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Numerical simulation and response surface analysis on combustion optimization of coal-fired boiler

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Introduction

The separated over-fire air (SOFA) is usually introduced to inhibit the generation of NOx effectively in the wall-type tangentially fired boiler. The effect of reducing NOx emission can be improved further with some reasonable technologhy reformations for the furnace burn-out. Changing the position of the sofa air nozzle, the sofa wind ratio and the sofa wind swing angle will have a beneficisal impact on the combustion and the pollutant generation. In this apper, the response surface method (RSM) was used to modelling and analysising the numerical simulation data to investigate the combined effects of the furnace outlet oxygen, sofa air ratio and sofa air vertical swing angle. With the boiler burn-out rate and furnace outlet NOx as the research objects, the combustion conditions of the furnace were optimized.

Numerical Simulation Experimental

1. Simulation object

In this paper, the simulation object is a 330MW coal-fired thermoelectric unit. The unit is of the subcritical pressure parameters, the natural circulation steam drum furnace, the single furnace, one intermediate reheat, burner swing temperature adjustment, the balanced ventilation, four-corner tangential combustion, tight-fitting closure, solid slag discharge, and the all-steel suspension structure. Its pulverizing system includes a cold primary fan and a positive pressure direct blowing pulverizing system. The general layout of the boiler is shown in Figure 1. The furnace has a width of 14022mm, a depth of 13640mm, and the elevation of the furnace roof is 61000mm. The primary air is arranged according to the combination of spatial density. The two layers A and B are plasma burners. There are 5 layers of primary air and 7 layers of secondary air arranged crosswise. The upper part of the main burner is arranged with 1 layer of compact over-burning air and 4 layers of high-level burn-out wind.

