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# Analysis of Factors on NO$_x$ Emission of a 600 MW Boiler under Different Conditions

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## ABSTRACT

In power stations, adjusting operating parameters to control NO$_x$ emissions has attracted more and more attention. In this study, a three-dimensional CFD model was established to simulate a 600 MW tangentially coal-fired boiler. The orthogonal tests were employed to analyze the effect of operating load, primary air rate, air staging, burner swing, and SOFA air swing on NO$_x$ emissions. Results show that at 35% BMCR, primary air ratio of 0.24, air staging of 0.75, burner swing of 15°, and SOFA air swing of 0°, the NO$_x$ emission is 208.8 mg/Nm$^3$, which is 27.8% lower than the basic case. Increasing the operating load has the opposite effect to the primary air ratio, so does the burner swing and SOFA air swing. Orthogonal analysis shows that the air staging is the most significant factor in NO$_x$ emissions. Appropriate reduction of air staging is beneficial to reduce NO$_x$ emissions.

**Keywords:** orthogonal analysis, NO$_x$ emission, numerical simulation

## 1. INTRODUCTION

NO$_x$ is one of the main pollutants emitted by coal-fired boilers. In China, according to relevant regulations, NO$_x$ emissions are limited to 50 mg/Nm$^3$ (@ 6% O$_2$) [1]. At present, the main methods to control NO$_x$ emissions from coal-fired boilers are using low-nitrogen burners, adjustment of operating conditions, and staged combustion, respectively. In actual operation, changes in load and coal types are often overcome by adjusting operating parameters. Therefore, it is very important to study the influence of operating parameters on NO$_x$ emissions.

In recent years, many researchers have studied the impact of operation on NO$_x$ emissions through numerical simulations [1-5]. With the deepening of research, it becomes more and more important to analyze the influence of various operating factors on NO$_x$ emissions. The orthogonal method can effectively reduce the workload in both experiments and simulations. And it is convenient to analyze the influence of various factors. For example, the orthogonal method was used to evaluate the sensitivity of influencing factors on NO$_x$ emission in gas-fired heating and hot water combi-boilers by Zhou et al [6]. They considered that the power of fan has the greatest influence on the formation of NO$_x$ of the gas-fired combi-boilers. Wu et al [7]. used the orthogonal test method, single factor analysis method and response surface method to study the influence of secondary air parameters (screw pitch, number of spiral blades, and primary air coefficient) on NO$_x$ emissions. They found that the effects of these three factors are screw pitch, primary air, and number of spiral blades in sequence. Zhang et al [8]. established orthogonal tests of a coal-fired boiler. Subsequently, they used artificial neural

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networks to predict the performance of boiler. In summary, few researchers conducted comprehensive orthogonal analyses on the effect of factors, including operating load, primary air rate, air staging, burner swing, and SOFA air swing, on $NO_x$ emissions of coal-fired boilers.

In this study, a series of orthogonal CFD simulation based on a 600 MW coal-fired boiler was established. The influence of operating load, primary air rate, air staging, burner swing, and SOFA air swing on $NO_x$ emissions would be evaluated in depth through the range analysis. From the above discussion, a set of optimal parameters can be obtained. It is expected that the results and conclusions could be helpful to adjust the operation of boiler.

## 2. MODELLING METHODOLOGY

### 2.1 Physical model

The simulations were on the basis of a 600 MW coal-fired boiler, which is shown in Fig 1. The height of furnace is 17.696 m, while the depth is 18.816 m. 24 direct-flow burners are arranged in 6 layers at the four corners of the lower part of the furnace. Coal and air are fed in from the four corners and burned tangentially in the furnace. For the burner arrangement, six layers of primary air (PA) nozzles (namely A to F) were placed at each corner. Three kinds of nozzles were used to inject the second air supporting for combustion. More precisely, under-fire air (UFA) nozzles, auxiliary air (AUX) nozzles, and close-coupled over fire air (CCOFA) nozzles were arranged layer-by-layer, as illustrated in Fig 1. Furthermore, separated over fire air (SOFA) nozzles were set above the primary zone for the burnout of coal. More detailed description could be found in the previous study [9].

