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Thermodynamic Calculation and Optimization of Thermal Power Boiler Based on Flexible Equilibrium Analysis Method

Aixia Duan*[a], Jinmei Wu[b], Yongzhi Huang[c]

[ab]North China University of Water Resources and Electric Power, Henan 450045, China
[c]China Resources Power Rundian Energy Science and Technology Co.,Ltd., Henan 450011, China
dax0307@163.com

In order to study thermal calculation and optimization scheme of thermal power boiler, through the flexible use of equilibrium analysis method, the practical problems brought about by too high exhaust gas temperature of thermal power boiler are studied. Through the thermodynamic calculation, the thermal calculation simulation is carried out under 95%, 85%, and 60% three kinds of operational loads for boiler after after low temperature reheater retrofit optimization and heating surface increase. In addition, it is compared with the calculation parameters under the corresponding condition before the transformation. The results show that the increase of low temperature reheater area can increase the low temperature reheater heat absorption, and make the reheat steam humidity improved significantly. At the same time, the flue gas baffle is adjusted and the gas ratio on the side of overheating is increased. As a result, we can effectively alleviate the serious uneven reheat and super-heat side baffle opening for a long time. However, low temperature reheater outlet flue gas temperature and economizer inlet gas temperature can be significantly reduced because of the transformation and optimization of low humidity reheater. It is conclude that the final temperature of flue gas has not been significantly reduced, which only completed part of requirement for the exhaust gas temperature reduction.

1. Introduction

Since the thermal power boiler has been put into operation, the temperature of exhaust gas has been higher than the designed value. During the great load in summer, the highest temperature is above 180 degrees Celsius, and even in winter, the load is more than 85%, and the exhaust gas temperature still reached 150 degrees Celsius. At the same time, the unit has the problem of insufficient reheat steam temperature in the lower load. When the load is lower than 85% and flue gas regulating baffles on the reheater side are all open, the opening of flue gas regulating damper on the super-heater side, at the limit around 40%, the reheat steam temperature is still lower than the main steam temperature for 5-8 degrees Celsius. The high exhaust temperature not only reduces the boiler efficiency, but also seriously affects the safe operation of the bag filter. The normal running temperature of bag filter is not higher than 160 degrees Celsius, and the maximum is not more than 170 degrees Celsius (Adamczyk et al., 2014). At present, a boiler is equipped with more than 7200 filter bags A filter bag is about 800 yuan, and it is needed to be replaced, it needs nearly 5.8 million. Once the filter bag is scrapped in advance, the maintenance cost is great. In addition, the high flue gas temperature has a negative impact on the desulfurization equipment. The factory has a wet desulfurization device, and in order to ensure the absorption tower corrosion resistant material intact, it also requires that the flue gas temperature cannot exceed 180 degrees Celsius, otherwise it is necessary to spray water cooling. The low temperature of reheat steam leads to the decrease of the unit economy, and the increase of steam humidity at the last stage of the steam turbine affects the safe operation of the steam turbine and reduces the service life. At the same time, in order to maintain the reheat steam temperature, the flue gas baffle in the tail flue is always fully opened at the reheat side, and in the extreme state the superheated side half opened, it weakens the effect of regulating the flue gas temperature. To this end, the power plant, for the insufficient reheat steam temperature and the problem of high gas temperature, puts forward the reform scheme (Antonucci, 2017). Considering increasing the low-temperature reheater area, it is expected to increase the absorption amount of low temperature reheater, thereby improving the reheat steam temperature. And it also reduces the heat

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absorption proportion of separated flue, and improves the final flue gas temperature. Moreover, it is expected to make a feasibility evaluation of the transformation with the help of heat calculation program. In this paper, with a power plant thermal power boiler as the research object, aiming at the efficiency reduction of the boiler based by too high flue gas temperature, practical problems such as insufficient reheat steam temperature, poor dedusting equipment operation safety and so on are studied. And through the thermodynamic calculation, the optimization scheme is proposed,which has a certain essential significance.

