Analysis of Sootblowing Experiments and Research on Sootblowing Strategy for Coal-fired Utility Boiler

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Abstract. For the research of the optimized sootblowing strategy, some experiments were set up to analyze the relationship between the time and operation parameters, such as NOₓ emissions, main steam temperature, reheat steam temperature, desuperheating water, etc. Based on these experiments, the characteristic models of steam temperature which described the maximum variation of steam temperature(ΔT) and the characteristic time of steam temperature(Δτ) were presented according to specific operation of sootblower. All these research can offer some help to optimize the sootblower grouping. Finally, the formulation of sootblowing strategies were studied, then a new strategy considering both NOₓ emissions and steam temperature was proposed, and it can guide the operation of power plant.

1. Introduction

During the operation of a coal-fired power plant boiler, the heating surface will inevitably generate fouling or slagging, thus affect the safe and economical operation of the boiler. The references [1] and [2] analyzed that the quality of coal used in domestic coal-fired power plant boiler is changeable, then it could result in the deviation of coal from the design and increase the heating surface pollution. The references [3] and [4] said that soot blowing can reduce the exhaust gas temperature, improve the boiler efficiency, ensure the steam quality, reduce the boiler NOₓ emissions and prolong the life of the boiler heating pipe. However, due to the particularity and complexity of the boiler operation, various kinds of monitoring methods of ash pollution and the soot-blowing guidance methods based on these theories cannot be fully adapted to actual boiler operation, or even produce large deviations, resulting in the inability to accurately give a simple and reliable soot blowing strategy.

In this paper, the arrangement of sootblowing tests of boiler sootblower was reasonable and orderly, then test data were obtained to show the impact that blowing process of every sootblower had on economic indicators of the boiler and the environment. According to the influence of soot blowing on operating parameters of many units, such as steam temperature, overheat water injection, exhaust gas temperature, NOₓ emission and so on, the law of change and amplitude of above parameters when different sootblower purging was tested. Then the sootblowers which have larger impact on boiler operation were found out. In this paper, the optimization of sootblowing strategy was studied mainly from the perspective of reducing NOₓ emission and stabilizing control of main and reheat steam temperature.
2. Sootblowing experiment
It is assumed that the operating parameter is a single univalent function of soot blowing, the influence caused by external disturbances such as load, fuel, coal, air volume, boiler burners and its swing angle can be negligible. To reduce the influence of defect data and ensure the reliability of the results, the same combination of test are carried out at different load conditions to repeat the experiment.

2.1. Study Object
The object of the paper is a 600MW boiler of a power station #1 unit. The compressed air is used as the blowing medium. There are four types of sootblowers for different heating surface of boiler. In the furnace, retractable rotary short-blown sootblowers are divided into layer I, II, III. There are 12 sootblowers in each layer, 4 in front wall, 4 in back wall, 2 in left wall and 2 in right wall. The sootblowers in first layer are numbered counterclockwise from the front wall as LT-Ⅰ-1 to LT-Ⅰ-12. Retractable rotary long-blown sootblowers in horizontal convection flue are symmetrically arranged in left and right walls, and can be divided into 4 groups, from the first group DL-L-1, DL-R-1 in the furnace outlet to the fourth group DL-L-4, DL-R-4 in the vertical convection flue. The sootblowers in tail flue air preheater area are not considered in this paper.

2.2. Experiment Arrangement
The tests were carried out under steady and full-load conditions. Twelve sootblowers were selected in the furnace section for testing. Eight sootblowers were selected in horizontal convective flue for testing. The sootblowers begin to blow in order of arrangement. Specific arrangements for soot blowing test are shown in Table 1 and Table 2.

| Testing order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---------------|---|---|---|---|---|---|---|---|---|----|----|----|
| Serial number | III-3 | III-9 | III-5 | III-11 | II-2 | II-10 | II-8 | II-12 | I-3 | I-9 | I-5 | I-12 |

Table 2. Arrangement for convection pass’s sootblowing experiments.

| Testing order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---------------|---|---|---|---|---|---|---|---|
| Serial number | L-1 | R-1 | L-2 | R-2 | L-3 | R-3 | L-4 | R-4 |

3. Analysis of test data
Furnace sootblowing will lead to the decrease of NOx production, meanwhile, heat transfer effect of water cooling wall is improved, which will increase the radiant heat release in the furnace, reduce the flue gas temperature in the furnace and the flue gas temperature at the furnace exit, make main and reheat steam temperature drop. Sootblowing in convection flue has no significant effect on the combustion of the furnace, does not affect the formation of NOx, but enhances convection heat and has positive effect on main and reheat steam temperature, so that the steam temperature rises. Sootblowing in furnace and convection flue can purge the heating surface, enhance the heat transfer between the flue gas and the working fluid, make the exhaust gas temperature drop.

