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Sensitivity Analysis and Optimization of a Coal-Fired Power Plant in Different Modes of Flue Gas Recirculation

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Abstract

In a coal-fired power plant with flue gas recirculation, recirculation rate and coal input have a great effect on the performance of the power plant. In this paper, a 600 MW coal-fired boiler is taken as base case, the main parameters of the boiler are calculated at different recirculation rates and coal input conditions, an optimization is carried out and the optimum recirculation rate and coal input are reported. The results show that under optimum recirculation rate and coal input conditions, the net coal consumption rate can be reduced by 3.5g/(kW·h) at 575MW load; while it is 4.36g/(kW·h) and 5.11g/(kW·h), respectively, at 450MW load and 300MW load. Compared to the conventional flue gas recirculation system, the net coal consumption rate can be reduced by 2.31 g/(kW·h), 2.42 g/(kW·h) and 2.41 g/(kW·h), respectively, at 575MW, 450MW and 300MW load.

Key Words: sensitivity analysis, optimization, reheat steam temperature, net coal consumption rate, recirculation rate

1. Introduction

A flue gas recirculation system is used to extract the flue gas from the tail of the boiler and lead it back into combustion chamber, which can change the velocity and the temperature of the whole flue gas, and further will change the heat transfer rate of the radiant heating surface and convection heating surface. Studies show that, per 1% recirculation gas can increase reheat steam temperature by 2K[1]. Besides, recirculation gas can prevent the super heater from slagging, and reduce the formation of NO_x.

In a flue gas recirculation system, there are many parameters that have an effect on thermal efficiency in practical operation, such as the recirculation rate, coal input, steam flow and so on. At present, many scholars have researched the flue gas recirculation. Zhengwu Xie[2]researched the function of flue gas recirculation and its effect on thermodynamic calculation; Daolin Li[3]analyzed the influence of flue gas recirculation on steam temperature, heat transfer and net coal consumption rate through experiment; but the research on the optimization of recirculation rate and coal input under variable work conditions is rare. In this study, the thermal calculation under different recirculation rate and coal input is carried out in a proposed flue gas recirculation system. The impact of recirculation rate and coal input on performance of the boiler is analyzed and the optimum recirculation rate and coal input are achieved under different load conditions.

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2. Optimization method

2.1 The improved flue gas recirculation system

Guigang Power Plant is the based case in this study, whose turbines are 600MW supercritical condenser steam units of single intermediate reheat and single-shaft. The case study of the power plant with different recirculation locations was presented in Ref. [4]. The main results of the case study are listed in the Tab. 1, based on which the sensitivity analysis will be performed in this study.

Tab.1 The performance comparison of two CASE

Load	Items	CASE1	CASE2
575 (MW)	Exhaust gas temperature (°C)	154.2	158.4
	Boiler efficiency (%)	0.8534	0.8511
	Turbine power (MW)	605.3	611.5
	Net coal consumption rate (g/kWH)	333.84	333.04
450 (MW)	Exhaust gas temperature (°C)	146.3	148
	Boiler efficiency (%)	0.8533	0.8561
	Turbine power (MW)	471.9	477.3
	Net coal consumption rate (g/kWH)	331.55	330.8
300 (MW)	Exhaust gas temperature (°C)	135.7	137.4
	Boiler efficiency (%)	0.8463	0.8421
	Turbine power (MW)	319.5	324.6
	Net coal consumption rate (g/kWH)	358.6	357.43

CASE1: The conventional flue gas recirculation; CASE2: The proposed flue gas recirculation

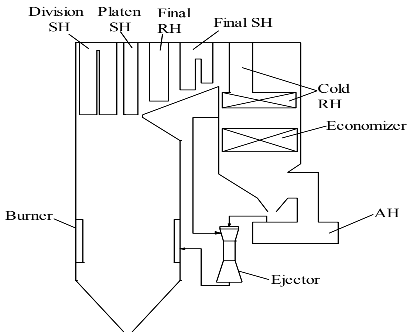

Fig.1 The diagram of boiler structure

2.2 Calculation model

Radiation heating surface calculation steps: 1) Assuming the outlet of the flue gas temperature of furnace; 2) According to the radiation heat transfer parameter of furnace heating surface, calculating flue gas temperature of the furnace outlet; 3) Check the temperature difference of furnace outlet.

