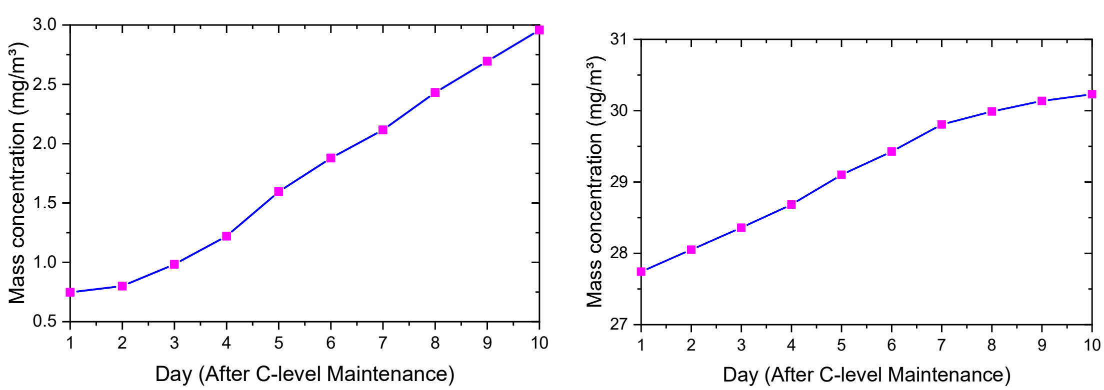


Figure 1. Schematic diagram of the flue gas collaborative treatment technology process

In above figure, SCR (Selective Catalytic Reduction) is a technology used to reduce NOx (nitrogen oxides) emissions from flue gas. The desulfurization system (FGD) adopts a limestone powder-gypsum wet flue gas desulfurization process, one furnace and one tower. The desulfurization absorption tower is 1 layer of tray +4 layers of spraying layer +3 levels of ridge demister +1 level of plate flue demister, without a bypass baffle. The main function of the desulfurization absorption tower is to achieve efficient removal of SO2, and at the same time, achieve the synergistic removal of smoke and SO3 [3-6], so that the net flue gas emission sulfur and smoke meet the ultra-clean emission standards.

II. Abnormal Increase in the Mass Concentration of Clean Flue Gas Dust

After the C-level maintenance of the power plant unit 1, it was started and connected to the grid. At the beginning of the grid operation, the mass concentration of the FGD inlet dust of unit 1 was 27.74 mg/m3, and the mass concentration of the clean flue gas dust at the FGD outlet was 0.747 mg/m3; the output of the high-frequency rectifier transformers of the first and second electric fields of the electrostatic precipitator was 62%, and the output of the high-frequency rectifier transformers of the third, fourth and fifth electric fields was 81%. With the increase of the continuous operation time of the unit, on the 10th day of grid operation, it was found that the mass concentration of the clean flue gas dust at the FGD outlet increased to 2.957 mg/m3 (the oxygen mass concentration correction conversion value was 5.25 mg/m3); the mass concentration of the smoke dust at the FGD inlet increased slightly and remained at around 30.22 mg/m3. After taking a series of measures such as calibrating the smoke mass concentration measuring instrument, strengthening the flushing of the mist collector, and increasing the output of the electrostatic precipitator, the smoke mass concentration of the net flue gas at the FGD outlet did not change significantly and continued to increase as shown in figure 2.



(a) Exit

(b) Entrance

Figure 2. Trend of smoke mass concentration at FGD inlet and outlet

III. COMMON CAUSES AND SOLUTIONS FOR THE INCREASE OF SMOKE MASS CONCENTRATION IN CLEAN FLUE GAS

A. Common causes

Failure of Smoke Mass Concentration Measuring Instrument
Common failures in the operation of laser scattering smoke concentration measuring instrument include: Optical mirror contamination, no signal output, power failure, back-purge fan failure, zero drift, and span drift, etc.
Common faults in the operation of direct extraction smoke concentration measuring instruments include: sampling probe failure, large jumps in detection data after backflush, failure to return to normal for a long time, and contamination of the analyzer gas chamber.