3.1. Influence of sootblowing on NOx generation
Figure 1. Variation curve of NOx emissions.

Figure 2. Variation curve of exhaust gas temperature.

Figure 1 takes time as abscissa and the absolute change of NOx content after sootblowing as ordinate (the reference value is 200 mg m\(^{-3}\)). The NOx formation tends to decrease after sootblowing. The sootblowers in layer II have a more obvious effect on inhibiting NOx generation compared with other layers. This is because the sootblowers in layer II are closest to the central combustion zone and have the greatest impact on combustion. The sootblowers in layer III is located in the top of combustion zone, which mainly affects the combustion of the upper layer, and then the effect on the whole zone is limited. The position of layer I is lower and the effect on combustion is weaker than that of the layer II, but the effect is more obvious than that of the layer III.

3.2. Impact of Furnace, convection flue sootblowing on the exhaust temperature

Figure 2 takes time as abscissa and the absolute change of exhaust gas temperature after sootblowing as ordinate (the reference value of exhaust temperature is 125 °C in full load design). After sootblowing, the exhaust temperature drops obviously, about 5°C lower than before purging, so that the exhaust heat loss of the boiler can be reduced and the thermal efficiency of the boiler can be increased by about 0.5% according to the reference [5].

3.3. Impact of sootblowing on main and reheat steam temperature

In case of normal operation of the boiler, main and reheat steam temperature must be within the set allowable temperature fluctuation range, and the steam temperature is finally adjusted by spraying water. Therefore, in order to study the effect of sootblowing on the steam temperature, the effect due to water spray must be eliminated. Here, amendatory steam temperature was introduced to eliminate the impact of the spray water, the change in the temperature of the steam is only the result of sootblowing.

3.3.1. Amendatory steam temperature. It is assumed that the main and the reheat steam temperature are expressed by \( T_g \) and \( T_z \), respectively; superheat water spray \( d_g \), reheat water spray \( d_z \); amendatory main and reheat steam temperature, respectively \( T_g' \) and \( T_z' \). Defined as follows:

\[
T_g' = T_g + m \cdot d_g \tag{1}
\]

\[
T_z' = T_z + n \cdot d_z \tag{2}
\]

Where, \( m \) is the change value of main steam temperature under unit spray water and \( n \) is the change value of reheat steam temperature under unit spray water, which can be calculated from the heat balance. Here, \( m \) and \( n \) are 0.408 (°C/(th\(^{-1}\))) and 0.701 (°C/(th\(^{-1}\))), respectively.

3.3.2. Impact of furnace sootblowing on the steam temperature. Sootblowing in furnace will reduce the steam temperature, and a huge difference will be produced while different sootblowers running. Figure 3 and Figure 4 respectively show the influence of the operation of the second-layer sootblowers on the main and reheat steam temperature. The II-2 and II-8 sootblowers have a great influence on the steam temperature, but II-10 and II-12 express no significant effect.
3.3.3. Influence of convection flue sootblowing on steam temperature. In convection flue, the effect of the left and right side sootblowers operation for main steam temperature is shown in Figure 5 and Figure 6. Sootblowing process can strengthen the convective heat transfer, and increase the main steam temperature. But for R-1 sootblower, steam temperature declines after the purge, the reason is that the sootblower installation is too close to the furnace exit, resulting in the same sootblowing characteristics as in the furnace. The changing characteristics of reheat steam temperature in convective flue are roughly as same as the main steam temperature’s.

4. Study on the optimization of sootblowing strategy

4.1. Classification of the study on blowing strategy
The reference [6] said that the optimization of sootblowing strategy should be determined by specific optimization objectives, and different optimization objectives lead to different optimization strategies. Optimization strategies include: sootblower optimization grouping, control of furnace ash levels (including control of furnace exit flue gas temperature), control of main and reheat steam temperature, control of exhaust gas temperature, control of pollutants (NOx, SOx, CO, etc.) emission and the like. For different application objects, it is not necessary to consider all of the above factors. Instead, the sootblowing strategy and the sootblowing mode should be formulated according to the actual conditions of the generating units and the most important influencing factors.

4.2. Extract characteristic data of the steam temperature to guide soot blower grouping
According to experimental data analysis, two important characteristic parameters are extracted to describe the steam temperature variation with sootblowing. That is, the maximum variation of steam...
temperature ΔT and the characteristic time of steam temperature Δτ in the soot blowing process, which is quantitatively used to describe the law of the steam temperature variation. See Table 3 and Table 4.

