Impact of Flue Gas Recirculation on Operating Performance 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: To a certain extent, the operation of flue gas recirculation system will reduce boiler efficiency, which is more obvious under low load conditions. However, The operation of the flue gas recirculation system can effectively increase temperatures of reheat steam and superheated steam.Comparing the economics of the front and rear units of the flue gas recycling system, it can be find that net coal consumption of the unit under the load of 200MW and 140MW can be reduced by up to 1.51g/kW·h and 1.86g/kW·h respectively.

1. Introduction
Technology of flue gas recirculation has been used in power station boilers to suppress the formation of NOx and increase the reheat steam temperature [1]. Researchers [2-4] found that with the increase of flue gas recirculation, the NOx concentration at the outlet of coal-fired furnace decreased gradually, and the inlet flue gas temperature of SCR was improved effectively, feeding the circulating flue gas from the secondary tuyere into the pulverized coal furnace would further reduce the production of NOx. SUN Junwei et al [5] found that different introduction point of recirculating flue gas can bring different effects, the introduction of recirculating flue gas into the bottom of the furnace can increase the temperature of the reheat steam and the main steam, If the introduction point is the upper part of the furnace, the reheat steam temperature can not be obviously increased and the main steam temperature would be reduced. ZHAO Zhidan [6] found that, for reheat steam temperature control in secondary reheat ultrasupercritical units, flue gas recirculation system can improve the control quality of reheat steam temperature for the control system under various disturbances.In order to improve the flexibility of the #5 unit boiler of a power plant in China, a flue gas recirculation system was designed, This paper aims to fully grasp the effect of flue gas recirculation on operating performance of coal-fired unit boiler.

2. Equipment and Test method

2.1. Equipment Introduction
The boiler is a pulverized coal boiler with ultra-high pressure, one intermediate reheat, natural circulation, single furnace, balanced ventilation, four-corner tangential combustion, solid-state slagging,
and sputum-type arrangement, adopting positive pressure direct blowing pulverizer. It is equipped with five MPS-212 medium-speed coal mills. The main design parameters of the boiler are shown in Table 1.

| Item          | Rated evaporative power | Steam drum pressure | Superheated steam temperature | Reheated steam flow | Reheat steam temperature |
|---------------|-------------------------|---------------------|--------------------------------|---------------------|--------------------------|
| Unit          | t/h                     | MPa                 | ℃                              | t/h                 | ℃                        |
| Value         | 670                     | 15.3                | 540                            | 582                 | 540                      |

The flue gas recycling system is shown in Figure 1. The system delivers flue gas (recirculation flow rate is designed according to 15% of flue gas volume under BMCR conditions) from the outlet of the induced draft fan to the primary and secondary air systems. Each of the two flue pipes is equipped with a flue gas booster fan, which is named primary flue gas recirculation fan and secondary flue gas recirculation fan. The primary flue gas recirculation fan is a centrifugal fan with a design pressure of 21.45 kPa and an air volume of 54,729 Nm$^3$/h. The secondary flue gas recirculation fan is a centrifugal fan with a design pressure of 9.49 kPa and an air volume of 82,080 Nm$^3$/h.

2.2. Test Method
The test is based on Chinese standards GB/T 2015-10184 “Performance test code for utility boiler” [7]. Under the load of 200MW and 140MW, the effects of different flue gas recirculation modes on boiler thermal efficiency, and superheat/reheater outlet steam temperature 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. Equipment and Test method
3.1. Effect of flue gas recirculation on boiler efficiency
The effect of flue gas recirculation on boiler fuel efficiency is shown in Figure 2.
Figure 2. Effect of flue gas recirculation on boiler efficiency

It can be seen from Fig. 2 that under the load of 200 MW and 140 MW, the boiler efficiency is the highest when the flue gas recirculation system is not put into operation, and the combined operation mode of the primary/secondary flue gas recirculation has the greatest negative impact on the boiler efficiency. This is mainly because the heat transferred into the system by the recycled flue gas is less than the heat that is brought out of the boundary, especially when the primary/secondary flue gas recirculation combination is put into operation. In addition, when the flue gas recirculation system is put into operation, the temperature of the recirculated flue gas is higher than the temperature of the cold air, which leads to a decrease in the heat exchange amount of the air preheater and an increase in the exhaust gas temperature [8], which is one of the causes of the decrease in the thermal efficiency of the boiler. Under the load of 200 MW and 140 MW, the operation of flue gas recirculation system will result in a maximum reduction of boiler efficiency of 0.45% and 0.36%.

3.2. Effect of flue gas recirculation on superheat/reheat steam temperature

Under the premise of controlling the same amount of operating oxygen, when the primary flue gas recirculation system is put into operation, the primary air rate is reduced, and a large amount of air enters the furnace from the secondary air or the exhausted wind. Although the outlet temperature of the coal mill has increased, the coal particles ignite in advance, but the burning time of coal particles is prolonged, which causes the location of the furnace flame center to rise, which is conducive to raising the reheat steam temperature [5]. When only the secondary cold flue gas recirculation is put into operation, the opening of the secondary damper is increased, which will cause the temperature level in the furnace to decrease, thereby reducing the amount of radiative heat exchange in the furnace, increasing the convective heat transfer, and increasing the reheat steam temperature [9]. The effects of the flue gas recirculation system on the reheat steam temperature and superheated steam temperature of the unit are shown in Figures 3.

