Adjustment and research of 623 °C reheat steam temperature in the commissioning of 660 MW ultra-supercritical boiler

Yongjia Wang¹°³, Ying Chen², Guanhua Xiao¹ and Qingguo Zhang¹

¹ Huadian Electric Power Research Institute Co., Ltd., Jinan 250000, China; ² CNOOC Petrochemical Engineering Co., Ltd., Jinan 250000, China.

³ Email: yongjia-wang@chder.com

Abstract. The 623 °C reheat steam temperature is adopted for 660 MW ultra-supercritical unit. During the operation, the materials of the high temperature reheater surface have less safety margin, leading to the result that the reheat steam temperature cannot reach the design value. During the commissioning process, the combustion adjustment plan was optimized. After a lot of adjustment of combustion deviation, the main steam temperature and reheat steam temperature reached to the design value. The temperature of the reheater surface was lower than the alarm value.

1. Introduction

The reheat steam temperature of the boiler of the single reheat ultra-supercritical unit that has been put into production in China is mainly 603 °C, and some of the ultra-supercritical units with 623 °C reheat steam temperatures that have already been put into production have less margin between the wall temperature of high temperature reheater [1] and reheat steam temperature due to the limitation of high temperature reheater materials [2]. Resulting in the fact that the reheat steam temperature cannot reach the design value [3]. Although some of the power plants had conducted combustion adjustment, it was difficult for adjustment, and at the same time it could cause coking and high-temperature corrosion [4]. At present, there are few researches on reheat steam temperature adjustment from the units commissioning to the operation.

The boiler is a high-efficiency ultra-supercritical pressure-changing direct-current boiler, with single reheat, single furnace chamber, and front-and-rear wall hedging combustion. The 36 swirling pulverized coal burners are arranged in 3 layers of front and rear wall hedging, with 6 burners on each layer, numbered from 1 to 6 from left to right. The burner on the lowermost layer of the back wall is a pure oxygen combustion-supporting micro oil ignition burner. The other burners are respectively equipped with an ignition gun and high-energy igniter. The main design parameters of the boiler are shown in Table 1.

No.9 unit strictly controlled each commissioning phase during the commissioning process, and an in-depth analysis of the reheat steam temperature and wall temperature control methods [5] was carried out in the commissioning project involving the impact of combustion and reheat steam temperature, developing and optimizing the combustion commissioning program to ensure that the reheat steam temperature reaches 623 °C. After a series of adjustment measures and combustion adjustments, the reheat steam temperature was successfully increased to 620 °C, and the highest point of the wall temperature was controlled below 637 °C (alarm value: 644 °C), with zero-input of the desuperheated water.
Table 1. Main design parameters of the boiler.

| Item                        | Unit          | Boiler Maximum Continuous Rating | Turbine Heat-Acceptance |
|-----------------------------|---------------|----------------------------------|-------------------------|
| Superheated steam flow      | t·h⁻¹         | 2002                             | 1783                    |
| Superheated steam pressure  | MPa           | 29.40                            | 27.05                   |
| Superheated steam temperature| °C           | 605                              | 605                     |
| Reheat steam flow           | t·h⁻¹         | 1685.75                          | 1514.86                 |
| Reheat steam pressure       | MPa           | 6.21                             | 5.59                    |
| Reheat steam temperature    | °C            | 623                              | 623                     |
| Flue gas temperature at     | °C            | 1045                             | 1013                    |
| furnace outlet              |               |                                  |                         |
| Flue gas exhaust temperature.| °C           | 121.7                            | 118.9                   |
| Boiler efficiency           | %             | 94.19                            | 94.30                   |

2. Measures for controlling the reheat steam temperature

2.1. Adjustment on the uniformity of wind powder
Due to the site layout and the position of the burner, the length, height and number of elbows of the primary air piping of the boiler are all different, resulting in differences in the resistance of each primary air piping [6]. If this deviation is not eliminated, it will cause uneven distribution of the amount of air volume and coal volume in 6 burners on the same layer, affecting the combustion stability and flow field distribution in the furnace, resulting in uneven distribution of heat load in the furnace and deviation of the flue gas temperature at the hearth outlet, leading to a larger deviation of temperature of wall temperature of high temperature reheater, which limit the increase of reheat steam temperature.