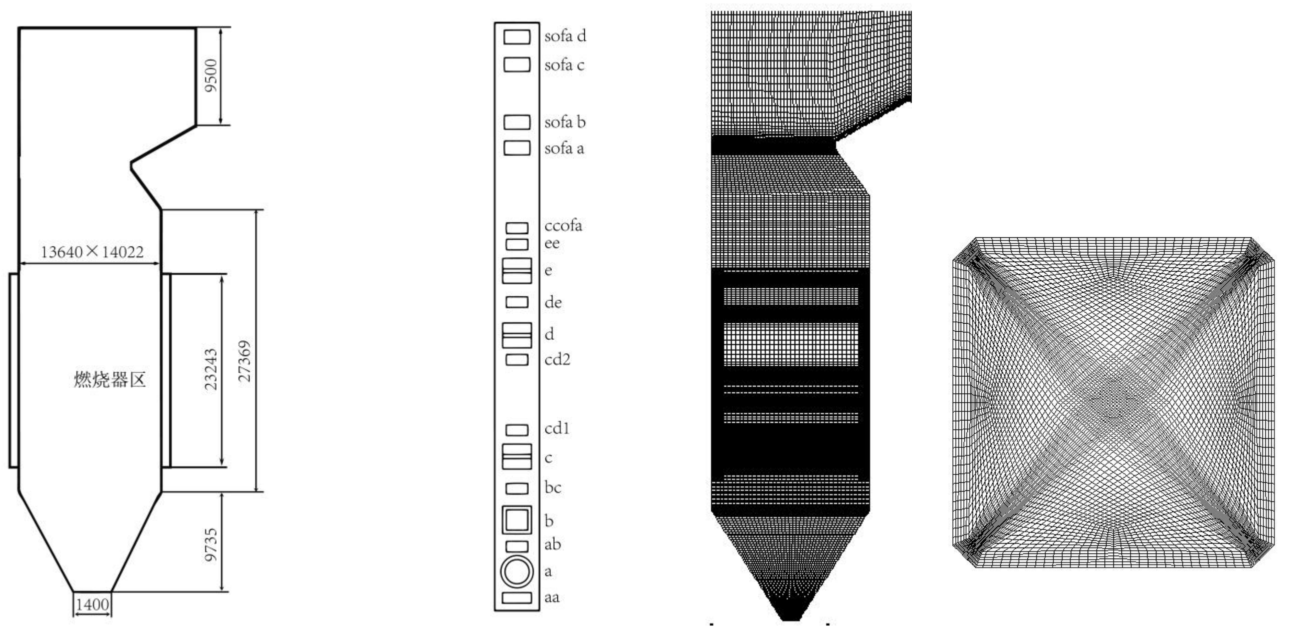

Fig. 1 Boiler structure and grid division

2. Simulation experimental

Regarding oxygen (X1), sofa air ratio (X2), sofa air vertical swing angle (X3) as influencing factors, boiler burn-out rate (Y1) and furnace outlet NOx (Y2) as evaluation indicators, a 3-factor, 3-level simulation experiment is carried out with Box-Behnken central combination method. The response surface experiment is designed as follows.

Table.1 Response surface test design and numerical simulation results

No.	O_2 (%)	Sofa retio (%)	Sofaair vertical swing angle (°)	burn-out rate (%)	furnace outlet NOx (mg/m3)
1	3	20	0	95.63	209.39
2	5	20	0	97.91	267.6
3	3	40	0	95.02	198.84
4	5	40	0	97.32	241.53
5	3	30	−15	95.49	195.27
6	5	30	−15	97.87	237.94
7	3	30	15	94.86	189.89
8	5	30	15	97.32	228.41
9	4	20	−15	97.31	249.17
10	4	40	−15	97.1	204.08
11	4	20	15	96.53	226.19
12	4	40	15	95.94	221.4
13	5	30	0	97.53	233.75
14	4	30	0	96.87	207.24
15	4	20	0	97.18	235.86
16	3	30	0	95.26	192.49
17	4	40	0	96.35	214.94

Result & Discussion

The simulation results were showed in Fig. 1 to Fig. 4. When the sofa air ratio is 30 %, the sofa air vertical swing angle is 0°, and the furnace outlet oxygen content is 3 %, 4 % and 5 %, the boiler burn-out rate and furnace outlet NOx increase with the inrease of the furnace outlet oxygen content. When the fixed furnace outlet oxygen content is 4 % and the sofa air vertical swing angle is 0 °, and the sofa air volume is 20 %, 30 % and 40 %, the boiler burnout rate decreases with the increase of the sofa air volume, and the furnace outlet NOx content at the furnace outlet decreases firstly and then increases with the increase of sofa air ratio. When the fixed furnace outlet oxygen content is 3 % and the sofa air volume is 30 %, and the sofa wind vertical swing angle is -15 °, 0 ° and 15 °, the boiler burnout rate decreases with the increase of the sofa wind vertical swing angle , and the NOx of the furnace outlet increases with the increase of the vertical swing angle of the sofa wind.