Convection heating surface calculation steps: 1) Assuming flue gas outlet temperature, and calculating the convection heat transfer (Q_1); 2) Based on the thermal balance principle, calculating outlet temperature of steam, logarithmic mean temperature difference and convection heat transfer coefficient; 3) Calculate the convection heat transfer (Q_2), compared with Q_1, the difference should be within the allowable range; otherwise repeat the above calculation.

2.3 Optimization steps

The main parameters in this calculation model are coal input and recirculation rate whose optimization steps are as follow: 1) Changing the recirculation rate at a certain coal input and obtain the optimal recirculation rate with minimum coal net coal input rate; 2) Changing the coal input under the optimal recirculation rate and obtain the optimal coal input with minimum coal net coal input rate

3. The optimization results

In practical application of flue gas recirculation, a 1% rise in recirculation rate will add 1.47~1.92°C to reheat steam temperature[3], the exhaust gas temperature will increase 0.7~2.1°C[3] for each 1% recirculation rate while the net coal consumption rate reduces 0.1~0.52 g/(kW·h)[3]. In this calculation model, the reheated steam temperature increases 2~2.3°C for each 1% recirculation rate while the exhaust temperature increases 0.63~1.17°C, and the net coal consumption rate reduces 0.11~0.98 g/(kW·h). Because of the higher temperature of the recirculation gas in this improved system, the whole flue gas temperature and velocity increase as well, so the heat absorption of the steam increases. However, a blower's power consumption almost remains the same because it mainly depends on the recirculation gas volume. Thus there are some differences between the model and the experiment, but judging from these calculations, the model is reasonable.

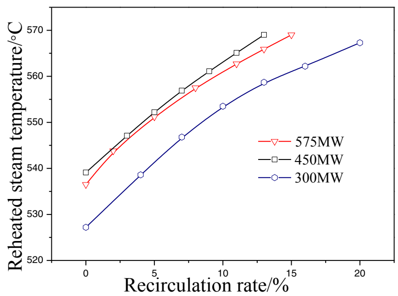

Fig.2 Reheat team temperature

3.1The influence on reheated steam temperature of different recirculation rate

It can be seen in Fig.2 that the reheat steam temperature rises with the ascending of the recirculation rate. This is because the higher recirculation rate results in an increase of the gas velocity and the heat transfer coefficient, and the reheater's convective heat absorption increases as well. As Fig.2 shows, the gradient of the curves declines with the increase of recirculation rate, that is to say, with the increase of recirculation rate, the contribution of each 1% recirculation gas to the temperature rise of reheat steam drops. Although, the gas velocity and heat transfer coefficient increase with ascending recirculation rat, the flue gas temperature decreases, so that the increment of reheat steam temperature decreases.

3.2 The change of exhaust gas temperature for different recirculation rates

As mentioned above, an increase of the recirculation rate leads to an increase of gas velocity, but the flue gas temperature decrease, so that the heat absorption and recirculation rate do not possess linear relationships. On the contrary, the increment of heat absorption decreases. Besides, with the increase of recirculation rate, the heat absorption in the furnace and the amount of vapor decreases which leads to the increase of coal input. In a sense, an increase of the recirculation rate leads to an increase of the excess air factor. Thus, exhaust gas temperature increases. The temperature of exhaust gas under different loads and different flue gas recirculation rate is shown in Fig.3.

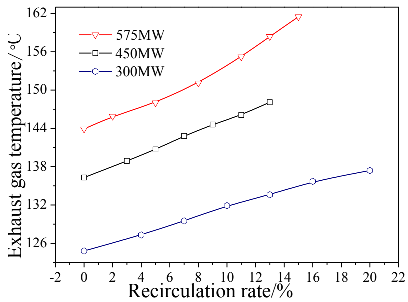

Fig.3 The exhaust gas temperature

3.3 The influence on thermal efficiency of different recirculation rate

The improved recirculation system adopts ejectors[4], so that the plant internal service power consumption rate increases as the recirculation rate increases. At the same time, the decrease of boiler efficiency increases the consumption of coal. Due to the increase of reheat steam temperature, the turbine power increases as well which leads to the decrease of net coal consumption rate. As Fig.4 shows, at the same load, with the increase of recirculation the net coal consumption rate reduces first and then increases. At 575MW load, the optimum rate is 8%, while it is 11% and 10%, respectively, at the load 450MW and 300MW.

