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Optimization of Key Technologies of Boiler Low Concentration Nitrogen Combustion and Temperature Control

Anpeng Zhao

School of Energy and Power Engineering, North China Electric Power University, Baoding, China

*Corresponding author e-mail: 20666802056@qq.com

Abstract

Boiler is an important combustion device, which can efficiently convert the physical energy, chemical energy and electric energy in fuel into steam, high-temperature water or organic heat carrier with certain heat energy. However, due to the high emission concentration of nitrogen oxides(NOx), it will easily lead to serious air pollution problems. In addition, too high combustion chamber temperature will cause a waste of resources. In this paper, the combustion process state of the boiler is simulated in detail by means of numerical simulation. It is proposed to increase the secondary controllable burnout air and reduce the area of the secondary air nozzle in the main natural area, and the NOx emission affected by it is further simulated. According to the simulation results, the transformation design of low nitrogen combustion is carried out, and the optimization scheme of low nitrogen combustion and combustion chamber cooling is put forward.

Keywords

Nitrogen Oxides (NOx); High Emission Concentration; Combustion Chamber Temperature; Numerical Simulation.

1. Introduction

Boiler is an important combustion device, which can efficiently convert the physical energy, chemical energy and electric energy in fuel into steam, high-temperature water or organic heat carrier with certain heat energy. However, due to the high NOx emission, it will easily lead to serious air pollution problems[1].

Nitrogen oxides are serious hazards and are the culprit of air pollution. Nitrogen oxides, mainly nitric oxide and nitrogen dioxide, are an important factor in the formation of photochemical smog and acid rain. Nitrogen oxides will also bring harm to human health[2]. NO2 in nitrogen oxides can destroy human respiratory system and cause bronchitis and emphysema. When the concentration of no is large, it is very toxic to human body. It will reduce the oxygen delivery capacity of blood, cause tissue hypoxia and even damage the central nervous system. [3].

In this paper, the combustion process state of the boiler is simulated in detail by means of numerical simulation[4]. It is proposed to increase the secondary controllable burnout air and reduce the area of the secondary air nozzle in the main natural area, and the NOx emission affected by it is further simulated. According to the simulation results, the transformation design of realizing low nitrogen combustion is carried out, and the optimization scheme of realizing low nitrogen combustion is put forward [5].

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2. Boiler Operation State Model

2.1 Introduction to Basic Equations

The process of boiler combustion is extremely complex, including the drying, volatilization, ignition, fluctuation and combustion of fuel pulverized coal. Each state and the process of state transition are extremely complex. Among them, the fluctuation state involves gas-solid two-phase flow. Heat transfer mainly involves the process of radiation, convection and heat transfer. The models of boiler operation include turbulent flow model, pulverized coal particle motion and combustion model, heat transfer model and thermochemical combustion model. Firstly, the basic equations used in this paper are introduced.

The continuity equation is shown:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_j}(\rho u_j)=0$$

The expression of momentum equation is shown:

$$\frac{\partial}{\partial t}(\rho h)+\frac{\partial}{\partial x_j}(\rho u_j h)=-p\frac{\partial u_j}{\partial x_j}+\frac{\partial}{\partial x_j}\left(\lambda\frac{\partial T}{\partial x_j}\right)+\phi+S_h$$

Where,

$$\sigma_{ij}=p\delta_{ij}-\tau_{ij},\tau_{ij}=\mu(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})-\frac{2}{3}\mu\frac{\partial u_i}{\partial x_j}\delta_{ij},\delta_{ij}=\begin{Bmatrix}0,i\neq j\\1,i=j\end{Bmatrix}$$

The expression of the energy equation is:

$$\frac{\partial}{\partial t}(\rho h)+\frac{\partial}{\partial x_j}(\rho u_j h)=-p\frac{\partial u_j}{\partial x_j}+\frac{\partial}{\partial x_j}\left(\lambda\frac{\partial T}{\partial x_j}\right)+\phi+S_h$$

Where, $-p\frac{\partial u_j}{\partial x_j}$ is the work done by the surface micro element to the fluid micro element; $\frac{\partial}{\partial x_j}\left(\lambda\frac{\partial T}{\partial x_j}\right)$ is the energy transformation caused by heat conduction per unit volume; ϕ is the part of viscous action that converts mechanical energy into heat energy. S_h is radiant heat, chemical reaction heat, heat conduction between phase flows and natural heat convection.