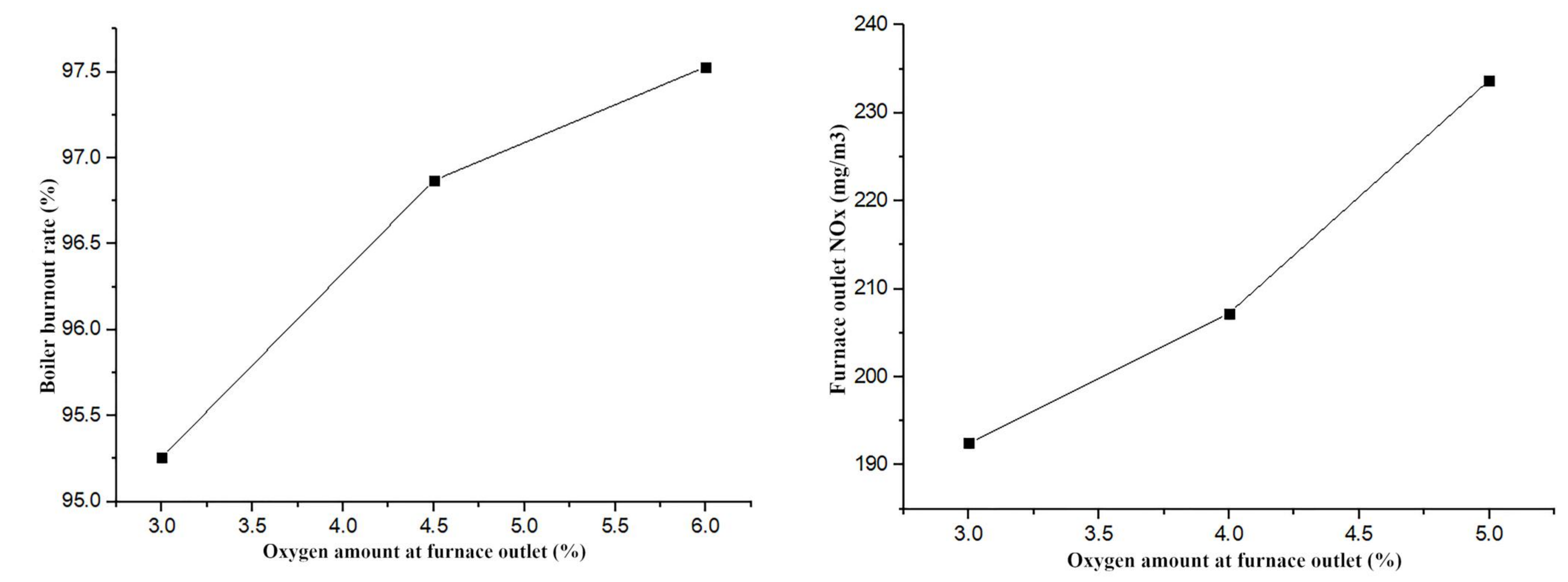

Fig. 2 Influence of furnace outlet oxygen content on boiler burnout rate and furnace outlet NOx

