Effect of Flue Gas Recirculation on Nitrogen Oxide Emission of Coal-Fired Unit Boiler

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Abstract. Taking the flue gas recirculation system of 220MW coal-fired unit as the test object, effects of the operation mode of the flue gas recirculation system on the operating characteristics of the boiler under different working conditions was studied. The results show: the operation of flue gas recirculation system will suppress the amount of NOx generated in the furnace, and the best way to restrain the formation of NOx is to send the recycled flue gas into the furnace through primary and secondary air simultaneously. The flue gas recirculation system can effectively improve the inlet flue gas temperature of SCR, especially when the secondary flue gas recirculation system is put into operation, and the effect of increasing the inlet flue gas temperature of SCR is obviously better than that of the other two operation modes. The operation of flue gas recirculation system can effectively save net coal consumption.

1. Introduction
Nitrogen oxides are one of the main causes of haze in China in recent years. How to effectively control nitrogen oxides has become one of the most pressing environmental problems. Nearly 70% of the emissions of nitrogen oxides come from direct combustion of coal. About 1.9 billion tons of coal are used for coal-fired power generation in China every year. Therefore, Coal-fired utility boilers become one of the main sources of nitrogen oxide emissions [1-2]. In addition, with the requirement of ultra-low emission and deep peak shaving in recent years, more and more coal-fired utility boilers are limited by SCR operation characteristics and can not operate at low load [3]. Flue gas recirculation refers to the re-introduction of combustion flue gas into the combustion area to control combustion temperature and oxide concentration. Flue gas recirculation technology has been widely used in coal-fired and gas-fired boilers, which can effectively inhibit the formation of nitrogen oxides and improve combustion in the furnace [4]. LEI YU et al [5] found that the application of flue gas recirculation coupled SNCR technology in industrial chain boilers can achieve denitrification efficiency of 56%. Zeng Qiang et al [6] found that flue gas recirculation can significantly reduce the production of NOx in non-premixed gas burners. This paper takes an ultra-high pressure coal-fired boiler as the test object, when the boiler is under low load, the SCR inlet smoke temperature is lower than the design value and cannot participate in the deep peak shaving. To improve the ability of in depth peak load cycling, a flue gas recirculation system was installed on 200 MW boilers.
2. Equipment and Test method

2.1. Equipment Introduction
The type of boiler used as the test object is WGZ 670/13.7-6 pulverized coal boiler. The boiler has five MPS-212 medium-speed pulverizers. The pulverizing system adopts positive pressure direct-blown pulverizing system, and corner tangential firing is adopted. Proximate analysis of coal during the experiment is shown in Table 1.

Table 1. Proximate analysis of coal

| Item     | Mt   | Mad | Aar | Vdaf | St,ad | Qnet,ar |
|----------|------|-----|-----|------|-------|---------|
| Unit     | %    | %   | %   | %    | %     | MJ/kg   |
| Value    | 15.7 | 7.08| 15.01| 37.24| 0.42  | 18.34   |

The flue gas recycling system is shown in Figure 1. The flue gas recirculation system consists of two recirculating pipelines, one is primary air-flue gas recirculation and the other is secondary air-flue gas recirculation. The two pipelines are equipped with a 100% capacity flue gas booster fan. The primary flue gas recirculation fan is a centrifugal high pressure fan with a pressure head of 21.45 kPa and a capacity of 54729 Nm³/h. The secondary flue gas recirculation fan is a centrifugal fan with a pressure head of 9.49 kPa and a capacity of 82080 Nm³/h. The total recirculation flue gas volume is designed according to 15% of the flue gas volume in BMCR. The maximum design flow rate of primary flue gas recirculation is 6% of that in BMCR, and the maximum design flow rate of secondary flue gas recirculation is 9% of that in BMCR. The recirculating flue gas is taken from the position after the induced draft fan and before the desulfurization booster fan.

![Flue gas recycling system](image)

2.2. Test Method
The test is based on GB/T 2015-10184 “Performance test code for utility boiler”. Under the load of 200MW and 140MW, the effects of different flue gas recirculation modes on NOx production, inlet flue temperature of SCR, ammonia injection were studied. The flue gas recirculation system is put into
operation by: Condition A: only the primary flue gas recirculation system; Condition B: only the secondary flue gas recirculation system; Condition C: simultaneous primary/secondary flue gas recirculation system; Condition D: no using the flue gas recirculation system.