It can be seen from Fig. 3(a) that after the flue gas recirculation system is put into operation, the reheat steam temperature of the boiler is obviously improved, especially when the primary flue gas recirculation is put into operation, under the load of 200 MW and 140 MW, Compared with the condition that flue gas recirculation system un-operated, the reheat steam temperature is increased by 18 ℃ and 25 ℃ respectively. It can be seen from Fig. 3(b) that the flue gas recirculation system also has a significant effect on raising the superheated steam temperature. Under the load of 200 MW, the simultaneous operation of the primary/secondary flue gas recirculation system is most effective for raising the main steam temperature, which can be improved by 14 ℃. Under the load of 140 MW, the operation of secondary flue gas recirculation system can increase the main steam temperature by 16 ℃.
3.3. Impact of flue gas recirculation system on auxiliary power consumption of the boiler

There are two centrifugal fans in the flue gas recirculation system. When the flue gas recirculation system is put into operation, the auxiliary power consumption of the boiler will be affected. The results are shown in Fig. 4.

Figure 4. Effect of flue gas recycling on auxiliary power ratio of boiler

It can be seen from Fig. 4 that when the primary/secondary combined flue gas recirculation system is put into operation at 200 MW and 140 MW loads, the auxiliary power consumption of the boiler side increases by 0.39% and 0.55% respectively.

3.4. Impact of flue gas recirculation on operating efficient performance of the coal-fired unit

Considering the influence of flue gas recirculation on boiler efficiency, reheated steam temperature, superheated steam temperature and auxiliary power consumption rate of boiler, the influence of flue gas recirculation on unit operation economy is calculated based on the uncommissioned flue gas recirculation system under the same load [9]. The results are shown in Table 2 and Table 3.

Table 2. Influences of flue gas recirculation on net coal consumption (200MW)

| Items                                             | Condition A | Condition B | Condition C |
|---------------------------------------------------|-------------|-------------|-------------|
| The influence of various projects on net coal consumption (g/kW·h) |             |             |             |
| Boiler efficiency                                 | 0.16        | 1.48        | 0.38        |
| Superheated steam temperature                     | -1.25       | -1.29       | -0.97       |
| Reheat steam temperature                          | -1.72       | -1.69       | -1.34       |
| Auxiliary Power Consumption Rate                  | 1.30        | 1.35        | 0.89        |
| Total                                             | -1.51       | -0.15       | -1.03       |
Table 3. Influences of flue gas recirculation on net coal consumption (140MW)

| Items                                      | Condition A | Condition B | Condition C |
|--------------------------------------------|-------------|-------------|-------------|
| Boiler efficiency                          | 0.64        | 1.17        | 0.45        |
| Superheated steam temperature              | -1.42       | -1.35       | -1.58       |
| Reheat steam temperature                   | -2.37       | -2.16       | -1.81       |
| Auxiliary Power Consumption Rate           | 1.30        | 1.90        | 1.10        |
| Total                                      | -1.85       | -0.43       | -1.86       |

As can be seen from Tables 2 and 3, comparing the economics of the front and rear units of the flue gas recycling system, it can be find that net coal consumption of the unit under the load of 200MW and 140MW can be reduced by up to 1.51 g/kW·h and 1.86 g/kW·h respectively.

4. Conclusion

(1) 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 primary flue gas recirculation on increasing reheated steam temperature is the best.

(2) Flue gas recirculation can effectively improve the unit's economy. Under 200 MW and 140 MW load, the net coal consumption can be saved up to 1.51 g/kW·h and 1.86 g/kW·h.

References

[1] LEI Xiaoyun. Study on calculation method of flue gas recirculation [J]. Energy Base Construction, 1994 (6): 52-54.
[2] HU Manyin, QIAO Huan, DU xin, etal. Numerical simulations of the influence of flue gas recycle on nitrogen oxide formation in boiler [J]. Journal of North China Electric Power University, 2007, 34 (6): 77-82.
[3] LIN Luhui. The Study of Operation Characteristics of Coal-fired Boilers on Conditions of Flue Gas Recirculation [D]. North China Electric Power University, 2018.
[4] WANG Xihong. Study on reducing NOx emission by using flue gas reflux method [J]. Petrochemical Equipment Technology, 2017, 38 (3): 26-32.
[5] SUN Junwei, DAI Weibao, YAN Weiping. Influence of Different Flue Gas Recirculation Schemes on 1000 MW Ultra-supercritical Double Reheat Boiler [J]. JOURNAL OF ENGINEERING FOR THERMAL ENERGY AND POWER, 2019, 34 (5): 49-56.
[6] ZHAI Zhidan, HAO Defeng, WANG Haitao, etal. Double reheat ultra-supercritical unit reheat steam temperature control [J]. Thermal Power Generation, 2015, 44 (12): 113-118.
[7] GB/T 2015-10184. Performance test code for utility boiler [S]. National Energy Agency of China. 2015.
[8] GAO Jilu, ZOU Tianshu, WU Jingxing, etal. Analysis on Retrofit for Blending Cold Flue Gas into Coal Pulverizing System of an 800MW Unit [J]. POWER EQUIPMENT, 2013, 27 (1): 20-23.
[9] DL/T 904-2015.Calculating method of economical and technical index for thermal power plant [S]. National Energy Agency of China. 2015.