2.2. Soot blowing’s effect on steam temperature
Soot blowing has a greater influence on the main steam temperature and reheat steam temperature, which can reduce the temperature of the main reheat steam, especially when the long retractable steam soot blower in the platen superheater, high-temperature superheater, and high-temperature reheater are put into operation for a long time, the wall temperature will be affected to a larger extent, and the long-blowing from beginning to the end can change the reheat wall temperature by 16 °C. During the soot blowing process, the reheated steam temperature should be reduced, and it should be increased to 620 °C after soot blowing is completed.

2.3. Over-fire air adjustment
The ideal statement of current low-nitrogen combustion air grading technology is to avoid high temperature and high oxygen conditions in the main combustion zone [7]. According to the coal quality during commissioning, the dry ash-free volatile content (V_daf) was about 36%. During the Commissioning, the amount of burned air should be increased as much as possible to reduce the temperature and oxygen content in the main combustion zone, but the oxygen in the combustion zone should be controlled at a proper level to avoid the delay of the combustion and the overheating of the wall temperature of the high-temperature reheater caused by the high flue gas temperature at the outlet of the furnace [8]. The oxygen content was controlled at about 3% at high load. By appropriately adjusting the air distribution, the amount of burned air could be increased, which had a certain effect on reducing the wall temperature of the high-temperature reheater [9]; the NOx content of the denitrification inlet should be controlled at about 340 mg/Nm³. After repeated tests, it has been found that increasing the over-fire air volume can reduce the maximum temperature of the high-temperature
reheater’s wall temperature. Since the high wall temperature of the high-temperature reheater was in the area of the No. 1 and No. 6 burners, thus reducing the amount of over-fire air in the central burner could increase the over-fire air amount in the No. 1 and No. 6 burners’ areas. The degree of opening each lever in the over-fire air is shown in Table 2.

| Item                      | Central Wind | 1  | 2  | 3  | 4  | 5  | 6  | Degree of Full Opening |
|---------------------------|--------------|----|----|----|----|----|----|------------------------|
| Upper Levels of Front Wall|              |    |    |    |    |    |    |                        |
|                           | Surrounding Air | 400| 200| 180| 200| 200| 400| 400                    |
| Lower Levels of Front Wall|              |    |    |    |    |    |    |                        |
|                           | Surrounding Air | 300| 150| 150| 200| 200| 400| 400                    |
| Upper Levels of Back Wall|              |    |    |    |    |    |    |                        |
|                           | Surrounding Air | 200| 90 | 50 | 50 | 100| 200| 200                    |
| Lower Levels of Back Wall|              |    |    |    |    |    |    |                        |
|                           | Surrounding Air | 300| 150| 150| 50 | 100| 300| 300                    |

| Table 3. The amount of the secondary air.  |
|-----------------------------------------|
| A Layer Secondary Air                    |
|                                        |
| 1(%)  | 2(%)  | 3(%)  | 4(%)  | 5(%)  | 6(%)  |
| internal | 90    | 75    | 45    | 45    | 75    | 90    |
| external | 75    | 60    | 45    | 45    | 60    | 75    |
| B Layer Secondary Air                    |
|                                        |
| 1(%)  | 2(%)  | 3(%)  | 4(%)  | 5(%)  | 6(%)  |
| internal | 90    | 75    | 45    | 45    | 75    | 90    |
| external | 75    | 60    | 45    | 45    | 60    | 75    |
| C Layer Secondary Air                    |
|                                        |
| 1(%)  | 2(%)  | 3(%)  | 4(%)  | 5(%)  | 6(%)  |
| internal | 90    | 75    | 45    | 45    | 75    | 90    |
| external | 75    | 60    | 45    | 45    | 60    | 75    |
| D Layer Secondary Air                    |
|                                        |
| 1(%)  | 2(%)  | 3(%)  | 4(%)  | 5(%)  | 6(%)  |
| internal | 90    | 75    | 45    | 45    | 75    | 90    |
| external | 75    | 60    | 45    | 45    | 60    | 75    |
| E Layer Secondary Air                    |
|                                        |
| 1(%)  | 2(%)  | 3(%)  | 4(%)  | 5(%)  | 6(%)  |
| internal | 90    | 75    | 45    | 45    | 75    | 90    |
| external | 75    | 60    | 45    | 45    | 60    | 75    |
| F Layer Secondary Air                    |
|                                        |
| 1(%)  | 2(%)  | 3(%)  | 4(%)  | 5(%)  | 6(%)  |
| internal | 90    | 75    | 45    | 45    | 75    | 90    |
| external | 75    | 60    | 45    | 45    | 60    | 75    |
2.4. Inside and outside secondary air of the burner's adjustment
The temperature distribution of high temperature reheater’s wall temperature at the beginning of the adjustment was type M, and the high position of high temperature reheater’s wall temperature was at the corresponding area of No. 1 and No. 6 burners. Due to the difference of the wall temperature, the overall reheat steam temperature could not reach the design value. In order to solve the contradiction between the wall temperature and the steam temperature, to reduce the maximum wall temperature of the high-temperature reheater on both sides, and to improve the wall temperature of the intermediate high-temperature reheater so as to the deviation of the overall wall temperature was low. We could increase the reheat steam temperature based on the circumstance that the wall temperature was not beyond the alarm value.

