Optimization experiments of the SNCR denitrification system in circulating fluidized bed boiler after ultra-low emission transformation

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Abstract: The current work firstly aims to improve denitrification efficiency of the selective non-catalytic reduction (SNCR) denitrification system in a circulating fluidized bed (CFB) boiler after ultra-low emission transformation, to reduce the operating pressure of the subsequent selective catalytic reduction (SCR) denitrification system, and to extend the service life of the boiler. Secondly, it attempts to ensure that the concentration of nitrogen oxides (NOx) does not exceed the emission standard, to drop the consumption of the reducing agent, and to save operating costs. Therefore, some key factors, such as the number of spray guns affect denitrification efficiency and the amount of ammonia escape, were chosen as the operating parameters to be optimized. Meanwhile, a 150 MW CFB boiler in the Inner Mongolia Autonomous Region of China was employed for the experimentation. We then designed and implemented the optimization experiments of the SNCR denitrification system, including optimizing the operating parameters and deeply optimizing the SNCR denitrification process. The denitrification efficiency can reach 76.6% when there are four spray guns with valve opening of 50, 100, 100, and 50% respectively from top to bottom. The current work can be used as a frame of reference for carrying out relevant experiments on similar units.

1. Introduction

1.1. Status quo of ultra-low emission transformation of CFB boilers in China

In 2011, the Chinese government promulgated GB13223-2011 of Emission Standards of Air Pollutants in Thermal Power Plants. The standard clearly stipulates that the concentration of nitrogen oxides (NOx) of the flue gas emitted from existing circulating fluidized bed (CFB) boiler units has to be less than 200 mg/m³ (in the standard state, on a dry basis, at a reference oxygen volume fraction (φO2) of 6%, the same as below) after July 1, 2014. Moreover, the NOx concentration of the flue gas emitted from the newly built CFB boiler units should not exceed 100 mg/m³. Issued in 2014, the Coal Power Energy Saving and Emission Reduction Upgrade and Transformation Action Plan (2014–2020) requires and encourages newly built units to approach or reach the emission limit of gas turbine units as follows. The limits to the mass concentration of air pollutants SO2 and NOx must be less than 35 and 50 mg/m³ respectively, and the concentration of particulates has to be lower than 5 mg/m³.

The combustion temperature of CFB boilers is usually controlled in a low range of 850–950 °C to reduce the initial discharge of NOx. Under appropriate operating conditions and by using low-temperature and staged combustion, the concentration of NOx could be lower than 200 mg/m³. However, to meet the existing environmental protection standards, especially ultra-low emission
standards, it is still necessary to transform the boilers or add denitrification devices according to the actual conditions of the units, that is, ultra-low emission transformation is required. Among many flue gas denitrification technologies, selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) are two widely used methods. Compared with the SCR denitrification process, SNCR denitrification method has the advantages of requiring no catalyst and no special reactor, demanding lower capital investment and operating costs, and reducing the influence of flue gas components on the denitrification efficiency. Hence, the SNCR denitrification technology is suitable for the transformation of the existing CFB boilers. At present, more than 300 SNCR denitrification units are used in power station boilers, industrial boilers, garbage incinerators, and other combustion devices around the world[1–3].

The denitrification process for the ultra-low emission transformation of CFB boilers could follow the technical route to low nitrogen burning (LNB), that is, LNB—LNB + SNCR—LNB + SNCR + SCR. [4] When the previous denitrification process fails to satisfy the emission requirements, an additional denitrification device could be supplemented, so that the emission data comply with the environmental protection regulations[5].

It is worth mentioning that LNB transformation is a furnace denitrification transformation, while the SCR and SNCR processes belong to the typical flue gas denitrification transformation.

1.2. SNCR denitrification process
A process diagram of the SNCR denitrification system is depicted in Figure 1.

![Figure 1. A process diagram of the SNCR denitrification system.](image)

It could be seen in Figure 1 that the urea solution was first transferred from the urea circulation pump to the urea metering device. The urea solution with a concentration of 50% was mixed with the demineralized water (from the dilution water tank) in the metering unit, and the concentration was reduced to about 10%, which was then sent to the distribution unit. After distribution, the urea solution entered the spray guns and was then sprayed into the furnace chamber.

