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NUMERICAL ANALYSIS OF INFLUENCE OF DIFFERENT SOFA RATIOS ON NOX EMISSIONS FOR PULVERIZED COAL BOILER

Xiangcun Qi and Mo Yang
School of Energy and Power Engineering
University of Shanghai for Science and Technology
Shanghai, PR China

Yuwen Zhang
Department of Mechanical and Aerospace Engineering
University of Missouri
Columbia, MO 65211, USA

ABSTRACT

Influences of different SOFA ratios on NOx emission in a tower pulverized coal fired boiler that burners are arranged in the front and the rear wall are investigated in this paper. The front wall is arranged with three layers of burners, and the rear wall is arranged with two layers of burners. The upper layers are the SOFA nozzles. We adopt the method of adding SOFA to reduce NOx emission, and analyze the influence of SOFA on the internal combustion and NOx emissions for pulverized coal boiler. The results show that the addition of SOFA makes the pulverized coal fired boiler form a reduction zone in the main combustion zone, which can inhibit the NOx production increase, so as to achieve the goal of reducing NOx emissions. And the results show that, it is not true that the more SOFA ratio, the less NOx emissions. In fact, the percentage of SOFA has an optimal value, and below or above of this value, NOx yield will increase. Through comparison of different ratios of SOFA distribution modes with the furnace temperature, O_2, CO and NOx, we analyze the influence of SOFA ratio on the internal combustion for pulverized coal boiler, and provide some guidance and bases for the optimization of other similar units.

Keywords: Pulverized coal boiler; NOx; SOFA; Numerical simulation

1. INTRODUCTION

With the rapid economic development, pollution control began to be taken seriously in developing countries. Wherein the nitrogen oxide pollution has brought great damage to the mankind, it will not only cause acid rain to damage plant, but also damage the ozone layer, and cause the greenhouse effect. Nitrogen oxides can react in the atmosphere, and produce photochemical smog, meanwhile, the harm to human and other animals is also serious that there is a strong stimulation to respiratory organs and carcinogenic effect.

NOx comes from the burning of fossil fuels mainly, especially the combustion of pulverized coal in thermal power plants. At present, there are two main ways to reduce the NOx emission of coal-fired power plants [1]: one is to increase the denitrification device at the outlet of economizer [2], and the other is to improve the combustion in the furnace to reduce the NOx emission [3-4]. The cost of the initial investment for the former is large and the subsequent reaction and catalyst are also very high. Therefore, it will be desirable to reduce the NOx emissions by the second method. The NOx emission at the outlet of economizer is related to the boiler capacity, structure, combustion equipment, coal, furnace temperature, and oxygen content and operation mode.

Gao et al. [5] analyzed the distribution characteristics of temperature, thermal NOx and fuel NOx in the furnace by numerical simulation under different loads, and results showed that the input of SOFA will make the fuel NOx emissions decrease significantly. Li et al. [6] and Hao et al. [7] studied a 300MW coal-fired boiler and a 1000 MW Tangentially Fired Pulverized-Coal Boiler of low NOx combustion retrofit, which increase the SOFA system, making air depth classification, can reduce the production of NOx. Ma et al. [8] reported that the introduction of SOFA resulted in a low-oxygen and strong-reducing atmosphere in the lower furnace region to reduce NOx emissions evidently. Li et al. [9] focused on the tangentially fired boiler with low nitrogen transformation and analyzed the furnace NOx emission characteristics. The results showed that the SOFA can effectively reduce the NOx yield and the higher of air damper opening degree, the smaller NOx yield of furnace outlet.

However, it is not true that the more SOFA, the less NOx emissions. Influences of different SOFA ratios on NOx emission in a tower pulverized coal fired boiler that burners are arranged in the front and the rear wall are investigated in this paper. Through comparison of different ratios of SOFA distribution modes with the furnace temperature, O_2, CO and NOx, we will analyze the influence of SOFA ratio on the internal combustion for pulverized coal boiler, and provide some guidance and bases for the optimization of other similar units.