2.2 Model Introduction and Meshing

Considering that the gas flow in the boiler is a three-dimensional turbulent reaction flow, which is mainly a two equation model based on the k-ε model of turbulent kinetic energy k and dissipation rate and there is a strong swirling flow in the boiler, the turbulence model adopted is a realizable k-ε model with swirling correction. Considering that the movement of pulverized coal particles is a typical turbulent gas-solid two-phase flow with chemical reaction, the stochastic particle trajectory model is adopted. Its principle is that particles are grouped according to the initial size, the velocity, temperature and basic physical properties of particles are defined, and the effects of turbulence and

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gas-phase fluctuating random velocity on particles are added to the Lagrange coordinate system, The random orbits of particles are calculated from the instantaneous momentum of particles. P-1 model is selected for thermal radiation, because under normal working conditions, the combustion flame temperature of the boiler is high, but the flow rate of flue gas is not high. Considering that the amount of fast NOx is very small and the process is very complex, the influence of fast NOx will be ignored in this paper. For thermal NOx, this paper adopts a set of chemical formulas that are highly temperature dependent, that is, the extended Zeldovich mechanism. For fuel type NOx, the overall reaction rate model is adopted, which assumes that N in coal volatile is released in the form of HCN and NH and oxidized to produce NO, and N in coke reacts directly to produce NO. The boiler model and simulation grid division are shown in Figure 1.

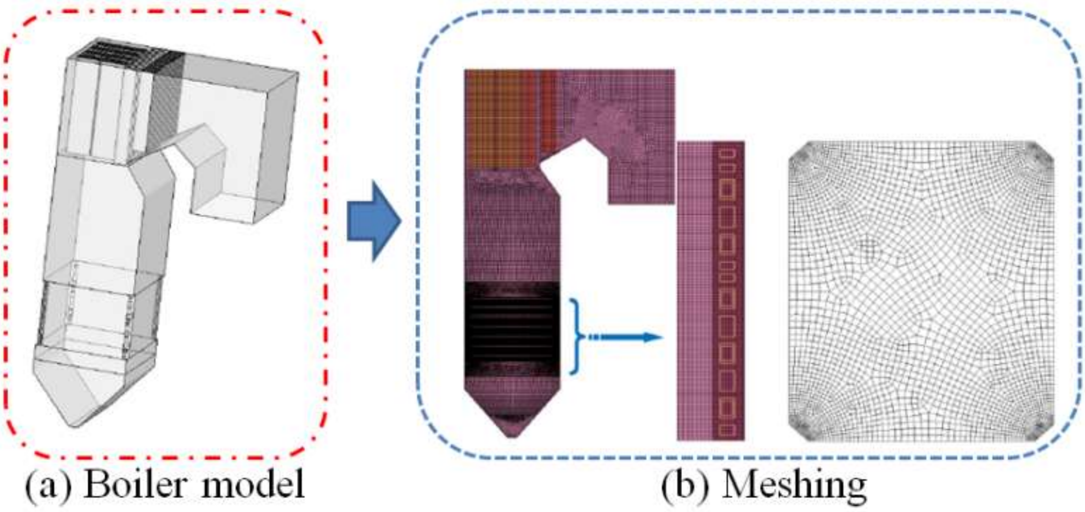

Figure 1. Motor output torque change waveform

3. Transformation Scheme and Results

3.1 NOx Generation Mechanism

Generally, NOx refers to NO, N, O, no, N, O, etc. the NOx generated by pulverized coal during combustion is mainly no and no, most of which is no, accounting for about 90% ~ 95%. According to the basic theory of its generation, NOx can be divided into thermal NOx, fast NOx and fuel NOx. The main factors affecting the formation of NOx during coal combustion include the characteristics of coal, the peak temperature in the combustion area, the oxygen concentration in the reaction area and the residence time of combustibles in the reaction area.

