Low-nitrogen combustion reformation for boiler burner

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Abstract. In view of the current reformation for denitrification and cost reduction in coal-fired power plants, the boiler burner was upgraded in our company. On the basis of the comprehensive study of the low nitrogen burners of the major coal-fired power plants, the following low nitrogen retrofit measures were implemented: low NOx retrofit measures of the burners, anti-slagging and anti-corrosion measures, as well as high-efficiency measures for stable combustion. The results showed that the improved burner had better air counterweight ratio and could ensure the stable combustion of pulverized coal. Under the pure coal condition, NOx was reduced from 600mg/m³ to 210mg/m³. Under the mixed combustion condition, NOx in the flue gas decreased from 410mg/m³ to 160mg/m³. The boiler efficiency was slightly improved after the reformation, for the boiler efficiency increased from 91.49% to 91.79% under the condition of gas mixing and increased from 92.92% to 93.79% under pure coal condition. As shown above, the NOx emission for burner was reduced without affecting the working efficiency and the cost of denitration was also controlled after reformation.

1. Introduction

Nowadays, with the increasing degree of industrialization, air pollution is becoming more and more serious. Nitrogen oxide is one of the main air pollutants, and the key to controlling its pollution is to control the emission of NOx from fixed sources [1]. Though countries around the world pay more and more attention to new energy power generation in recent years, the thermal power generation is still the most important power source. Countries attach great importance to the control of NOx emission from coal-fired power plants [2]. Strict control of NOx generation and emission, and the operation of thermal power plants in the most effective way with the least environmental pollution are still the primary problems that all coal-fired power plants have to face at this stage [3]. The low NOx technology is mainly the denitrification technology in the furnace, which use a variety of combustion technologies to control the NOx produced in the combustion process, among which, the reformation of boiler burner is still one of the main means to reduce NOx formation and emission. By changing the swirl burner from co-rotating mode to counter-rotating one and introduced separated over-fire air, a remarkably reduction of NOx emissions from 1085 mg/m³ to 547 mg/m³ was achieved for a 600 MWe Babcock & Wilcox boiler [4]. The solid fuel burning process was calculated on low-temperature swirl technology, the results showed that low-temperature swirl technology of coal and peat combustion could improve ignition and burning of fuel, and considerably the emissions of NOx was reduced [5].
fuel-rich jet to form a partial area of high-temperature and high pulverized coal concentration in the furnace, the low NOx emission, prevention of slagging and high-temperature corrosion, as well as high combustion efficiency were realized [6]. A combustion system was applied to a 600 MW Foster Wheeler (FW) down-fired pulverized-coal utility boiler by moving fuel-lean nozzles from the arches to the front/rear walls, rearranging staged air and introducing separated over fire air (SOFA) [7]. The recirculation zones below the arches were enlarged in the reformed combustion system, thereby strengthened the combustion stability considerably, which resulted in a low-oxygen and strong-reducing atmosphere in the lower furnace region and so reduced NOx emissions evidently. The NOx emission and coal combustion were evaluated be three-dimensional numerical investigation in a supercritical 600 MW wall fired utility boiler fed with lean coal. The influence of over fire air (OFA) ratio as well as OFA port position was studied. With increasing OFA ratio, the carbon content in fly ash and the temperature of the burner zone increased, while the NOx emission decreased [8]. A sub-air injection was induced in a 500 MW tangentially fired coal boiler to improve the combustibility and reduce NOx emission [9]. The secondary air flow rate was lowered properly to ensure a constant total quantity of combustion air. For an air-staged combustion retaining the effect, the over-fire air was not adjusted. According to the coal particle trajectory, the injection ports were set. The simulated results showed that reductions of NOx by 6.3 and 13.2% were achieved when the sub-air was set for 5 and 10% of the combustion air, respectively. Cold airflow experiments for a down-fired pulverized-coal 300 MWe utility boiler with direct flow split cyclones burners were conducted [10]. A deflected flow field formed in the lower furnace and larger deflections produced by increasing staged-air ratios. When the staged-air dampers fully opened in differences of gas temperatures and heat fluxes, carbon in fly ash and NOx emission decreased, as well as the boiler efficiency increased.

