

Effect of Flue Gas Recirculation on Reheated Steam Temperature of a 1000MW Ultra-supercritical Double Reheat Boiler

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Abstract. In view of the problem that the reheat steam temperature is lower than the design value in the operation of a 1000MW ultra-supercritical double reheat boiler in a power plant, this paper puts forward the method of flue gas recirculation (FGR) to improve it. Two schemes are put forward: the extraction of flue gas from the economizer or the draft fan to the bottom burner of the furnace. In different load conditions, using the standard method of boiler thermodynamic calculation, the influence of different FGR schemes on boiler operation parameters is calculated. The results show that above FGR schemes can obviously improve the reheat steam temperature; with the increase of the amount of recirculating gas, the rise of the reheat steam temperature increases; with the decrease of the load, the influence of FGR on steam temperature increases; the scheme of extracting recirculating flue gas from the economizer outlet has little effect on the boiler efficiency, which is more suitable for the boiler, and the reasonable FGR rate is about 10%.

1. Introduction

In response to the requirements of the current national exploration and promotion of efficient clean coal and electricity technology, the ultra-supercritical double reheat power generation technology is being paid more and more attention [1-3]. The units with the ultra-supercritical double reheat technology can increase the thermal efficiency by about 2% more than the single reheat unit [4]. But the reheater series and the reheat steam heat absorption of the double reheat boiler have both increased, Yan et al. [5] pointed out that because of the double reheat technology, the heat absorption ratio of 1000MW capacity unit's superheated steam decreased and the reheat steam's heat absorption proportion increased. That makes the structure of the thermal system of the double reheat unit more complex, and the coordinated control of the reheat steam becomes more difficult. And it may lead to the phenomenon that the reheat steam temperature is lower than the design value when the unit is running, which reduces the operation economy of the unit.

In view of the difficulty of the problem of the reheat steam temperature of the double reheat unit below the design value. Many scholars have carried on the related research. Dang et al. [6] has studied the problem of low reheat steam temperature of the 660MW ultra-supercritical boiler by remoulding the heating area of reheater. Zhang et al. [7] has studied the effect of FGR on reheat steam temperature and set a 600MW single unit as an example to calculate. In summary, the transformation of reheater



heating area and the use of FGR can effectively solve the problem of low temperature of reheat steam, but the method of remodeling the heating area of reheater is influenced by the structure and layout of the boiler.

Therefore, based on the original temperature regulation methods of reheat steam, flue gas recirculation is proposed to increase reheat steam temperature in this paper. Two FGR schemes are developed for the different extraction points of recirculating flue gas and will be adopted to calculate thermodynamic parameters of boiler, and then the effect of different recirculation rate will be analyzed to obtain a reasonable scheme.

2. Overview of the boiler and FGR schemes

This is a 1000MW ultra-supercritical double reheat tower boiler. The temperature regulation methods of reheat steam are swing nozzle and flue gas baffle. The main design parameters of the boiler are shown in table 1.

Table 1. Main design parameters of the boiler. SUP: superheated steam outlet pressure; SUT: superheated steam outlet temperature; SIP: single-reheated steam outlet pressure; SIT: single-reheated steam outlet temperature; SEP: secondary reheated steam outlet pressure; SET: secondary reheated steam outlet temperature; BMCR: boiler maximum continuous rating; THA: turbine heat-acceptance.

Load	SUP (MPa)	SUT (°C)	SIP (MPa)	SIT (°C)	SEP (MPa)	SET (°C)
BMCR	33.03	605	11.17	613	3.30	613
75%THA	23.12	605	7.55	613	2.24	613

2.1. Problems in operation

The temperature of single-reheated and secondary reheated steam are lower than the design value under the actual working conditions. The specific parameters are shown in table 2.

Table 2. The steam temperature of the operation condition. DV: design value; RV: runtime value.