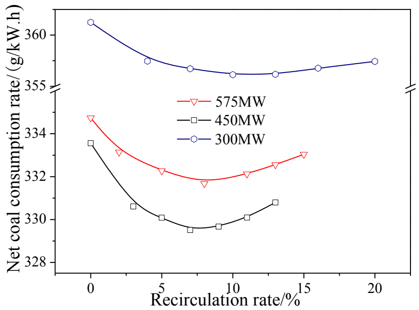

Fig.4 Net coal consumption rate

3.4 The influence of different coal input on steam temperature

At the same recirculation rate condition, a change of coal input will change the net coal consumption rate. To achieve the optimum coal input, the thermodynamic calculation was carried out based on the optimum recirculation of different coal input.

According to the steam temperature characteristics of the convection superheater, the gas velocity and heat transfer coefficient on the flue gas side increases with the increase of coal input. Besides, the flue gas temperature increases as well, which increases the temperature difference of heat transfer, thus heat absorption increases and the reheated steam temperature increases.

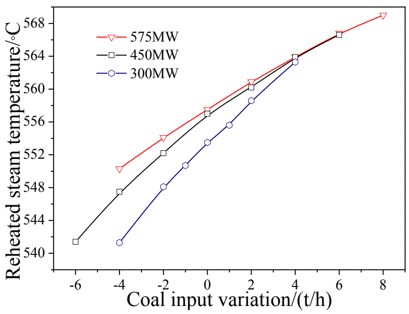

Fig.5 Rheated steam temperature

3.5 The exhaust gas temperature for different coal input

As explained above, an increase of coal input leads to an increase of gas velocity and heat transfer coefficient. Besides, the flue gas temperature increases which increases the temperature difference of heat transfer. Thus the increment of heat absorption of convection surface is larger than the increment of coal input. Compared to the recirculation rate, the increment of exhaust gas temperature caused by the change of coal input is smaller.

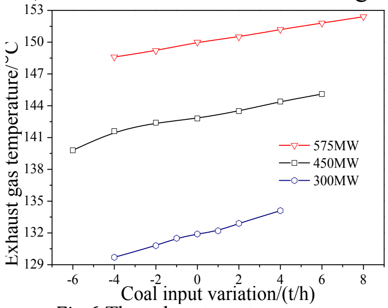

Fig.6 The exhaust gas temperature

3.6 The influence of different coal input on thermal efficiency

The increase of coal input can increase the steam temperature, the turbine power and reduce the net coal consumption rate. As is shown in Fig.7, with the increase of coal input, the net coal consumption rate reduces at first, when the main steam temperature reaches the designed value, if the coal input increases continuously, spray desuperheating water is raised to control the superheated steam temperature. Thus the increment of turbine power decreases which results in the increase of the net coal input rate. At 575MW load, the optimum recirculation rate and increment of coal input are 8% and 2t/h(0.74%), which can reduce net coal consumption rate by 3.5g/(kW·h); while it is 7% and 2t/h(0.98%) at 450MW load, which reduce net coal consumption rate by 4.36g/(kW·h); 10% and 0t/h(0%) at 300MW load , which reduce net coal consumption rate by 5.11g/(kW·h).

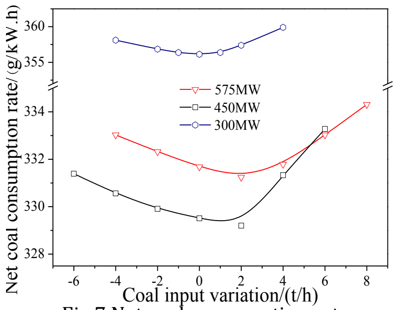

Fig.7 Net coal consumption rate

4. Conclusion

A 600MW coal-fired boiler with different recirculation rate and coal input was studied. The impact of recirculation rate and coal input on performance of the boiler is analyzed and the optimum recirculation rate and coal input are achieved under different load conditions. Under different load conditions, the reheat steam temperature increases with the increase of recirculation rate and coal input, while the net coal consumption rate reduces first and increases then. That is to say, there is an optimum recirculation rate or coal input corresponding to a minimum net coal consumption rate. At 575MW load, the optimum flue gas recirculation rate and coal input increment are 8% and 2t/h which reduce the net coal consumption rate by 3.5 g/(kW·h); while it is 4.36g/(kW·h) at 450MW load, with 7% flue gas recirculation rate and 2t/h coal input increment; and 5.11g/(kW·h) at 300MW, with 10% flue gas recirculation rate and 0t/h coal input increment.

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Biography

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