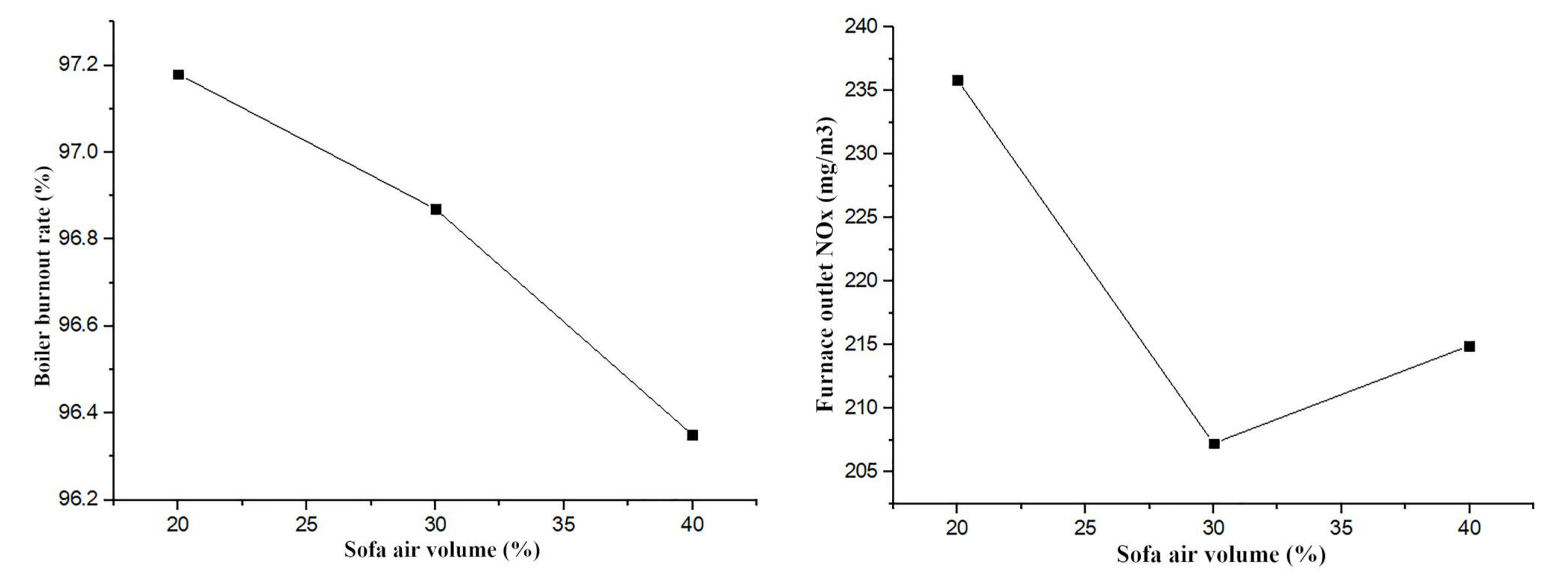

Fig. 3 Influence of sofa air volume on boiler burn-out rate and furnace outlet NOx

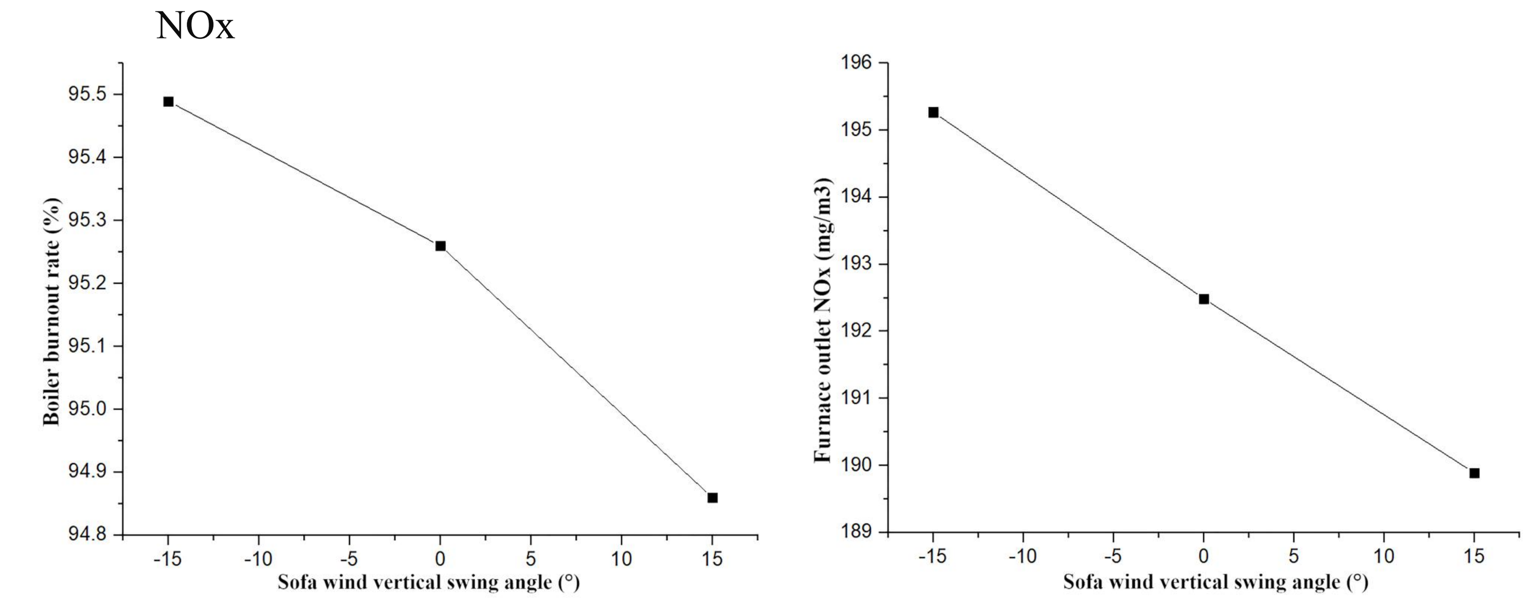

Fig. 4 Influence of sofa wind vertical swing angle on boiler burn-out rate and furnace outlet NOx

The optimal solution obtained within the range of the interaction of various factors with the response surface method. The elliptical contour line indicates that the interaction is significant. The synergy between X1 and X2 is more significant. Within the value range of X1 and X3, Y1 increases with the increase of X1 and the decrease of X3. The contour line is elliptical, that indicated that the synergy is significant. Y2 increases with the increase of X1, and also increases when X2 is too high or too low. Y2 is the lowest when X2 is about 30%. Using the expected value of the maximization function to optimize each response, it can be obtained that Y1 is greater than 97.3% and Y2 is less than 210mg/m³ when X1 is 4.27%, X2 is 35.15% and X3 is -15°.