2. Method

2.1 Thermal balance calculation method of thermal power boiler

The boiler heat balance refers to the balance between the heat input of the boiler and the output heat of the boiler. The heat input mainly comes from the combustion of the fuel, and the output heat includes the effective heat utilization and the heat losses used to generate steam. Each heat loss is calculated according to the corresponding formula or the recommended data. Corresponding to the 1Kg fuel, the following equilibrium equation can be listed, namely:

$$Q_r = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \tag{1}$$

In the above formula, Q_r suggests the heat brought about by 1kg fuel into the furnace, and the unit is KJ/kg; Q_1 represents the effective utilization energy of boiler, and the unit is KJ/kg; Q_2 refers to the smoke loss, and the unit is KJ/kg; Q_3 means chemical incomplete combustion loss, and the unit is KJ/kg (Euh et al., 2016); Q_4 is a solid incomplete combustion loss, and the the unit is KJ/kg; Q_5 is the heat loss, and the unit is KJ/kg; Q_6 is the physical heat loss of slag, and the unit is KJ/kg.

For coal-fired power boilers, compared with ordinary pulverized coal boiler, due to the existence of desulfurization effect, $CaCO_3$ calcined into CaO needs to absorb heat. While the CaO and SO_2 reaction to generate $CaSO_4$ needs to release heat, which should be considered. In this paper, we use the unit equivalent amount of fuel for the weighted average simplification, as shown in (2):

$$Q_{ar}^{D} = \frac{Q_{net,ar} + Q_T \quad Q_A}{1 + B_d} \tag{2}$$

In the formula, Q_{ar}^{D} suggests the thermal heat power can be controlled, KJ/kg;$Q_{net,ar}$ indicates fuel received base low calorific value, KJ/kg; Q_T is desulfurization heat release, KJ/kg; Q_A refers to the absorption amount when limestone burns to generate CaO, KJ/kg; B_d means the limestone quantity into the furnace matched with 1kg fuel, kg/kg. On the basis of the heat balance equation, the boiler thermal efficiency and fuel consumption can be calculated.

2.2 Calculation method of boiler ash balance in thermal power plant

Ash balance is one of the key data of circulating fluidized bed boiler heat calculation. The largest feature of thermal power boiler is fly ash of small size produced by combustion entering the flue tail with the flue gas. While large particle ash, through the separator, returned to the furnace and became a circulating ash. This process will undoubtedly increase the difficulty of the calculation of ash balance. The assumption of ash balance calculation is that the share of ash remains unchanged in a certain period of time when the boiler is in stable operation, which is consistent with the actual situation. And the circulating ash enthalpy and fly ash concentration in flue gas can be calculated. In order to facilitate the calculation, the circulation ratio α_n of ash is defined as:

$$\alpha_n = \frac{B_s}{F_G} = \frac{B_s}{BA_{ar}} \tag{3}$$

In the above formula, α_n is the ash circulating ratio, and B_s means the circulating ash, kg/h; F_G suggests the ash into the furnace, kg/h; B represents the furnace fuel consumption, kg/h; A_{ar} refers to the base ash received by fuel, % (Ma et al., 2015).

2.3 Optimization scheme of boiler low temperature reheater

Low temperature reheater tube, through the fixed block, is fixed on the tail bag wall, which expands together with the wall. The low temperature reheat steam introduces the low-temperature reheater inlet header from both ends. And flue gas counter-current flows upward through the low temperature reheater tube into the low-temperature reheater outlet header, and extracts from both ends of the outlet header.

Low temperature reheater is composed of three groups of four rings around a horizontal tube along the width direction of the furnace body, which is in the in-line and counter-current arrangement. The pipe diameter is 70mm, and the conventional wear protection measures are adopted. Each pipe section entrance and the wall are arranged with orifice plate to prevent gas drift, and the windward side on the first row of tubes adopts abrasion proof cover.

The optimization scheme and the data are supplied by the power plant: increase the heating surface of a parallel layout in the original low temperature reheater outlet section. Through the actual measurement, the increased low temperature reheater tube is about 9.56m in length, thus increasing the heating area of 857 square meters (Ma et al., 2013).

After increasing the heating surface of the low temperature reheater, its heat absorption increases, and finally the reheated steam outlet temperature rises. It is estimated that reheat steam can be increased by more than 14 degrees under the condition that the opening of the flue gas damper is constant. Considering the actual needs of the project, the flue gas damper should be adjusted to reduce the share of the reheat side flue gas and ensure the reheat steam temperature to meet the design requirements, that is, the main steam temperature.