The adjustment of the ratio of internal and external secondary air was carried out under the premise of a certain amount of oxygen content, a certain ratio of primary air and secondary air, and the determination of the over-fire air opening degree [10]. Taking into account the high temperature corrosion, high temperature reheater wall temperature distribution and non-uniform distribution of air in the furnace, we turned up the internal and external secondary air on both sides of the burners to increase the oxygen amount on both sides of the boiler. The pulverized coal burnout time was advanced, and the flue gas temperature on both sides of the high-temperature reheater was lowered, thereby reducing the maximum wall temperature of the high-temperature reheater on both sides. We turned off the internal and external secondary air of the middle burners to prolong the time of pulverized coal burn-out, and increasing the flue gas temperature at the hearth exit, so as to raise the temperature of the intermediate wall of the high-temperature reheater [11]. The amount of the secondary air is shown in Table 3.

2.5. Primary air thermal adjustment

![Figure 1](image)

**Figure 1.** The composition of the economizer exportation flue gas before adjustment.

When the distribution of the combustion in the furnace is uneven, it is necessary to perform the thermal adjustment of the primary air [12]. The overall situation of the No. 9 boiler before thermal adjustment was as follows: 1) the high points of wall temperature were the 6th, 7th, and 8th pipes of the 12th screen from left to right, and the second, third and sixth pipes of the 89th screen. The high
points of wall temperature were in the area corresponding to No. 1 and No. 6 burners; 2) Considering the wall temperature upper limit, the steam temperature at the left outlet of the high-temperature reheater was lower than that at the right side, if the left steam temperature was increased, over-temperature would happened at the left side of the wall temperature; 3) The left superheater desuperheating water was more than the right side; 4) The left oxygen content was lower than the right one, with the average value lower about 1.5% (see Figure 1), the CO content at the left side was obviously more higher than the right side; 5) By detecting the carbon content of fly ash during the commissioning, the average value was about 1.4% on the left side and about 0.8% on the right side. According to the analysis of desuperheating water volume, the heat load of the left side was higher than that of the right side; on the basis of the testing result of the oxygen content and carbon content of fly ash, burnout degree of coal powder at the left side was lower than that at the right side, but due to the similar amount of air volume at the left and right side, it meant that the amount of coal burned on the left side was more than that on the right side, and the heat load at the left side was higher than that at the right side. Therefore, turned down the shrinkage hole of the No. 1 burner (at the left side) in the B, C, D, and E layers, to reduce the amount of coal powder on the left side, to redistribute the heat load in the furnace, and transferred the wall temperature high point toward the center [13]. The opening of the shrinkage hole after adjustment is shown in Table 4.

| Primary Air | Left 1(%) | Left 2(%) | Left 3(%) | Right 4(%) | Right 5(%) | Right 6(%) |
|-------------|----------|----------|----------|-----------|-----------|-----------|
| A Layer     | 100      | 100      | 100      | 100       | 100       | 100       |
| B Layer     | 45       | 50       | 100      | 100       | 100       | 100       |
| C Layer     | 55       | 55       | 100      | 100       | 100       | 100       |
| D Layer     | 45       | 50       | 100      | 100       | 100       | 100       |
| E Layer     | 50       | 55       | 100      | 100       | 100       | 100       |
| F Layer     | 100      | 87       | 100      | 82        | 82        | 100       |

3. Wall temperature distribution of the high temperature reheater

3.1. High-temperature reheater wall temperature during steam purging and low-load operation

The fuel consumed during the steam purging of No. 9 boiler was 25t/h. Only the F coal mill was working, the highest wall temperature at the left side was 438.6 °C, and the highest temperature at the right side was 438.9 °C. And during the low-load operation period, the unit load was 130 MW, the fuel consumed by the boiler was 80t/h, with 435.8 °C main steam temperature, and 438.2 °C reheat steam temperature. When the A and F coal mills were ran, the highest wall temperature at the left side was 456.2 °C, and with 448.3 °C at the right side. It operated well during the period of steam purging and low-load operation, especially during the period of low-load operation, with the wall temperature deviation within 30°C, and the high wall temperature was in the middle position, as shown in Figure 2.
3.2. High temperature reheater's wall temperature during high load conditions