Load	SIT		SET	
	DV(°C)	RV(°C)	DV(°C)	RV(°C)
BMCR	613	605.8	613	613
75%THA	613	595.3	608.7	594.5

2.2. The principle of FGR

The principle of the FGR technology of steam temperature regulation: The gas recirculation fan extracts a part of low temperature flue gas from the outlet of the economizer or induced draft fan and sends into the furnace. Thereby, it reduces the level of flue gas temperature inside the furnace and increases the amount of the flue gas in the furnace. Finally, the reheater and other heat exchangers can be enhanced and the reheat steam temperature is improved.

2.3. Concrete scheme of flue gas recirculation

According to the structure of the boiler and the arrangement of the heating surface, the following FGR schemes are formulated:

Scheme 1: the recirculating flue gas is extracted from the exit of coal economizer and sent to the bottom of the burner at the bottom of the hearth.

Scheme 2: the recirculating flue gas is extracted from the outlet of the induced draft fan and sent to the bottom of the burner at the bottom of the hearth.

The different FGR extraction locations correspond to different gas temperatures. The gas temperature from the economizer outlet is about 379 degrees, and the gas temperature from the outlet of the draught fan is about 117 degrees. The FGR schemes are shown in Figure 1.

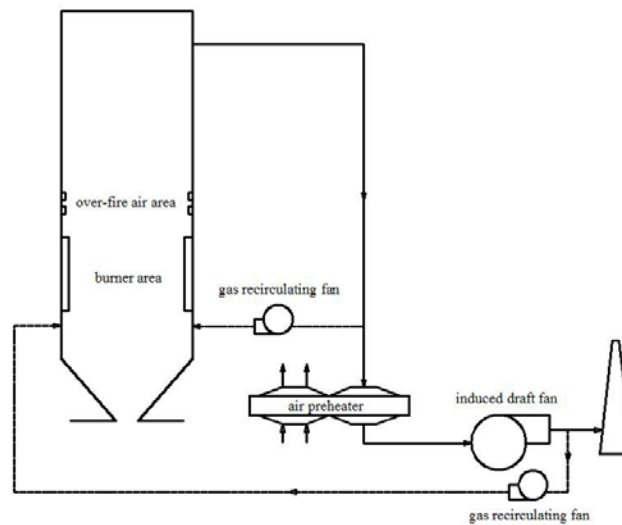


Figure 1. Schematic diagram of the recirculating flue gas extraction positions.

In view of above FGR schemes, under the BMCR and 75%THA load conditions, this paper calculated and analyzed the influence of different schemes on boiler parameters when there was no recirculation, 5%, 10% and 15% FGR rate.

3. The thermodynamic calculation method for boiler with FGR

According to the standard method of thermal calculation of boiler unit, the thermal calculation of boiler unit is realized through VB software programming. Because of the use of FGR, the flue gas volume, composition and gas enthalpy from the return point to the extraction place have changed. When the boiler thermodynamic calculation is carried out, it is necessary to recalculate the gas characteristic parameters and the enthalpy of the flue gas.

The volume and enthalpy of mixed flue between the return point and the exit point are:

$$V_r = V + r * V_c \quad (1)$$

$$I_r = I + r * I_c \quad (2)$$

Where, V is the flue gas volume (m^3kg^{-1}); r is the FGR rate (%) and I is the flue gas enthalpy (kJkg^{-1}).

Then, the flue gas temperature after mixing is solved:

$$\theta_r = I_r / (VC)_r \quad (3)$$

Where, θ_r is the mixed flue gas temperature ($^{\circ}\text{C}$); $(VC)_r$ is the average thermal capacity of the mixed flue gas ($\text{kJ}(\text{kg}^{\circ}\text{C})^{-1}$).

It is necessary to pay attention to the amount, the flow rate and the characteristics of flue gas and the parameters of the enthalpy meter should be based on the actual flow of flue gas after mixing the heated surface.

4. Results and discussions

4.1. Comparison of the results of flue gas recirculation schemes under the BMCR load condition

The influence of the ratio of different recirculation flue gas on the theoretical combustion temperature, the flue gas temperature of the furnace outlet, the temperature of the single-reheated and secondary reheated steam are shown in the following figures.