3. Results and discussion

3.1 Thermal calculation of boiler under different conditions before and after optimization

Through the checking of thermal data calculation program of the designed data, combining with the data provided by the power plant and DSC interface operation parameters of thermal power boiler groups, the 300MW thermal power boiler in the actual operation conditions are simulated. Table 1~ Table 3 are the thermal calculation tables for boiler in 95%, 85%, and 60% operating conditions.

Table 1: Thermal calculation table of boiler 95% running condition

Items	Inlet temperature of flue gas	Outlet temperature of flue gas	Inlet temperature of working medium	Outlet temperature of working medium	Total heat absorption	Flue gas heat release
Symbols	T_{in} (°C)	T_{out} (°C)	t_{in} (°C)	t_{ou} (°C)	Q (KJ/kg)	Q_v (KJ/kg)
Fire-pot	—	905.5	352.1	352.1	7575.5	7557.6
Separator	905.5	880	352.1	367.6	772	775.3
Cladding wall super-heater	880	—	367.6	379	435.6	—
Low temperature super-heater	669.2	504.1	379	400	601.5	604.1
Platen super-heater	—	—	394	509.1	2014	—
High temperature super-heater	831.3	669.2	499	539	614.9	617.5
Low temperature reheater	859.8	555.5	326.1	455.2	1286.9	1292.5
Platen reheater	—	—	455.2	537.4	739.7	—
Economizer	531.3	332	279.2	333.5	1489.5	1496
Air preheater	332	167.6	38.2	240	1169.1	1174.2

In the above calculation table, the inlet and outlet temperature of flue gas side and water side in all heating surfaces accord with the operation condition. The error between the heat absorption on each heating surface and the corresponding heat deviation is in the range of error. As a whole, it meets the requirements, which reflects the actual situation of the unit to the maximum, and the problems of insufficient reheat steam temperature and too high exhaust gas temperature are reflected, which has high reference value.

Thus, on the basis of previous operation simulation platform, after increasing low-temperature reheater area, first of all, modified calculation is carried out for heat balance for the low temperature reheater. Then, flue gas on the reheating and overheating sides is regulated to ensure that the reheat temperature is maintained in the main steam temperature (Pan et al., 2015). Next, we calculate the exchanger parameters of super-heater after calculating the flue gas share, economizer, and air preheater. Finally, we can get the operation parameter after transformation on the corresponding working condition.

Table 2: Thermal calculation table of boiler 85% running condition

Items	Inlet temperature of flue gas	Outlet temperature of flue gas	Inlet temperature of working medium	Outlet temperature of working medium	Total heat absorption	Flue gas heat release
Symbols	T_{in} (°C)	T_{out} (°C)	t_{in} (°C)	t_{ou} (°C)	Q (KJ/kg)	Q_v (KJ/kg)
Fire-pot	—	857	351.7	351.7	7487.7	7536.8
Separator	857	825	351.7	375.1	974.1	978.3
Cladding wall super-heater	825	—	375.1	385	384.1	—
Low temperature super-heater	651.3	527.1	385	400	410.6	412.4
Platen super-heater	—	—	398	517.2	1947.4	—
High temperature super-heater	778	651.3	510	539	431	432.8
Low temperature reheater	805.4	492.8	313.4	447.9	1283.1	1288.7
Platen reheater	—	—	447.9	534	740.6	—
Economizer	508.2	312.1	271.2	326.2	1382.2	1388.2
Air preheater	312.1	159.1	40.7	231.8	1025	1029.5

Table 3: Thermal calculation table of boiler 60% running condition

Items	Inlet temperature of flue gas	Outlet temperature of flue gas	Inlet temperature of working medium	Outlet temperature of working medium	Total heat absorption	Flue gas heat release
Symbols	T_{in} (°C)	T_{out} (°C)	t_{in} (°C)	t_{ou} (°C)	Q (KJ/kg)	Q_v (KJ/kg)
Fire-pot	—	772	338.5	338.5	6978	6936
Separator	772	753.5	338.5	361.1	641.9	644.7
Cladding wall super-heater	753.5	—	361.1	365	366.1	—
Low temperature super-heater	587.6	436.1	365	401	452.9	454.9
Platen super-heater	—	—	393	519.2	1619.4	—
High temperature super-heater	707.2	587.6	508	537	363.4	365
Low temperature reheater	734.1	428.4	298.9	454.7	1227.5	1232.8
Platen reheater	—	—	454.7	532	563.1	—
Economizer	430.4	275.9	249.7	304	1034.4	1038.9
Air preheater	275.9	133.9	36	207	901.9	905.9