2. OBJECT OF STUDY

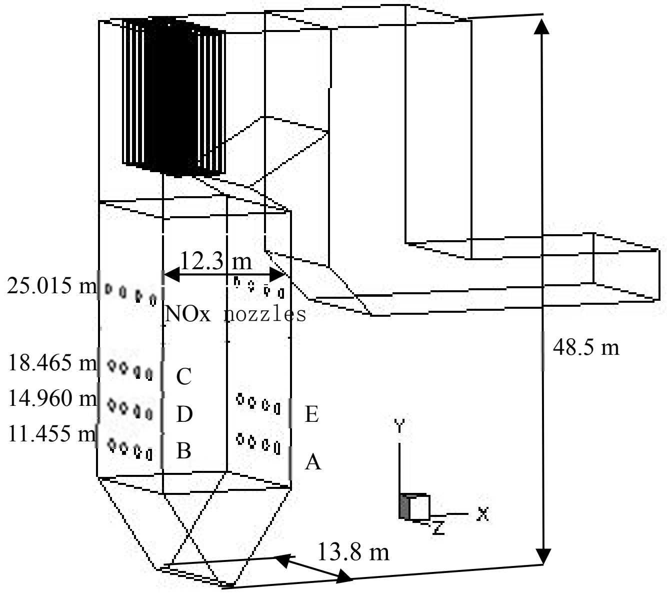


Fig.1 Physical model and calculation model

The object of this paper is to study a B&WB-1025/17.5-M type single chamber, single steam drum, front and back wall convection combustion of pulverized coal boiler (Babcock & Wilcox Beijing Company). Burners are arranged in the front and the rear wall of the boiler. The front wall is arranged with three layers of burners (from bottom to top are B, D and C), and the rear wall is arranged with two layers of burners (from bottom to top are A and E), with each layer having 4 burners. The upper layers are the SOFA nozzles at the same elevation. This model of pulverized coal boiler is shown in Figure 1, and width is 13.8m (X direction), high is 48.5m (Y direction), depth is 12.3m (Z direction) of the furnace. The height of the first layer burners is 11.455m, the height of the second layers is 14.960m, the height of the third layers is 18.465m, and the height of the SOFA nozzles is 25.015m.

In this paper, the analysis of the boiler operating conditions is 270MW (The full load of the boiler is 300MW, but in the actual operation of the power plant, it is running under the 270MW load most of the time), with opening B, A, D, E layers (C only two times the wind) of the boiler. Firstly we simulate the currently existing plants working conditions, and the distribution of pulverized coal and air is in accordance with the actual conditions. The simulation results and the experimental error are low, so that the simulation method is valid. Through comparison of different ratios of SOFA distribution modes with the furnace temperature, O2, CO and NOx, we will analyze the influence of SOFA ratio on the internal combustion for pulverized coal boiler.

3. NUMERICAL METHOD AND MESH GENERATION

Three-dimensional steady-state model is employed to simulate the combustion and NOx formation in pulverized coal fired boiler. Grid is structured hexahedral mesh, and specific division as shown in Figure 2. After grid size independent test, the total number of grids is about 2.26 million. The pressure-based solver is used to simulate the cold and hot state of the boiler, and use the method of initial temperature field (2000K) for ignition. Firstly, the combustion in the furnace is simulated only, and the generation of NOx is not considered. Finally, the post processing is used to generate the NOx.