Reduced efficiency of electrostatic precipitator
Factors affecting the efficiency of electrostatic precipitators include design deficiencies, installation defects, quality of coal and operating conditions [7-9]. The impact of operating conditions is mainly reflected in changes in flue gas properties, dust characteristics, and electrical operation modes of rectifier transformers. Increased flue gas temperature and reduced humidity will cause increased smoke resistance, thereby reducing the dust removal efficiency of the electrostatic precipitator; insufficient rectifier transformer output, such as frequent tripping and high spark rate, will block the output current limit of the rectifier transformer, resulting in reduced efficiency of the precipitator; unreasonable vibration mode of the precipitator electrode will cause secondary flying of smoke in the precipitator.

Abnormal flushing of demister
The demister of the absorption tower can effectively remove water mist and entrained solid particles in the flue gas. If it is not flushed in time or the flushing water volume and water pressure are insufficient, solid particles will accumulate or even scale on the demister, the efficiency of the demister will decrease, and the mass concentration of smoke dust in the clean flue gas will increase.

High density of slurry in the absorption tower
The increase in the slurry density in the absorption tower will increase the content of entrained solid particles in the FGD outlet flue gas, exceeding the ability of the demister of the absorption tower to remove solid particles, causing the demister and LGGH reheater to scale [10-13], and even directly lead to an increase in the smoke dust content of the clean flue gas.

Dust purge of LGGH reheater at chimney inlet
As the operation time increases, the dust in the clean flue gas will be deposited on the surface of the heat exchange tube of the LGGH reheater at the chimney inlet. When the surface of the heat exchange tube is purged, the deposited dust will be secondary dusted, causing the dust mass concentration in the clean flue gas to increase in a short period of time.

B. Elimination of common causes

The power plant's FGD inlet dust mass concentration measuring instrument uses a domestic laser scattering CEMS dust measuring instrument, and the FGD outlet dust mass concentration measurement uses a direct extraction dust mass concentration measuring instrument. To eliminate the possibility of a malfunction in the FGD outlet net flue gas dust mass concentration measuring instrument, the power plant's thermal control maintenance technicians calibrated the FGD outlet and inlet dust mass concentration instruments. The results of repeated calibrations all showed that the FGD outlet and inlet dust mass concentration measuring instruments were accurate. At the same time, by comparing the historical data of the FGD outlet dust mass concentration, it was found that its value was gradually increasing, which also eliminated the possibility of a malfunction in the FGD outlet net flue gas dust mass concentration measuring instrument.
After the dust mass concentration increased, the operator adjusted all the high-frequency rectifier transformers of the ESP to the maximum output and adjusted the flue gas temperature at the ESP inlet from 100°C to 91°C to improve the efficiency of the ESP. It was found that, except for a slight decrease in the dust mass concentration at the FGD inlet, the dust mass concentration of the net flue gas at the FGD outlet did not change. The operation parameters and electrode vibration mode of the ESP were checked and verified to be normal, eliminating the possibility of reduced efficiency of the ESP.
After the unit was connected to the grid, the gypsum in the absorber was removed as required to keep the gypsum density in the absorber within the normal range. By adjusting the demister flushing water pressure to 1.5 times the normal value and the flushing water volume to 2 times the normal value, the demister was flushed

more vigorously, and the dust mass concentration of the net flue gas at the FGD outlet was only reduced by 0.2 mg/m3.
Judging from the above adjustment operation results, the common reasons for the increase in the net flue gas dust mass concentration have been eliminated.

IV. DETERMINATION OF THE CAUSE OF AN ABNORMAL INCREASE IN NET FLUE GAS DUST MASS CONCENTRATION

A. Analysis of the cause of abnormal increase

The technicians took samples of the absorption tower slurry and observed them statically. They found that the slurry was stratified. Except for the bottom gypsum and CaCO3 mixture layer and the top clear water layer, the middle layer was a thick black suspended matter. Comparing the gypsum test data of the absorption tower after the unit was started and connected to the grid, it was found that the gypsum colour was darker than normal, the purity continued to decrease, the CaCO3 content increased slightly, and the total solid content of gypsum and CaCO3 also decreased, while the content of solid hydrochloric acid insoluble matter in the absorption tower slurry increased slightly as shown in figure 3.