3.2 Analysis of temperature and water spray quantity of heat exchanger at different levels

Table 4 shows the change of inlet and outlet temperature of heat exchangers at three operating conditions after increasing the area of low temperature reheater. It can be seen that, after the optimization and transformation, the heat absorption of low temperature reheater increased. In the case of not changing inlet steam temperature, outlet steam temperature under three kinds of conditions were increased by 1.89 DEG C, 5.64 DEG C, and 5.73 DEG C. The final platen outlet steam temperature, namely reheat steam humidity, correspondingly increase by 1.64 DEG C, 5 DEG C, and 5 DEG C, basically reached the main steam temperature (Szega and Nowak, 2015). In the super-heat side, due to the increase of flue gas share in the super-heat side within the separation flue, the heat absorption of low temperature super-heater and high temperature super-heater both increases. The low temperature super-heater outlet steam temperature is increased about 3 DEG C compared with that before the optimization. In order to ensure the stability of steam temperature in the superheated side, we are supposed to increase the first and secondary water volume, as shown in Figure 2. After the optimization and transformation, the conditions, compared with the corresponding working conditions, the water volume increased significantly.

Table 4: The change of working fluid temperature of heat exchanger after optimization

Heating surface	After 95% operating conditions optimization		After 85% operating conditions optimization		After 60% operating conditions optimization	
	Temperature variation of working medium inlet /°C	Temperature variation of working medium outlet /°C	Temperature variation of working medium inlet /°C	Temperature variation of working medium outlet /°C	Temperature variation of working medium inlet /°C	Temperature variation of working medium outlet /°C
Low temperature super-heater	0	3.3	1	3	0	3.5
Platen super-heater	-1	-0.81	0	1.18	1.5	3.14
High temperature super-heater	-3	0	-2.5	0	-2	0
Low temperature reheater	0	1.89	0	5.64	0	5.73
Platen reheater	1.89	1.64	5.64	5	5.73	5
Economizer	0	-2.5	0	-2.5	0	-4
Air preheater	0	-1.5	0	-0.4	0	-2

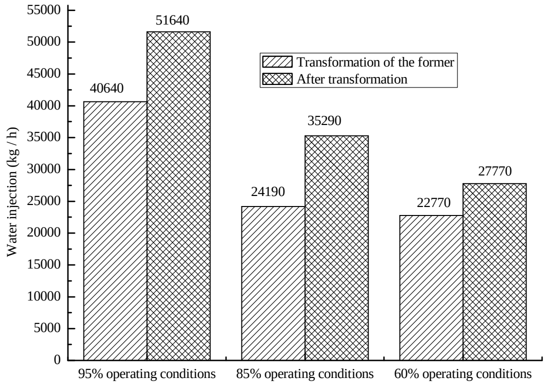

Figure 2: The total spray amount at the superheated side before and after the transformation

4. Conclusion

The heat balance calculation of thermal power boiler is different from that of the common boiler because of the desulfurization process and unique ash circulation process in the furnace, so it is necessary to consider more in the calculation. This paper introduces two thermal calculation methods of thermal power boiler, heat balance and ash balance. Then, after low temperature reheater retrofit optimization and increase of the boiler low heating surface, thermal calculation simulation is carried out under 95%, 85%, and 60% three kinds of operation loads, and compared with the calculation parameters of corresponding conditions before the transformation. The results show that the increase of the low temperature reheater heat absorption area can increase the low temperature reheater, and finally significantly improve the reheat steam humidity. In addition, it can regulate gas baffle and increase the proportion of the flue gas side heat, which relieves serious irregularities of reheating and overheating side baffle opening for a long time. Whereas, despite the low humidity reheater transformation can significantly reduce the low temperature reheater economizer outlet flue gas temperature and the entrance temperature of flue gas. But eventually, only the exhaust temperature was reduced for a small amount, and only a part of requirement for the exhaust gas temperature reduction was completed.

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