Five nozzles were arranged outside of the cyclone separator inlet as illustrated in Figure 2. Each nozzle has three inlets, namely urea solution, atomizing purge air, and nozzle jacket cooling air. The injection flow was adjusted with a switching valve.
2. Experimental procedures
The optimization of operating parameters of the SNCR denitrification system was performed at different unit loads of 150 MW (operating condition I), 140 MW (operating condition II), and 110 MW (operating condition III). During the whole test, the SCR denitrification system was operating normally. The denitrification efficiency and the amount of ammonia escape were selected as the evaluation criteria for the optimization of operating parameters.

The test steps for evaluating the efficiency of the denitrification system were as follows. First, the boiler was adjusted to a specific test condition and continued operating for about 30 minutes. Then, the relevant data were recorded and measured after stopping spraying the urea solution for 60 minutes. Subsequently, after spraying the urea solution into the furnace and stably operating the system for 60 minutes, the relevant data were recorded and measured again. The efficiency of the denitrification process was calculated using the relevant formula.

3. Results and discussion
To examine the effect of the number of spray guns on denitrification efficiency, the test was carried out with two, three, four, and five spray guns under the three operating conditions; the maximum flow of the reducing agent in the main pipe was also set at 1.2 t/h. The test results are depicted in Figures 3–6.
Figure 3. Effect of the number of spray guns on the denitrification efficiency.

Figure 4. Effect of the number of spray guns on the denitrification efficiency and the amount of ammonia escape (operating condition III).

Figure 5. Effect of the number of spray guns on the denitrification efficiency and the amount of ammonia escape (operating condition II).
Figure 6. Effect of the number of spray guns on the denitrification efficiency and the amount of ammonia escape (operating condition I).

The obtained results demonstrated that the denitrification efficiency was significantly improved by an increase in the number of spray guns. The denitrification efficiency of the unit operating with five spray guns was close to that of the unit operating with four spray guns; nonetheless, the amount of ammonia escape of the unit equipped with five spray guns was significantly higher because the position of spray gun No. 5 was lower than the bottom end of the flue gas discharge pipe of the cyclone separator, which caused the reducing agent sprayed by spray gun No. 5 to be directly discharged from the exhaust pipe before entering the cyclone separator for denitrification reaction; therefore, the reducing agent was wasted. As a result, only the four upper spray guns could be operated during unit operation, and the bottommost spray gun, i.e. spray gun No. 5, could be shut down to reduce the consumption of the reducing agent and the amount of ammonia escape.

4. Conclusions
With the increase of the number of spray guns, the denitrification efficiency is improved. The position of the bottommost spray gun was lower than the bottom of the flue gas exhaust pipe of the cyclone separator, which led to ammonia escape and the waste of the reducing agent, thereby lessening the effect of the reducing agent on the denitrification reaction. As a result, it was suggested that the bottommost spray gun should be deactivated and only the four upper spray guns be operated. In the future technical transformation projects, the bottommost spray gun can also be moved up so as to place it at a position higher than the bottom of the flue gas exhaust pipe of the cyclone separator. It should also be noted that the nozzle position should not be set too low in newly built projects, otherwise, it is not conducive to the denitrification reaction.

Author Contributions
Formal analysis, YUJIE ZHU, JIANJUN SHEN; writing—original draft preparation, YUAN HAN; writing—review and editing, YUJIE ZHU; supervision, YUJIE ZHU, YONGJIANG LIU; project administration, ZHIYONG ZHANG, WENPING ZHANG, YONGJIANG LIU; funding acquisition, YUJIE ZHU. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.
References

[1] YUAN Qi-xin. Simulation of SNCR Denitrification in a Cyclone Separator of Supercritical Circulating Fluidized Bed. *Journal of engineering for thermal energy and power* 2019, 34(08), 109-115.

[2] YANG Mei; ZHANG Zhongxiao; Yu Juan; et al. Denitrification Mechanism Analysis and Experiment of Selective Non-Catalytic Reduction of Flue Gas of Circulating Fluidized Bed. *Journal of Combustion Science and Technology* 2014, 20(02), 101-105.

[3] BI Degui; ZHANG Zhongxiao; ZHANG Jian; et al. Experimental Study on Deep Denitrification by Injecting Ammonia into the Primary Combustion Zone and Combining with SNCR in PC-Boiler. *Journal of engineering for thermal energy and power* 2017, 32(08), 89-93+150.

[4] HUANG Zhong; GAO Hongpei; SUN Xianbin; et al. Recognition of CFB Boiler Environmental Protection Characteristics under Current Environmental Standards. *Power System Engineering* 2012, 28(06), 13-16.

[5] SHI Lei; ZHANG Shixin. Optimization of SNCR denitration technology in circulating fluidized bed boiler. *Clean Coal Technology* 2018, 24(06), 107-111.