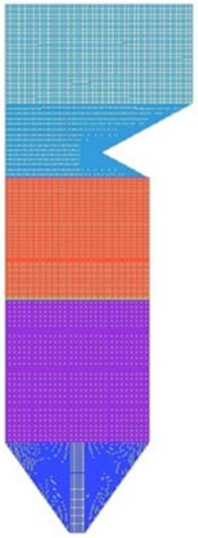


Fig. 2 Grid division in the furnace

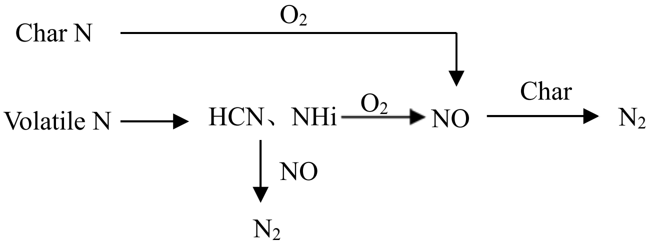


Fig. 3 Formation mechanism of fuel NOx

According to the theory of combustion of pulverized coal in the furnace, gas turbulent flow model is the realization k-ε (2eqn) model. Turbulent dispersion of coal particles uses discrete random walk model, and devolatilization model is single-rate. The char combustion model is kinetics/diffusion-limited, and the radiation heat transfer is simulated by the P1 radiation model; turbulent flow diffusion flame uses the Non-Premixed combustion model[10]. And NOx formation uses PDF transport equation model. Prompt NOx is less in pulverized coal boiler, so it is neglected. Thermal NOx formation process is a no branch chain reaction, with its formation mechanism represented by Zeldovich reaction [11]. The fuel NOx reaction is relatively complex, using the De Soete model [12], and its formation is divided into two parts, the oxidation of volatile N and the oxidation of char N, as shown in Figure 3.

4. NUMERICAL RESULTS AND ANALYSIS

The analysis of the boiler operating conditions is 270MW, and the total air volume and total amount of coal remain unchanged. Conditions of five different ratios of SOFA are numerically simulated by adjusting the air ratio. Different air distribution is shown in Table 1.

Table 1 different air distribution modes

	primary air ratio /%	secondary air ratio /%	SOFA ratio/%
Case 1	21.54	52.44	26.02
Case 2	21.54	47.51	30.95
Case 3	21.54	44.98	33.48
Case 4	21.54	43.48	34.98
Case 5	21.54	42.44	36.02
Case 6	21.54	39.98	38.48

4.1 NOx yield under different operating conditions

NOx yield changes with the SOFA ratio as shown in Figure 4. It can be obviously seen that there is a prominent relationship between NOx production and SOFA ratio. It is not to say that the more SOFA ratio, the better air staging and the less NOx emissions. In fact, the percentage of SOFA has an optimal value, below or above which NOx yield will increase. In this condition, when the SOFA ratio is 34.98%, NOx yield is minimum. When the ratio of SOFA is less than 34.98%, the NOx yield is decreased with the increase of the SOFA ratio, which accords with the characteristics of air staged combustion. In the main combustion zone there is a lot of NOx to be reduced to N_2, resulting in less NOx production.

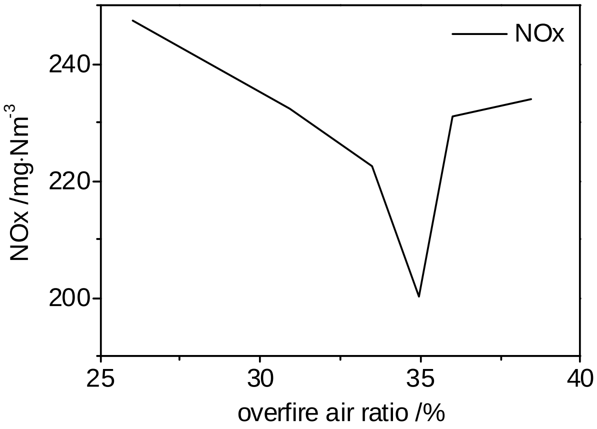


Fig. 4 The output of NOx under different SOFA ratios

When the ratio of SOFA is more than 34.98%, the yield of NOx is increased instead of be decreased with the increase of the SOFA ratio. In order to explore the reasons, this paper selects case 1, case 3, and case 5 as the research objects. Through comparison of different air distribution modes with the furnace temperature, O_2, CO and NOx, make a detailed analysis of the law.

4.2 Temperature distribution in furnace

The average temperature of each section in the furnace is changed with the height as shown in Figure 5. It is evident that the mean temperature of the section in the main combustion zone is the highest. And the highest average temperature is less than 1600K, so the thermal NOx production is less. The majority of NOx under this combustion condition is fuel NOx.