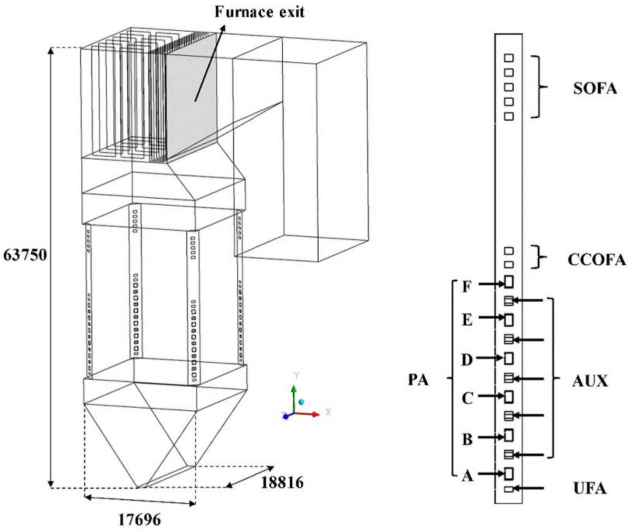


Fig. 1. geometry schematic of the boiler and burner [9]

The coal properties and operating parameters are given in Table 1 and Table 2, respectively.

### 2.2 Numerical methods

In this study, the FLUENT 19.0 was adopted for a series of calculations, which is frequently used in the simulation of coal-fired boiler [10]. The standard *k-ε* model was used to calculate the gas turbulence. The discrete ordinates (DO) model was chosen to solve the radiation transport, while the DPM model was selected to track the movement of particles, in which gravity, drag force and Saffman lift force were included. The eddy-dissipation finite rate model and the kinetic/diffusion-limited model were employed to describe the gas phase combustion and the char combustion, respectively.

Table 1 Coal properties

| Ultimata analysis (wt%) | | | | |
|---|---|---|---|---|
| $C_{ar}$ | $H_{ar}$ | $O_{ar}$ | $N_{ar}$ | $S_{ar}$ |
| 59.41 | 3.48 | 9.47 | 0.80 | 0.58 |
| Proximate analysis (wt%) | | | | |
| $A_{ar}$ | $M_{ar}$ | $V_{ar}$ | $FC_{ar}$ | $LHV_{ar}$ (MJ/kg) |
| 11.26 | 15.00 | 36.50 | 37.24 | 22.66 |

Table 2 Operation parameters under variable loads

| Load | Coal feed rate (t/h) | Layers of burner | Excess air coefficient |
|---|---|---|---|
| BMCR | 216.3 | A-E | 1.2 |
| 75% THA | 148.2 | B-E | 1.33 |
| 50% THA | 101.8 | A-C | 1.37 |
| 35% BMCR | 86.2 | B-C | 1.47 |

A high quality mesh is of great importance to get reliable results for FLUENT. Three structure meshes, with 1.34 million, 1.70 million, and 2.06 million cells, were simulated primarily. The difference between the average pressure of burner inlets in A layer and the average pressure of furnace exit was defined as the pressure drop, which was used in the grid independence test. The pressure drops of three meshes were 40.7 Pa, 29.0 Pa, and 22.1 Pa, respectively. Balancing the results and the consumption of computing resources, the mesh with 2.06 million cells was employed in present study.