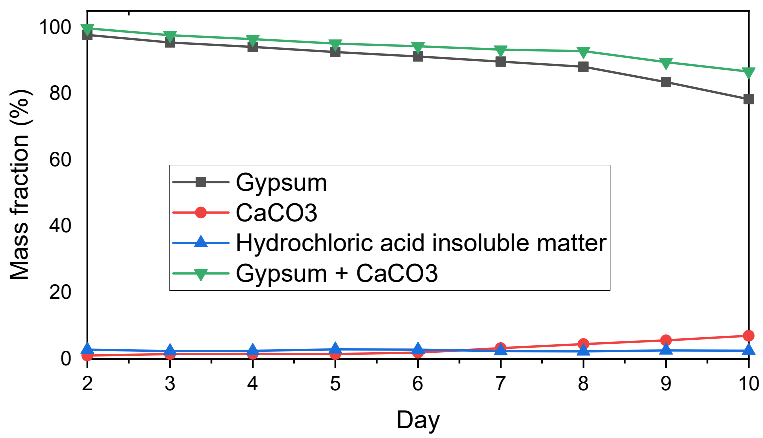


Figure 3. Trend of mass fraction of main substances contained in gypsum

Combined with the fact that the boiler was mixed with high-ash raw coal after the unit was connected to the grid, it is believed that a large amount of smoke dust may have been mixed into the absorber slurry, causing the smoke dust suspended matter in the absorber slurry to increase until saturation, reducing the slurry washing capacity, and causing the net flue gas smoke dust mass concentration to increase.
To prove the correctness of the above analysis, the power plant operators replaced the absorber slurry, poured 45% of the slurry in the absorber into the accident slurry tank, and then refilled the absorber to the normal liquid level. After the slurry replacement of the absorber was completed, it was found that the mass concentration of the net flue gas at the FGD outlet gradually decreased and was finally maintained at about 0.78 mg/m3.

B. Abnormal increase mechanism

According to the design technology route of the flue gas pollutant system treatment system of the power plant, the SCR denitrification, dust removal, and FGD facilities have a certain synergistic removal effect on other pollutants while removing their own corresponding pollutants. Due to the synergistic removal of smoke dust by the washing effect of the absorption tower slurry, the design value of the dust removal efficiency of FGD is ≥77%.
The design coal type of the power plant boiler is 32% of the basic ash content, but in actual operation, the weighted average of the basic ash content of the coal entering the furnace is about 41.6% (the maximum basic ash content of a single coal type is 57%), resulting in the dust content in the flue gas entering the electrostatic precipitator far exceeding the design value of the electrostatic precipitator. Even if all high-frequency rectifier transformers of the electrostatic precipitator work at maximum output, it is still impossible to achieve the requirement that the dust mass concentration at the outlet of the electrostatic precipitator is less than the design value (20 mg/m3), resulting in a large amount of dust passing through the electrostatic precipitator and entering the absorption tower.

C. Observations

- A large amount of dust carried in the flue gas enters the absorption tower. When the dust in the slurry of the absorption tower accumulates to a certain amount and reaches saturation, the washing efficiency of the slurry is greatly reduced, and the FGD dust removal efficiency decreases.
- The amount of smoke entrained in the flue gas increases, exceeding the ability of the demister to remove solid particles, resulting in an abnormal increase in the smoke quality concentration of the net flue gas at the FGD outlet.

IV. Optimization Operation and Transformation Suggestions

To ensure that the net flue gas dust mass concentration at the FGD outlet of the power plant meets the ultra-clean emission standards, combined with the actual operation of the power plant equipment, the following optimization operation and transformation plan is proposed.