From Figure 5 it is clear that the variation of temperature appears two obvious cooling zones along the furnace height. The first cooling zone is in the region about 11m, which is located in the vicinity of the first layer of burners. In this area, there is a large amount of secondary air into the furnace, which produces a cooling effect, so it appeared for the first time of the temperature drop. The second cooling zone is in the region around 23m, which is just NOx nozzle position. SOFA also has a cooling effect, so that the furnace temperature appeared to cool once. Since then the temperature is increased further with the unburned coal combustion.

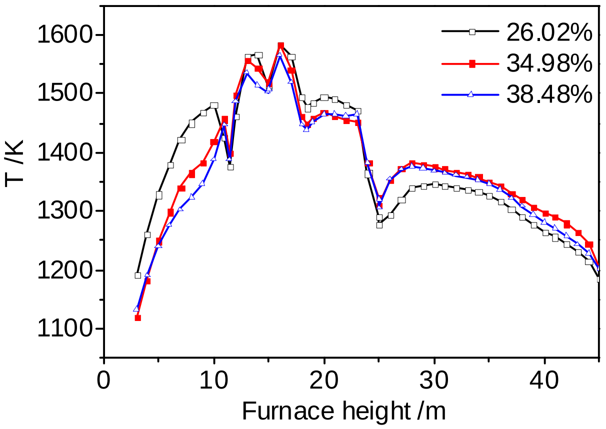


Fig. 5 Variation of temperature with the height

Comparison of these three conditions, when the SOFA ratio is 26.02%, the average temperature is highest in the main combustion zone and cold ash hopper zone; when the SOFA ratio is 38.48%, the average temperature is the lowest. Because when the rate of SOFA is 26.02%, air into the main combustion zone is most through the burner, and burning is the strongest; on the contrary, when the rate of SOFA is 38.48%, the air into the main combustion zone is least, so combustion is not sufficient and temperature is lowest. In the vicinity of NOx nozzle, when SOFA ratio is 26.02%, the temperature is the lowest; when the wind burn rate is 38.48%, temperature is slightly lower than the case when separated overfire air ratio is 38.48%. Although separated overfire air is more, burning is stronger in the upper region, the temperature does not rise very quickly due to the cooling effect of SOFA, and the temperature is higher when separated overfire air ratio is 34.98%.

4.3 O_2 distribution in furnace

The average oxygen content of each section in the furnace is changed with the height as shown in figure 6. It can be seen that in the main combustion zone, only the area nearby the burner nozzles has a higher oxygen content, and the oxygen content is very low between the two adjacent layers of burners; this is not conducive to the oxidation of N. Although there are three layers of burners to continue to provide the air required for combustion, oxygen presents a decreasing trend with the increasing of the height. The oxygen is less than 3% in most regions, indicating that the input of SOFA is conducive to the formation of fuel rich environment, which will greatly reduce the yield of NOx.

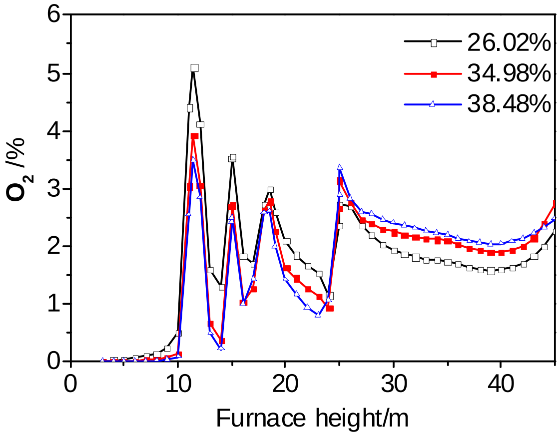


Fig. 6 Variation of O_2 with the height

From the figure it can be seen that when separated overfire air ratio is 26.02%, oxygen content is more in cold ash bucket zone and the main combustion zone, which is not conducive to air staged combustion and the reduction of NOx yield. However the oxygen content is obviously less in the two conditions of the more SOFA, and they are both in fuel rich combustion in the main combustion zone, which is conducive to reduce the NOx production. In the NOx nozzle position and above area, when separated overfire air ratio is 38.48%, oxygen content is more. Intense burning in this area will generate a lot of NOx, which is not conducive to the reduction of NOx, although there are favorable for the sufficient combustion of pulverized coal. The condition is better relatively when separated overfire air ratio is 34.98%, and the oxygen content is not too much in the NOx nozzle position and above area; this is beneficial to the formation of fuel-rich fires in the main combustion zone, and will not cause excessive NOx.