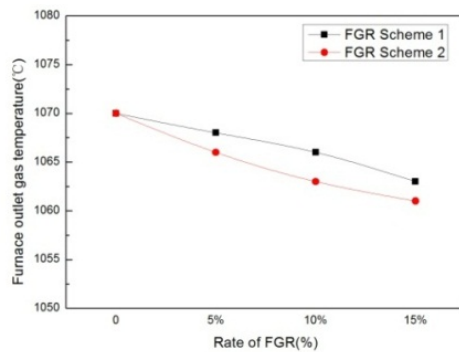


Figure 2. Furnace outlet gas temperatures under the BMCR load.

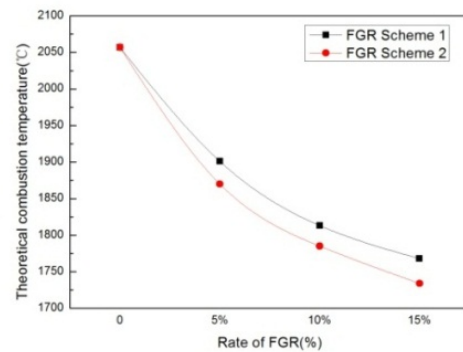


Figure 3. Theoretical combustion temperatures under the BMCR load.

As shown in the figures, the two schemes put the low temperature flue gas into the bottom area of the furnace, which will have an impact on the combustion and heat transfer in the boiler furnace. And the final result is that the furnace outlet gas temperature will decrease. Compared with the two schemes, the flue gas extraction point of scheme2 is the induced draft fan, which results in a lower gas temperature. For every 1% increase in recirculation rate, the furnace outlet of scheme 1 is reduced by 0.4°C and the theoretical combustion temperature reduced by 25°C, while scheme 2 reduced by 0.6°C and 28°C.

Due to the increase of flue gas volume and flue gas flow velocity on the convection heating surface, the flue gas heat release coefficient and convective heat transfer increase, which eventually leads to the rise of the temperature of the outlet working medium.

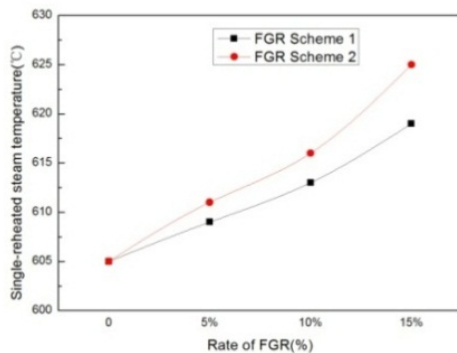


Figure 4. Single-reheated steam temperatures under the BMCR load.

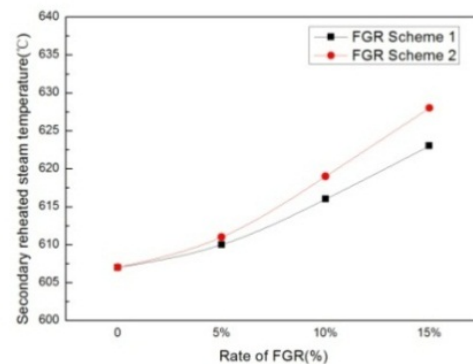


Figure 5. Secondary reheated steam temperatures under the BMCR load.

Figure 4 and 5 show that for every 1% increase in recirculation rate, the single-reheated steam temperature of scheme 1 increased by 0.8°C; the secondary reheated steam temperature increased by 1°C, while scheme 2 increased by 1.2°C and 1.4°C.

4.2. Comparison of the results of flue gas recirculation schemes under the 75%THA load condition

The influence of the ratio of different recirculation flue gas on the above parameters under 75%THA load condition is shown in the following figures.