- Strengthen the operation, maintenance, and troubleshooting of the dust collector. During the operation of the unit, according to the operating conditions of the boiler, timely adjust the output of the high-frequency rectifier transformer of the electrostatic precipitator, optimize the electrode vibration plan, and improve the dust removal efficiency of the electrostatic precipitator. Ensure that the mass concentration of the dust at the FGD inlet is within the design range and reduce the dust content entering the absorption tower.
- Ensure that the mist eliminator of the absorption tower is flushed normally. Strictly flush the mist eliminator regularly in accordance with the requirements, and strengthen the flushing when necessary to prevent the mist eliminator from scaling and damage, which affects the ability of the mist eliminator to remove liquid water mist and solid particles.
- Pay attention to the quality of the slurry and gypsum in the absorption tower, and replace the slurry in time according to various test indicators. Regularly sample the absorption tower slurry and gypsum for testing, analyze the gypsum purity, hydrochloric acid insoluble matter content and slurry precipitation stratification, etc. Combined with the changes in the quality and concentration of the net flue gas dust at the FGD outlet, regularly replace the absorption tower slurry to ensure that the FGD dust removal efficiency is qualified.
- Strengthen the management of coal blending for boilers. Rationally optimize the high-ash raw coal blending scheme. Before the system is upgraded, strictly control the dust content in the raw flue gas to ensure that it does not exceed the design processing capacity of each facility in the flue gas coordinated treatment system.
- Improve the dust removal capacity of the flue gas coordinated treatment system. With the adjustment of the India's energy structure, traditional coal-fired power plants reduce the cost of power generation fuel by blending inferior high-sulfur and high-ash raw coal, which will inevitably cause the content of various pollutants in the boiler raw flue gas to exceed the design processing capacity of each facility in the flue gas coordinated treatment system, and there is a risk of excessive atmospheric pollutant emissions [14-15]. To prevent the dust content in the original flue gas from exceeding the design value and fundamentally ensure that the dust quality concentration meets the emission standards, the dust removal capacity of the flue gas collaborative treatment system must be improved and transformed.

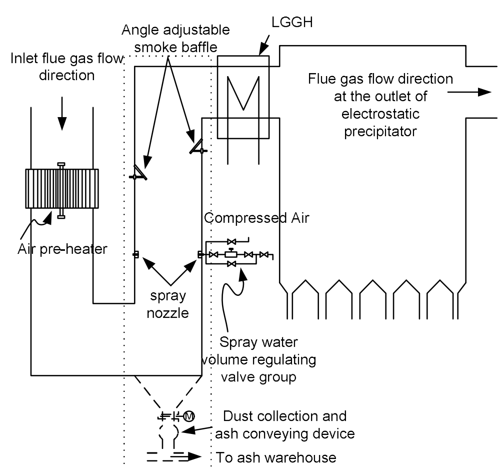


Figure 4. Schematic diagram of the flue gas collaborative treatment transformation principle

Under the premise of comprehensively considering the feasibility, cost and effect of technical transformation, a dust collecting device can be added before the electrostatic precipitator to reduce the smoke content entering the electrostatic precipitator. This can be bring to limelight by proper energy audit [16]. The transformation principle is shown in Figure 4.

VI. CONCLUSION

This article provides a complete analysis of the abnormal increase in the net flue gas dust mass concentration of a power plant. It also identifies the reason of the problem and eliminates it after treatment, thereby ensuring that the flue gas coordinated treatment system operates in a manner that is both safe and ecologically beneficial. The treatment experience can serve as a point of reference for power plants that are experiencing challenges that are comparable.

REFERENCES

[1] Elehinafe, Francis B., Ephraim A. Aondoakaa, Akinnike F. Akinyemi, Oluranti Agboola, and Oyetunji B. Okedere. "Separation processes for the treatment of industrial flue gases–Effective methods for global industrial air pollution control." Heliyon 10, no. 11, June 2024.

[2] Oreggioni, G. D., Ornella Mahiques, Fabio Monforti-Ferrario, Edwin Schaaf, Marilena Muntean, Diego Guizzardi, Elisabetta Vignati, and Monica Crippa. "The impacts of technological changes and regulatory frameworks on global air pollutant emissions from the energy industry and road transport." Energy Policy 168, pp. 113021, September 2022.