Based on the comprehensive study of various low nitrogen burners, the burner had been reformed in three longitudinal zones and two transverse zones, and the joint functional zone was established. Through the reformation, the NOx emission was reduced, and the slagging prevention, corrosion prevention, stable combustion and high efficiency were achieved.

2. Low-nitrogen combustion reformation

2.1 Reforming measures

2.1.1. Low nitrogen oxides reforming measures for burner. Although the low-nitrogen combustion technology and all kinds of low-nitrogen burners used by domestic and foreign coal-fired power plants can reduce NOx generation to a certain extent, they don’t always meet emissions standards of different countries. In order to better reducing the NOx emissions of boiler burners, in this study, the burner was modified by vertical three-zones and horizontal two-zones.

(1) Layout of vertical three-zones

The arrangement of vertical three-zones was shown in the figure 1. The air classification was achieved in the vertical aspect, which greatly increased the burner combustion area. At the same time, the heat load was reduced, which made the peak temperature of the furnace decreased. Thus, the generation and emission of thermal NOx were greatly reduced.

(2) Horizontal two-zone layout

The arrangement of the horizontal two-zone was shown in the figure 2. The direction of the primary air jet didn’t change in the secondary air jet direction of deflection 3°. The primary air nozzle was reformed into the separating thick and thin for upper and lower, and the steady burning blunt body was added in the middle part. Such reformation played an important role in stabilizing the combustion of pulverized coal fuel and ahead of the ignition time. Therefore, the high temperature smoke volume and stable combustion effect were increased, and the formation and emission of NOx were further reduced.
(3) Establishment of node functional areas

The primary air of the lower layer was redesigned so that it became the burner nozzle with the upper part thick and the lower part light. On the contrary, the upper primary air was also rearranged so that it becomes the primary air nozzle with lower thick and upper light. A small angle offset was formed for the secondary air in the middle part of the upper and lower layer came from the primary air nozzle and the primary air jet, and the nozzle attached to the wall air was installed at the same time. The schematic diagram of node function area was shown in figure 3. Due to secondary air bias could eject high-temperature hypoxic flue gas for such nozzle combination, concentrated pulverized coal and hot flue gas were mixed to form partial hypoxic combustion, and NOx at the initial stage of ignition could be reduced to nitride. Such configuration could stabilize combustion and reduce formation and emission for NOx. The effect of NOx and fly ash fuel could be reduced at the same time by enlarging secondary air in the middle part and the door attached to the wall air.

2.1.2 Anti-slagging and anti-corrosion measures. Through the use of horizontal two-zone arrangement, the primary and secondary air jets were adjusted and the attached air nozzle was installed to form the attached air (see figure 3). Three central and near-wall regions with different characteristics were formed on the cross section of the furnace. In the furnace, the primary air would form a small tangential circle opposite to the main air flow direction, so that it was easier to control the wall of pulverized coal fuel air flow. In this way, the molten ash would be difficult to throw to the water wall, so to achieve the effect of strengthening anti-slagging as well as to achieve anti-corrosion.

2.1.3. Stable combustion and efficient measures.

(1) All the primary air nozzles were changed into nozzles with top thick and bottom light, so as the side with high concentration would release more volatiles due to the high concentration of pulverized coal fuel, which makes it easier to realize early ignition and combustion. At the same time, a wide
waveform blunt body structure was installed between the side with higher concentration and the side with lower concentration, which could enhance the reflux effect of hot flue gas and make it easier to realize early ignition.

(2) The nozzles were reformed into those could swing up and down in multiple directions. The over-fire air nozzle oscillating in the horizontal direction could provide the required air volume to different areas in the furnace in advance (see figure 4). In this way, the air volume could not only effectively cover the furnace, but also ensure the effective control of combustible materials such as fly ash. While reducing the content of fly ash and other combustible substances, on the one hand, it could ensure the NOX formation and emission reduction, and on the other hand, it could obtain a relatively high economic applicability of boiler burners.

Figure 4. Schematic diagram of multi-angle over-fire air supply.

2.2. The main reformation contents
The reformation scope mainly included the reformation of the main burner and the over-fire air. The modification and replacement of the main burner section included: nozzle component of primary air and secondary air, bend of primary air pulverized coal pipeline, lower coke oven gas air chamber and blast furnace gas air chamber, the sealing of upper air chamber and lower air chamber, partial sealing and fixing of baffle bellows, connection of air duct for main combustion area, and so on. The design and installation of the over-fire air section included: water wall pipe, baffle bellows, outer guard plate, fixing device, bellows, over-fire air body and connecting air duct, repair of water cooling pipe of sealing dust blower needed for the new over-fire air bellows area, and so on. Summary of main reform contents saw table1.