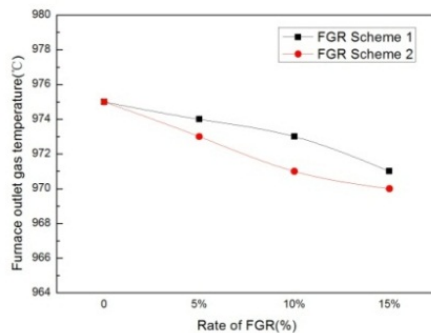


Figure 6. Furnace outlet gas temperatures under the 75%THA load.

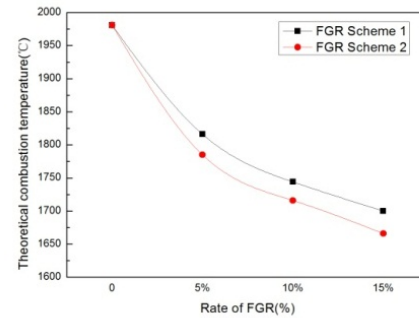


Figure 7. Theoretical combustion temperatures under the 75%THA load.

Figure 6 and 7 show that under the 75%THA load, for every 1% increase in recirculation rate, the furnace outlet gas temperature of the scheme 1 decreased by 0.2°C and the theoretical combustion temperature decreased by 23°C, while scheme 2 decreased by 0.4°C and 26°C.

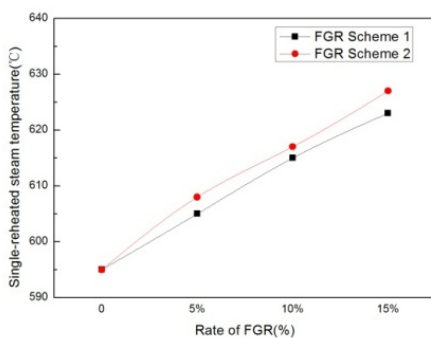


Figure 8. Single-reheated steam temperatures under the 75%THA load.

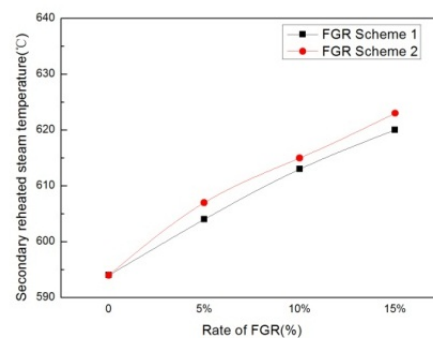


Figure 9. Secondary reheated steam temperatures under the 75%THA load.

Figure 8 and 9 show that under 75%THA load, for every 1% increase in recirculation rate, the single-reheat steam temperature of scheme 1 increased by 2°C and the secondary reheated steam temperature increased by 1.8°C, while scheme 2 increased by 2.2°C and 2°C.

The above results show that under the condition of BMCR and 75%THA load, when the FGR rate is about 10%, scheme 1 and 2 can make the steam temperature of single-reheated and secondary reheated reach the design value. With the increase of recirculation ratios, the drop of the furnace outlet gas temperature and the rise of reheated steam temperature are increased. And at low load conditions, the influence of the recirculation of the flue gas on the reheated steam temperature is increased. Compared with the scheme 1, the exhaust gas temperature of scheme 2 increased, and the boiler efficiency decreased. Therefore, the scheme 1 is more suitable for this boiler's FGR scheme.

5. Conclusion

Through the above calculation and analysis, this paper draws the following conclusions:

The reheat steam temperature of the double reheat boiler can be significantly improved by the FGR scheme of sending the recirculating flue gas into the bottom of the furnace. With the increase of the amount of recirculating flue gas, the rise of reheated steam increases and with the decrease of load, the influence of recirculating flue gas on reheated steam temperature increases. The scheme of extracting flue gas into the bottom of the furnace from the economizer is the suitable FGR scheme for the boiler, and the reasonable FGR ratio is about 10%, which can provide a reference value for solving the low boiler reheat steam temperature and the operation optimization of the unit.

References

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