4.4 CO distribution in furnace

The average CO content of each section in the furnace is changed with the height as shown in Figure 7. It can be obviously seen that in the cold ash bucket zone CO yield is the highest even more than 10%, indicating that the combustion is weak in this zone and the amount of oxygen in the region is almost 0 from Fig. 6. In the main combustion zone, CO content is relatively high, basically maintains at around 6% and oxygen is only about 3%, and this zone is in fuel rich combustion, indicating that the reducibility is good. This will make a lot of NOx to be reduced to N_2, so as to reduce the emission of NOx at the exit of furnace. But in the vicinity of NOx nozzle CO content begin to sharply reduce, until below 1%, indicating that in this region without the burnout of pulverized coal has been fully combustion, therefore CO content is relatively low, easy to produce a lot of NOx and make NOx yield increased.

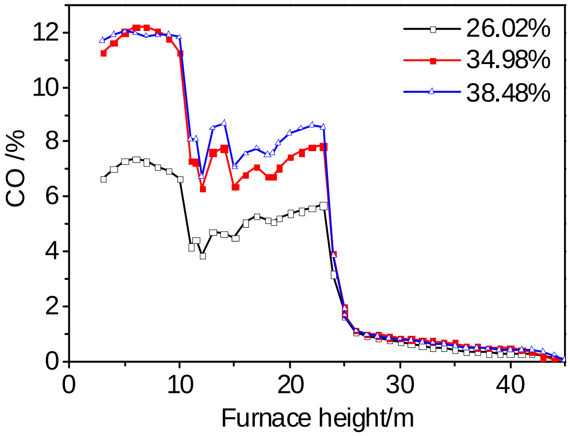


Fig. 7 Variation of CO with the height

From the figure can be seen that in cold ash bucket zone and the main combustion zone, the more SOFA ratio, the more CO, and the less NOx due to the good reducibility. But in NOx nozzle position and above area, unburnt pulverized coal has been fully combustion, therefore CO content is relatively low in this area, easy to produce a lot of NOx and making furnace outlet NOx emissions increase.

4.5 NOx distribution in furnace

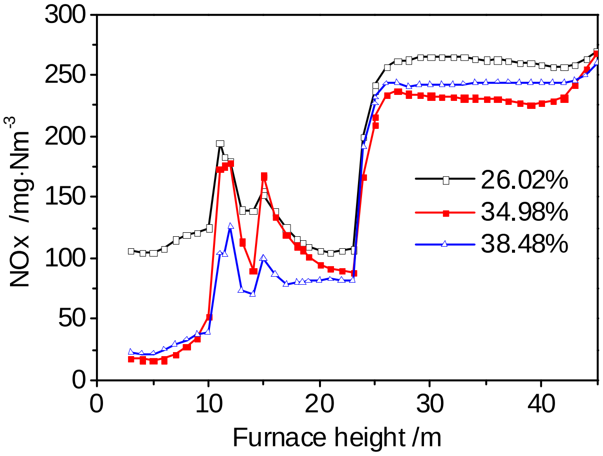
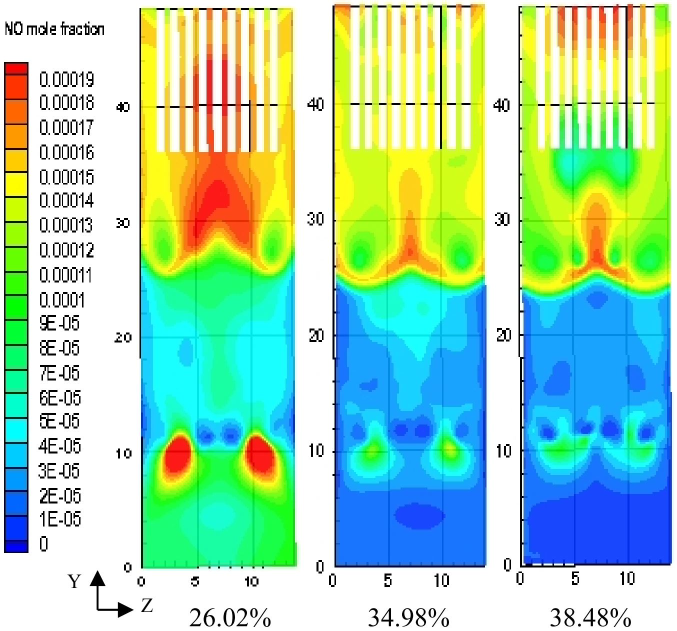