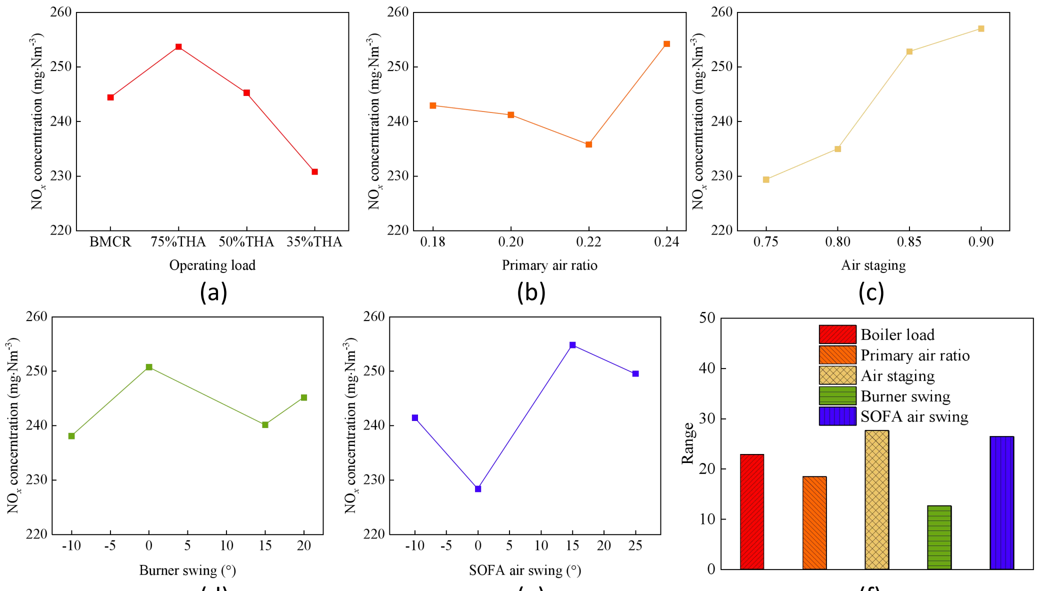
## 3. RESULTS AND DISCUSSION

### 3.1 Validation of the numerical models

The basic case was validated based on the experimental data of the 600 MW boiler. The simulation value of $NO_x$ emission at furnace exit was 289 mg/Nm$^3$, with a relative error of 0.77%. Meanwhile, compared

Table 3 $L_{16}(4^5)$ level table of orthogonal design

| Level | Factor | | | | |
|---|---|---|---|---|---|
| | Load | primary air rate | air staging | burner swing | SOFA air swing |
| 1 | BMCR | 0.18 | 0.75 | -10 | -10 |
| 2 | 75% THA | 0.2 | 0.8 | 0 | 0 |
| 3 | 50% THA | 0.22 | 0.85 | 15 | 15 |
| 4 | 35% BMCR | 0.24 | 0.9 | 20 | 25 |



(a) (b) (c)

(d) (e) (f)

Fig. 3. Orthogonal test results

with the experimental data, the relative error of furnace exit $O_2$ concentration (vol%) was -8.64%. To sum up, the numerical model established in this study was reliable. The following work would be carried out on the basis of the basic case.

### *3.2 Orthogonal analysis*

Table 3 shows the orthogonal design table, with 5 factors and 4 levels. The operating load, primary air rate, air staging, burner swing, and SOFA air swing are considered as influencing factors. Furthermore, $NO_x$ emissions at furnace exit are selected to evaluate the impact of each factor. The range analysis results are given in Fig. 3.

From Fig. 3(a), it can be seen that as the operating load decrease, the $NO_x$ emission increases firstly, then decreases rapidly. In Fig. 3(b), the curve of $NO_x$ emission versus primary air ratio shows the opposite trend. Similarly, the reverse effect of increasing burner swing and SOFA air swing can be observed. Moreover, the $NO_x$ emission rises monotonously with the growth of air staging. For Fig. 3(f), a larger range of impactor stands for the greater impact. Compared with each other, the air staging is the most influential factor, with the range of 27.7, which is very close to the SOFA air swing (26.4). The burner swing takes the least influence, with the range of 12.7. Among all 16 simulation cases, the lowest $NO_x$ emission is 208.8 mg/Nm$^3$, at 35% BMCR, primary air ratio of 0.24, air staging of 0.75, burner swing of 15°, and SOFA air swing of 0°.

## 4. CONCLUSIONS

In this study, the effect of operating load, primary air rate, air staging, burner swing, and SOFA air swing on $NO_x$ emissions at furnace exit is comprehensively investigated. The orthogonal tests are adopted to analyze the impact of influencing factors. Conclusions can be drawn as following:

(1) The effects of operating load and primary air ratio on $NO_x$ emissions are opposite. So does burner swing and SOFA swing. Only for the air staging, $NO_x$ emissions increase monotonously with its growth.

(2) The lowest $NO_x$ emission among all cases is 27.8% lower than the basic case. By adjusting the operating parameters, $NO_x$ emissions can be significantly reduced.

(3) Among all influencing factors, the air staging has the greatest impact on $NO_x$ emissions, while the burner swing takes the least impact.

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