3.2 Introduction to Transformation Scheme

Through air classification and highly turbulent mixing, the excess air coefficient in the main combustion zone is controlled to be less than 1, so as to form a reducing atmosphere in the main combustion zone. The fuel burns under the condition of hypoxia and rich fuel, and the combustion temperature decreases, so as to inhibit the generation of fuel NOx. In the secondary combustion area, the residence time of pulverized coal in the furnace is prolonged, the mixing intensity of fuel and air is increased, the temperature field is evenly distributed, the combustion efficiency is improved, and the secondary generation of NOx is controlled. In the burnout area, the remaining air is sent to the furnace to supply fuel for burnout, and high-speed turbulence and rotating jet are used. At this time, although the oxygen concentration is high, the generation of thermal NOx is reduced because the flame temperature has been reduced. The schematic diagram of transformation principle is shown in Figure 2.

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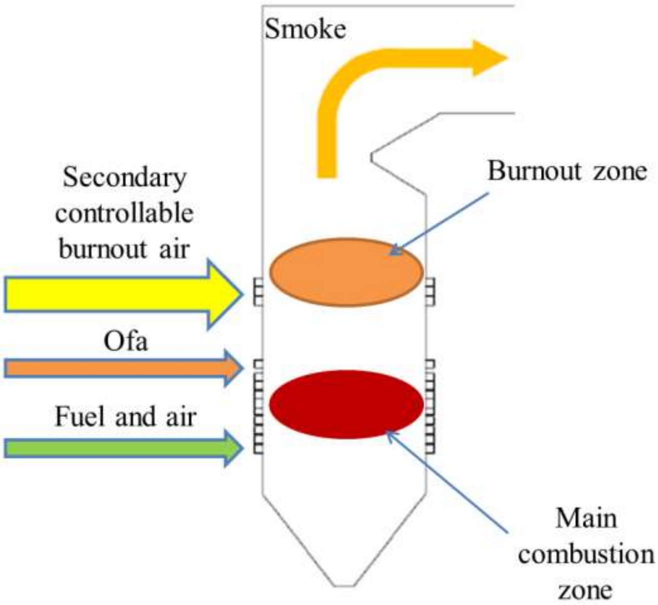

Figure 2. Schematic diagram of transformation principle.

The schematic diagram of the transformation scheme is shown in Figure 3. Two sections of secondary controllable burnout air are added in the area 3-6M away from the top primary air nozzle at the upper part of the furnace, and the air rate accounts for about 20% of the total air volume. Ensure that the primary air nozzle area remains unchanged, so as to ensure the primary air speed and air powder ratio. Finally, reduce the area of secondary air nozzle to ensure the rigidity of secondary air flow.