[3] Chen, Rong, Tongsheng Zhang, Yiqun Guo, Jiawei Wang, Jiangxiong Wei, and Qijun Yu. "Recent advances in simultaneous removal of SO2 and NOx from exhaust gases: Removal process, mechanism and kinetics." Chemical Engineering Journal vol. 420, pp. 127588, September 2021.

[4] Zhao, Zhongyang, Yongxin Zhang, Wenchao Gao, Jakov Baleta, Chang Liu, Wenjun Li, Weiguo Weng, Haobo Dai, Chenghang Zheng, and Xiang Gao. "Simulation of SO2 absorption and performance enhancement of wet flue gas desulfurization system." Process safety and environmental protection vol. 150, pp. 453-463, June 2021.

[5] Han, Yuan, and Yujie Zhu. "SO3 removal rate and emission test of the limestone-gypsum wet desulfurization system for coal-fired power plants." In Journal of Physics: Conference Series, vol. 2598, no. 1, pp. 012014. IOP Publishing, September 2023.

[6] Zhao, Xu, Houzhang Tan, Fuxin Yang, and Shuanghui Deng. "Field Studies on the Removal Characteristics of Particulate Matter and SO." Energy Engineering: Journal of the Association of Energy Engineers, vol. 119, no. 1, pp. 49-62, November 2021.

[7] Badran, Mohamed, and Abdallah Mahmoud Mansour. "Evaluating performance indices of electrostatic precipitators." Energies vol. 15, no. 18 pp. 6647, September 2022.

[8] Wang, Pan, Junjie Liu, Chenhua Wang, Zhiwei Zhang, and Jiayu Li. "A holistic performance assessment of duct-type electrostatic precipitators." Journal of Cleaner Production vol. 357, pp. 131997, July 2022.

[9] Chekalov, L. V., V. A. Guzaev, and M. E. Smirnov. "Increasing the Efficiency of Electric Precipitators for Thermal Power Plants by Improving Collecting Electrodes." Power Technology and Engineering vol. 55, no. 5, pp. 736-741, January 2022.

[10] Wu, Jianxun, and Fangming Xue. "Cause analysis and treatment of slurry foaming in desulfurization absorption tower of 300MW unit." In IOP Conference Series: Earth and Environmental Science, vol. 804, no. 3, p. 032008. IOP Publishing, 2021.

[11] Liu, Jing, Taoyong Liu, Changqing Su, and Songye Zhou. "Operation analysis and its performance optimizations of the spray dispersion desulfurization tower for the industrial coal-fired boiler." Case Studies in Thermal Engineering, vol. 49, pp. 103210, September 2023.

[12] Xiang, Yi, Di Wu, Guohua Yang, Yanyan Chen, and Wenhao Lyu. "Pilot study on demister-based dust removal methods for boiler flue gas." Environmental Science and Pollution Research, vol. 30, no. 13, pp. 37570-37578, December 2022.

[13] Zou, Renjie, Zehua Li, Guangqian Luo, Haoyu Zhang, Can Fang, Li Wang, Min Lyu et al. "Enhancement of selenium removal in coal-fired flue gas across wet flue gas desulfurization spray tower by internal components-part 1: Demister and wall ring." Journal of Cleaner Production, vol. 472, pp. 143489, September 2024.

[14] Cui, Jicui, Jiyang Li, Haoyu Zhang, Ruina Zhang, Wenchao Ma, Ying Zhu, Wenxiang Yuan, Michael Palocz-Andresen, Youcai Zhao, and Ziyang Lou. "Synergistic control potential of flue gas pollutants under Ultra-Low emission standards in waste incineration plants." Environment International, vol. 186, pp. 108590, April 2024.

[15] Han, Yuan, and Yujie Zhu. "Study on the effect of supercritical CFB boiler air preheater and flue gas treatment facilities on sulfur trioxide emission characteristics." Energy Reports, vol. 8, pp. 926-939, July 2022.

[16] Patel, Nilaykumar A., Khush N. Patel, and Keya N. Patel. "Evaluation of Electricity EPI through Preliminary Audit of Electric Energy at CHARUSAT Campus." Grenze International Journal of Engineering and Technology (GIJET), vol. 10, no. 1, pp. 2224-2229, January 2024 .