Table 1. Summary of the main reformed contents.

| Reformation project     | Main reformation contents                                                                 |
|-------------------------|-------------------------------------------------------------------------------------------|
| Primary air             | Replace 20 burner nozzles for primary air                                                  |
| Secondary air           | Replace 20 sets nozzles for secondary air                                                  |
| SOFA                    | Remove the original over-fire air and plug it. Add 16 SOFA burner spouts on 4 floors at 7 meters above the main combustion area |
| Coke oven gas           | No reformation                                                                            |
| Blast furnace gas       | No reformation                                                                            |
| Bellows duct            | Expand the original secondary air box and the exhaust air box into a large air box         |
| Water wall              | Add four nozzle screen in SOFA                                                             |

2.3. Benefit analysis
(1) The daily liquid ammonia consumption of the unit was reduced by 1.5 tons, the unit price of liquid nitrogen with tax was 3600 yuan/ton, and the annual operating time was about 330d. The cost of liquid ammonia consumption saved after the completion of the reformation was 1.5×3600×330= 1.782 million yuan
(2) Liquid ammonia was vaporized by heated to 80°C with steam water in bath. The heat of ammonia vaporization was 327.3 kcal/kg. 1.5 tons of liquid ammonia and 0.7 MPa of steam were saved per day. The enthalpy of 0.7 MPa steam was 2837 kJ/kg and the enthalpy for 0.7 MPa steam condensed to water was 340 kJ/kg. The hydrophobic loss along the road was 10%, therefore, it needed to be multiplied by the coefficient of 1.1. Annual steam saving benefit was as follows:

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1.5 \times 327.3 \text{kcal/kg} \times 4.18 \text{KJ/kcal} \div (2837 - 340) \text{ kJ/kg} \times 1.1 \times 100 \times 330 = 29833.3 \text{ yuan.}
\]

(3) The environmental protection index was optimized after NOx concentration reduced. The emission target would be reduced from 100 mg/m³ to 50 mg/m³ and the emission cost would be reduced accordingly. It was expected to reduce the sewage cost of power plants by 700,000 yuan in last year.

(4) The average boiler efficiency increased by 0.58%. Annual saving of coal consumption was 0.58% \times 315 \times 30 \times 24 \times 330 = 4,340 \text{ tons}. According to coal price of 500 yuan/ton, annual economic benefit was 4340 \times 500 = 2.17 \text{ million yuan.}

(5) After reformation, air volume could be reduced by about 49 t/h and current of the blower and induced draft fan could be reduced by about 3A. The saving of electricity consumption in the factory was 6 \times 3 \times 1.732 \times 0.8 \times 4 = 99.6 kW, and the saving benefit of annual electricity was: 99.6 \times 24 \times 330 \times 0.42 = 330,000 \text{ yuan.}

To sum up, after the completed reformation, the efficiency was increased and the annual cost reduction was about 178.2 + 2.98 + 70 + 217 + 33 = 5.012 million yuan.

3. Conclusion
The following effects were produced by operation of the reformed burner:

1. Under the pure coal condition, NOx of the original flue gas decreased from 600 mg/m³ to 220 mg/m³. Under the mixed combustion condition, NOx of the original flue gas decreases from 400 mg/m³ to 170 mg/m³.

2. The boiler efficiency was slightly improved after the reformation. Under pure coal condition, boiler efficiency increased from 92.92% to 93.79%. Under mixed gas combustion condition, boiler efficiency increased from 91.49% to 91.79%.

3. After the reformation, it meets the 2016 national environmental protection standard of NOx 50 mg/m³ for flue gas net emission. The average daily liquid ammonia consumption of the reformed burner unit had been reduced by 1.5 t, and the annual cost of liquid ammonia consumption had been saved by 1.782 million yuan. 1.5 t of liquid ammonia and 0.92 t of 0.7 MPa of steam was saved daily, and 30,000 yuan of steam yearly was saved.

After the reformation of the burner, the emission of nitrogen oxides was reduced without affecting the work efficiency, and the cost of denitration was well controled.

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