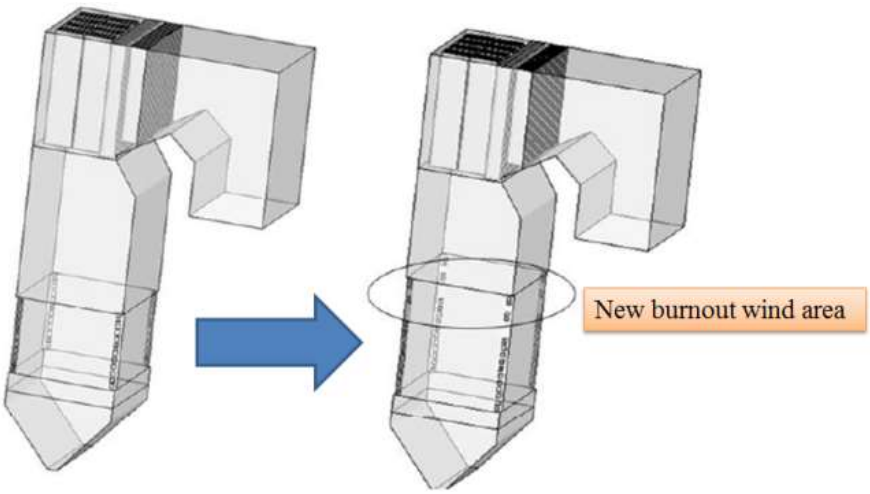

Figure 3. Schematic diagram of transformation scheme

4. Results

First, check the comparison of temperature distribution before and after transformation. Comparing the temperature distribution diagram of the central section before and after the transformation in Figure 4, it is found that the area of the high-temperature area of the main combustion area after the transformation is significantly smaller than that before the transformation, and the temperature gradient in the cross-section direction is also smaller than that before the transformation. After the secondary combustion in the upper part of the main combustion area, the temperature in the furnace rises to near the furnace outlet. Based on this scheme, the model selection is correct, which can accurately show the temperature state change of boiler combustion system.

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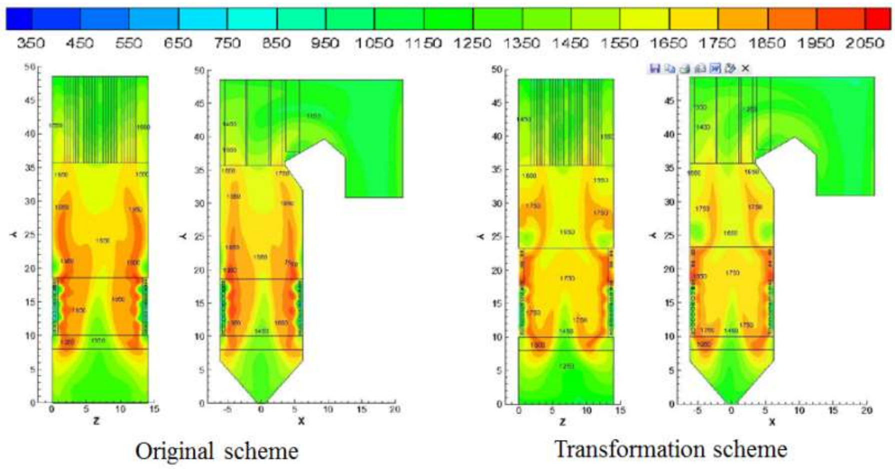

Figure 4. Temperature distribution of central section before and after transformation

At the same time, the mole fraction of NOx after combustion before and after transformation is tested through actual tests, as shown in Figure 5. Comparing the NOx concentration curve before and after the transformation in the figure, it can be found that the NOx concentration after the transformation is lower than that before the transformation, which is conducive to eliminating the reduction of hazard. Firstly, this shows that the scheme of increasing the secondary controllable burnout air and reducing the area of the secondary air nozzle in the main natural area is correct. Through the simulation test, the boiler temperature of the modified scheme is low. Through the real test, it is verified that the modified scheme can effectively reduce NOx and realize low nitrogen combustion.

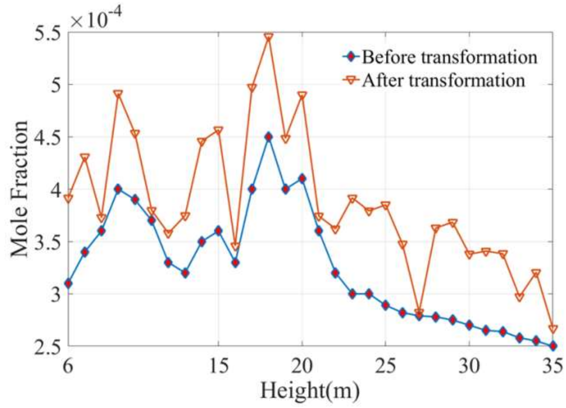

Figure 5. Mole fraction of NOx after combustion before and after modification

5. Conclusion

Boiler is an important combustion device. Due to the high NOx emission, it will easily lead to serious air pollution and excessive combustion chamber temperature. This paper studies it by combining numerical simulation with practical test. The scheme of reducing the area of the secondary air nozzle in the main natural area while increasing the secondary controllable burnout air is given. Through simulation and test, it is verified that the transformation scheme has positive significance for the reduction of combustion temperature. At the same time, it also reduces the NOx concentration, improves the cleanliness, and is of positive significance to environmental protection.

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