Fig. 8 Variation of NOx with the height

The average NOx variation of each section with height is shown in Figure 8, and Figure 9 is the distribution of NOx in the longitudinal section of the furnace (X=0). It can be seen from the Figs. 8 and 9 that there is a NOx reduction area in the main combustion zone, and the yield of NOx is decreased gradually. CO content is very high in this reduction area from Figure 7, and it shows that the reducibility is better, and it is not conducive to the formation of NOx; it will consume NOx constantly in this area, so that the yield of NOx has a downward trend. But in the vicinity of NOx nozzle， the NOx yield begin to increase rapidly from figure 8. This is due to the input of SOFA through nozzles which have destroyed the reductive environment, and supply a large amount of air for coal combustion, and NOx production begin to increase. So if we do not control the generation of NOx in the area, even though the main combustion zone NOx yield is very low, NOx yield is still large in the exit of furnace.



26.02% 34.98% 38.48%

Fig. 9 NOx distribution (X=0)

The case that the ratio of separated overfire air is 26.02% produces large amounts of NOx (which is more than the other two conditions 60mg/Nm^3) in cold ash hopper region. Although in the main combustion zone it also has obvious reduction, and NOx is reduced about 80mg/Nm^3, its yield is always the most among these three cases, and along with the injection of SOFA, there is a lot of NOx generation, resulting in the NOx yield of furnace exit is the most. Comparison of these three conditions, when the SOFA ratio is 34.98%, the average NOx yield is more than the condition which ratio of SOFA is 38.48% in the main combustion zone and cold ash hopper zone. But due to the reduction of NOx in reducing zone, the NOx production of these two working conditions is similar. And the case which ratio of separated overfire air is 38.48% invests more SOFA ratio, and from Figure 7 it can obviously find that the CO content is the highest in the main combustion zone; this indicates that combustion is more insufficient in the main combustion zone whit this condition. A lot of pulverized coal is burning strongly in the vicinity of SOFA nozzles, and the NOx yield increases rapidly, resulting in that NOx yield at the exit of furnace is higher than the condition which the SOFA ratio is 34.98%. So when the SOFA ratio is 34.98% the NOx yield is least at the exit of furnace.

5. CONCLUSION

Based on the detailed analysis of different ratios of SOFA conditions, the following conclusions can be drawn:

(1) Due to the addition of SOFA, the main combustion zone is in fuel rich combustion, and produces a large amount of CO forming a reduction zone which can suppress NOx generation.

(2) Due to the input of SOFA, unburnt pulverized coal is burning strongly in the vicinity of SOFA nozzles under the condition of oxygen enrichment, which is accompanied by a lot of NOx.

(3) The vicinity of SOFA nozzles will also produce a lot of NOx, and it is not to say that the more SOFA ratio, NOx yield of furnace outlet will be less. In fact the ratio of SOFA has an optimal value, and below or above of this value, NOx yield will increase.

(4) Not only control the main combustion zone to form a better reducibility to keep the NOx yield not too much, but also control the NOx production in the vicinity of SOFA nozzles, and the ratio of SOFA is not too much. Otherwise, the NOx production of furnace will increase due to the input of a large amount of SOFA.

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