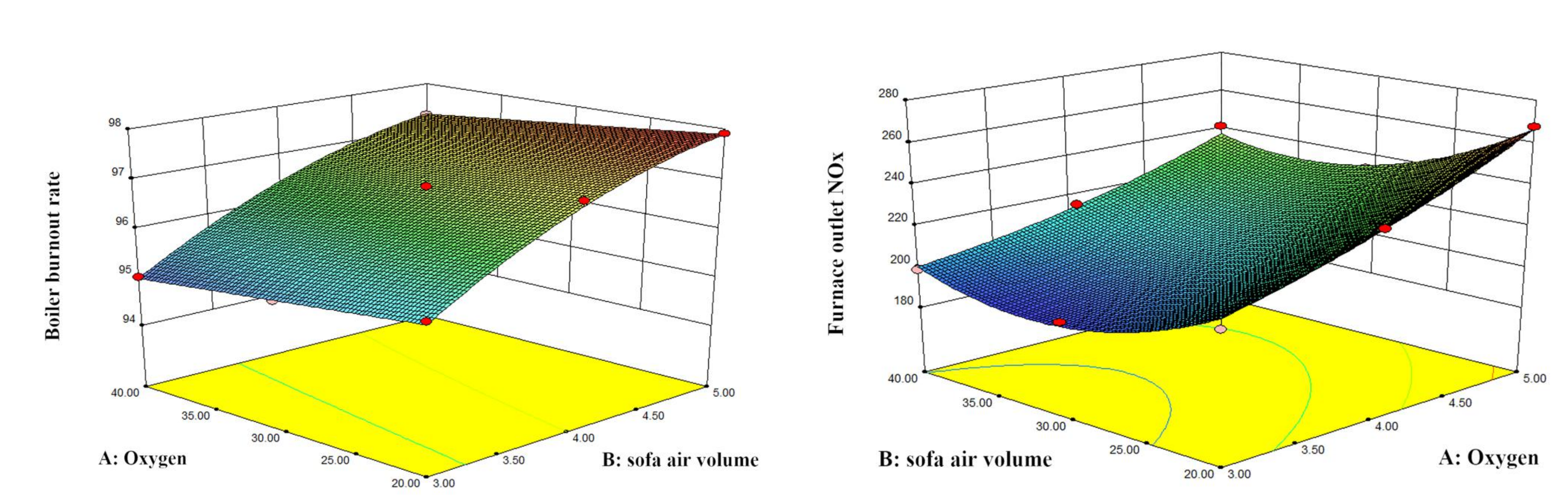

Fig. 5 Response surface diagram of various factors on the boiler burnout rate and the NOx at the furnace outlet

Conclusion

(1) With single-factor numerical simulation experiments, the influence of different single-factor operating conditions on the boiler burnout rate and furnace outlet NOx were analyzed. It was found that the change of the target value has a certain law. This is very important to guide the operating of the combined conditions.

(2) In order to optimize the combustion characteristics of the boiler, the numerical simulation methods are used to study the influence of furnace outlet oxygen, sofa air ratio and sofa air direction swing angle on the boiler burnout rate and furnace outlet NOx. The results showed that the design of the operating condition combination within a certain range can be achieve for the optimization purpose.

(3) With the response surface methodology, the optimized operation parameters were obtained. By a reasonable combination optimization of operating conditions, it can obtained that the boiler burnout rate is greater than 97.3%, and the furnace outlet NOx is less than 210mg/m³.