3. Test results and Analysis

3.1. Impact of flue gas recirculation system on SCR operation
The mechanism of flue gas recirculation to reduce the formation of nitrogen oxides in the furnace can be summarized as follows: (1) Reducing the oxygen output of the milling system and the supply of primary air can enhance the reducing atmosphere of the main combustion zone, which will reduce nitrogen oxides and inhibit the formation of fuel-type NOx. (2) Increasing the total amount of flue gas in the furnace, reduce the combustion temperature of the furnace which can reduce the formation rate of thermal nitrogen oxides. The effect of flue gas recirculation on the NOx concentration and temperature of the SCR inlet is shown in Figure 2.

Figure 2. Effect of Flue Gas Recirculation on NOx Concentration and Temperature at SCR Inlet

Figure 2(a) shows effect of flue gas recirculation on NOx concentration at SCR inlet, it can be seen that under the load of 200WM, after the primary/secondary combination of flue gas recirculation input, the SCR inlet NOx concentration is reduced from 347 mg/m$^3$ to 244 mg/m$^3$, a decrease of 30%. Compared with the uncommissioned flue gas recirculation system, the primary flue gas recirculation and secondary flue gas recirculation can reduce NOx by 61 mg/m$^3$ and 84 mg/m$^3$, respectively.
respectively, by 17% and 24%; Under the load of 140MW, the influence of flue gas recirculation system on the NOx concentration of SCR inlet is the same as that of 200MW, but the inhibition effect on NOx formation is more obvious, and the maximum reduction can be 172mg/m³, which is 48%.

Fig. 2(b) shows the effect of flue gas recirculation on the inlet flue gas temperature of SCR. It can be seen that all three schemes can increase the inlet flue gas temperature of SCR the effect of secondary flue gas recirculation scheme on the inlet flue gas temperature of SCR is better than that of the other two schemes.

3.2. Impact of flue gas recirculation system on ammonia injection

Based on the test results of Fig. 2 (a) (b), the effect of flue gas recirculation on ammonia injection cost was calculated. The calculation formula is as follows [7].

\[ G_{NH_3} = Q \times \frac{C_{NO_x}}{M_{NO_2}} \times n \times M_{NH_3} \times 10^{-6} \]

Where: 
- \( G_{NH_3} \) — Reagent Consumption, kg/h;
- \( Q \) — Inlet flue gas flow rate of SCR reactor (converted to standard state, dry base, 6% O₂), m³/h;
- \( C_{NO_x} \) — NOx concentration in the flue gas at the inlet of the SCR reactor (converted to standard state, dry basis, 6% O₂), mg/m³;
- \( M_{NO_2} \) — Molar mass of NO₂, g/mol;
- \( n \) — Mole ratio of NH₃/ NOx;
- \( M_{NH_3} \) — Molar mass of NH₃, g/mol;

In the above formula, the molar ratio of NH₃/ NOx is 0.99. The standard flue gas quantity is calculated according to the results of coal quality analysis and oxygen measurement, and then the corresponding recirculating flue gas quantity is added. The calculation result of ammonia injection quantity is shown in Fig. 3.

**Figure 3. Effect of recycled flue gas on SCR ammonia injection**

As can be seen from Fig.3, after putting into operation of flue gas recirculation system, the amount of ammonia sprayed by SCR is obviously reduced. Under 200 MW and 140 MW load, the maximum reduction of ammonia sprayed by SCR is 22% and 39.7% respectively, and the effect of combined operation mode of primary/secondary flue gas recycling is better than that of the other two modes. According to the annual utilization hours of 4500 hours and ammonia cost of ¥ 2400 /ton, the annual ammonia cost can be saved by ¥ 216,000/year.
4. Conclusion
The flue gas recirculation system can obviously improve the operation parameters of the boiler, and the operation mode of flue gas recirculation has different effects on the operation parameters of the boiler. The effect of secondary flue gas recirculation on increasing the inlet flue gas temperature of SCR is obviously better than the other two operation modes; the effect of primary/secondary combined operation mode on inhibiting the formation of NOx in furnace is better than the other two modes.

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