The boiler combustion test was carried out under different loads during the commissioning; the wall temperature distribution of the high-temperature reheater was shown in Figure 3. When the unit load was 400 MW, the boiler's burners in the lower (A and F layer) and middle (B and E layer) was put into operation, and the A, B, E, F coal mill ran, with the coal quantity of A and F coal mill were slightly greater than the B and E coal mill. The upper burners were not put into operation, and the wall temperature distribution of the high-temperature reheater was even. The reheat steam temperature was 610 °C. The highest wall temperature was 624 °C, with a small deviation of the steam temperature and wall temperature, and the temperature of the reheat steam could be increased to 620 °C.

When the unit load was 415 MW and 580 MW, the upper burners were put into operation. Because the C layer burners were on the upper layer, the coal quantity of C coal mill was minimized when the coal quantity of other coal mill met the requirements. From Figure 3, it could be seen that when the unit load was 580 MW, the wall temperature curve of the high-temperature reheater showed the shape of M. And when the reheating steam temperature was 605°C, the maximum wall temperature reaches 629°C. After adjusting the over-fire air, secondary air and primary air, when the unit load was 415 MW, and the A, B, C, E, F five-layer burners operated, the reheat steam temperature could reach 620 °C, and the maximum wall temperature of the high-temperature reheater was about 637 °C.

When the unit operation was in the full load, the main steam temperature was 598.2 °C, and the reheat steam temperature was 619.6 °C, and all burners operated. The A and F mill coal feed volume was 47 t/h, and the B and E mill coal feed volume was 45.5 t/h, C and D mill coal feed volume was 40.5 t/h, the valve opening of the second layer over-fire air at the left side was 82%, and with the right side being 38%. The valve opening of the first floor over-fire air at the left side was 75%, and with the right side being 37%, and the highest wall temperature was 637.4 °C, and with 631.9 °C of the right side. It can be seen from Figure 3 that the wall temperature distribution of the high-temperature reheater is more even when the unit operates at full load, and the difference between the reheat steam temperature and the maximum wall temperature is smaller.
4. Conclusions
The deviation of the wall temperature of the high-temperature reheater is the main limiting factor of the unit’s reheat steam temperature [14]. The main cause of the deviation of the wall temperature of the high-temperature reheater is the deviation of the boiler combustion [15]. For the front and back wall hedging boilers, the main way to reduce this deviation is to adjust the amount of coal and air distribution in different areas of the boiler. No. 9 unit strictly controlled each commissioning phase during the commissioning process and optimized the combustion commissioning program. No.9 unit was in normal operation after adjustment, with the main steam temperature and the reheat steam temperature all reached the design values under different loads. The wall temperatures of the heated surfaces didn’t exceed the alarm value, the wall temperature distribution of the high-temperature reheater is even, and the boiler operation is safe and stable.

References
[1] Pan L X, Bian Z H, Liu P 2015 J Boiler Technology 46 16
[2] Zhu Y F 2015 J Boiler Technology 46 30
[3] Yao J C, Meng H Y, Wang X P 2015 J Boiler Technology 58 56
[4] M Schutze 1995 J Oxidation of Metals 44 29
[5] Qi G L, Zhang S S, Liu X M 2017 J Applied Thermal Engineering 124 1505
[6] Quan W T, Lu X D, Wang J 2015 J Boiler Technology 46 12
[7] Xing C, Liu L, Qiu P H 2017 J Applied Energy 208 12
[8] Zhao H R, Shen J, Li Y G 2017 J Control Engineering Practice 58 127
[9] Zhai D S 2013 J Electric Power 46 28
[10] Xia K N, Wang F 2017 J Shen Hua Science and Technology 15 57
[11] Fu L L, Dang X J, Lei Z T 2016 J Boiler Manufacturing 5 1
[12] Gao X T 2002 J Electric Power 38 1
[13] Guo J, Qin X C 2015 J Electric Power 48 97
[14] Xia J, Qian Y G 2015 J Boiler Technology 46 52
[15] Yao D H, Zhu Y F 2015 J Boiler Technology 46 4