Table 3. Summary of steam temperature characteristics of convective flue.

| Layer | Reheat Steam Temperature | Main Steam Temperature |
|-------|--------------------------|------------------------|
|       | ΔT/°C   | Δτ/min | ΔT/°C   | Δτ/min |
| L-1   | 1.4     | 7      | 1.7     | 6      |
| R-1   | -1.6    | 7      | -1.8    | 8      |
| L-2   | 3.4     | 8      | 4.2     | 7      |
| R-2   | 3       | 3      | 3.8     | 5      |
| L-3   | 1.5     | 10     | 3.6     | 10     |
| R-3   | 2.4     | 7      | 1.2     | 4      |
| L-4   | 1.4     | 5      | 1.2     | 6      |
| R-4   | 1.2     | 7      | 0.7     | 9      |

Table 4. Summary of steam temperature characteristics of furnace.

| Layer | Reheat Steam Temperature | Main Steam Temperature |
|-------|--------------------------|------------------------|
|       | ΔT/°C   | Δτ/min | ΔT/°C   | Δτ/min |
| II-2  | -10.2   | 14     | -9      | 14     |
| II-8  | -4.7    | 13     | -4.1    | 12     |
| II-10 | -1.5    | 7      | -0.6    | 8      |
| II-12 | -0.6    | 7      | -0.8    | 7      |
| III-3 | -12.3   | 13     | -11.3   | 12     |
| III-5 | -1.5    | 12     | -2.7    | 13     |
| III-9 | -4.2    | 12     | -5.8    | 13     |
| III-11| -2.5    | 14     | -1.9    | 13     |

The above statistics show that the soot blower has the following characteristics.

1. Furnace sootblowing has a negative effect and most of the convection heating surface sootblowing has a positive effect on steam temperature. For the steam temperature, the overall effect of furnace sootblowing is greater than that of convection heating surface.

2. In furnace, main sootblowers are located in the middle of the front and rear walls. In this paper, the studied sootblowers are in layer II and III. Sootblowers in layer I have a small effect on the adjustment of steam temperature, so the characteristic parameters are not listed out.

3. In horizontal convection flue, the second and the third group of sootblowers have a greater impact on steam temperature, but for the response speed, the second group was significantly better than the third one. Thus, we can arrange soot blower operation reasonably, and classify them according to the effect of steam temperature. The sootblower with no obvious effect is still sootblowing according to the original regular quantitative manner, but the sootblowing cycle can be performed appropriately to extend or stop running to improve efficiency according to the characteristic parameters.

4.3. Control strategy considering NOx emission, main and reheat steam temperature

Through experiments, this paper proposes a comprehensive temperature control method that adjusts the temperature mainly by soot-blowing in consideration of NOx emission, and assists in minimum
water sprayed amount (especially the amount of reheat water) to regulate stable steam temperature. When any of the parameters exceed the limits, sootblowing starts. The specific strategy is as follows.

Stratified batch execution in the furnace. When the NOx value is too large, furnace main sootblowers need to be started, meanwhile the change of steam temperature is monitored. To take full advantage of its own balance, we can choose stratified purge, blow down the whole layer, stabilize it and then sweep the next layer. So it is possible to ensure that the steam temperature is within the allowable range while adjusting NOx.

Grouped action of sootblowers in convection flue. The sootblowing is performed in sequence according to the characteristic parameters. If the reheat steam temperature is low, you can just start a few sootblowers whose sootblowing effect is most obvious (such as soot blowers R-2 and L-2), then get the rapid recovery of steam temperature. By this way, it can not only ensure the reheat steam temperature, but also reduce the loss of sootblowing.

Cross dispatching of sootblowers in furnace and convective flue. When the main and reheat steam temperature is beyond the limit value, the main sootblowers in furnace are started to adjust the temperature. When the temperature overruns negatively, we can arrange sootblowing in convection flue to ensure the stability of main and reheat steam temperature.

5. Conclusion
This paper introduces the sootblowing optimization strategy based on the sootblowing tests, and comes to the conclusions as follows.

1) Based on the testing data, the influence of boiler furnace and convection flue soot-blowing on NOx generation, exhaust gas temperature, main and reheat steam temperature were analyzed. The modified steam temperature is adopted to eliminate the effect of spray water, the experimental results are consistent with the theoretical analysis.

2) The parameters of steam temperature (the maximum variation of steam temperature $\Delta T$ and the characteristics time of steam temperature $\Delta \tau$) during the main soot blower operation are analyzed. The influence degree of each soot blower on the steam temperature are obtained, then it can provide the basis for sootblower dispatch when adjusting steam temperature.

3) The sootblowing strategies are classified according to the different optimization objectives. The control of NOx emissions, the temperature of main and reheat steam are studied, and a new integrated control strategy is proposed which has a strong guiding significance on operation in plant.

Acknowledgments
Authors wishing to acknowledge top-notch Academic Programs Project of Jiangsu Higher Education Institutions (TAPP-PPZY2015C232) and Scientific Research Project of Nanjing Polytechnic Institute (NHKY-2016-04).

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