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Influence of Burnout Wind & Biomass Gas on Combustion Process of Coal-Fired Boiler: Based On Numerical Simulations

Hussain Ahmed Madni Gondal*, Xiaotao Zhang, Qincongcong
School of Electrical Engineering
North China University of Water Resource and Electric Power
Zhengzhou 450046, China

Abstract： *The air graded combustion of a coal-fired boiler of 400 MW units in a power plant was reconstructed, to see the impacts of the burnout wind and mixing biomass gas on combustion and NOx emission of coal fired boiler. Study is based on numerical simulation adding three layer separation burnout of (SOFA) to main burner. Coal combustion and pulverized coal blending was built. Simulation was carried out with pine gas and no SOFA (15% and 25% air distribution ratio) for combustion process and behavior. Different conditions were applied to analyze the NOx emission, Velocity field and temperature field. Results acquire through simulation suggest that under condition of no SOFA and only 15% SOFA wind can form a tangent circle and field of velocity is stable but burning wind is not ideal under 25% SOFA compared with non SOFA combustion process of coal fired boiler. Compared with the non SOFA pure coal combustion conditions, the central temperature of the main combustion zone is reduced under SOFA condition, and 2.31K, 22.48K, and 5 are reduced respectively. .56K and 45K, while the temperature in the SOFA region rises, the volume fraction of CO and O2 in the furnace outlet increases, the CO2 volume fraction decreases. When the SOFA air distribution ratio increases from 15% to 25%, the average mass concentration of NOx furnace outlet is reduced by 12.76% and 14.28% respectively under the pure coal condition, and 25% and 22.4% respectively under the combustion conditions.*

Key words: *burnout wind; pine wood gas; mixed combustion; NOx emission; numerical simulation*

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I. Introduction

Various measurements are taken in power plant for the coal fired boiler in order to reduce pollutant and elements harmful. In the air classification low NOx combustion, the literature [1-3] applied the low NOx combustion technology to the coal fired boiler, and obtained the better NOx removal rate. The literature [4-5] highlighted the impact of air graded combustion process on combustion traits of coal fired boiler and achieve economic benefits and removal of NOx. Literature was used to one dimension settler to get the best mixing scheme of pulverized coal; literature [8-10] finds that the removal rate of NOx is increased after mixing biomass, but the fly ash content in the furnace outlet is increased, the heat area ash and the corrosion degree are aggravated. By selecting the appropriate excess air emission coefficient GFB, optimum results can be achieved. Literature [15-16] based on the Aspen Plus platform to establish biomass gasification model, and compared the simulated numerical value with the experimental results, verifying the feasibility of the simulation study. [17-18] obtained the best reburning condition of burning biomass gas in coal-fired boilers; literature [19] simulated the combustion process of biomass gas with different proportions of coal fired boilers. Increase mixing ratio, lowering overall temperature level and the emission of pollutants were more visible and obvious. There are few studies on biomass burning on the combustion characteristics and NOx emissions of the boiler.

Based on the 400 MW CFB in a power plant, 3 layers of SOFA are added to the air graded combustion in 5 m above the main burner, and the influence of the mixed combustion of SOFA and biomass gas and pulverized coal on the combustion characteristics of the boiler is simulated and analyzed, which provides a theoretical basis for the emission reduction of nitrogen oxides and the utilization of biomass in the coal fired boiler.

1 BOILER CHARACTERISTICS

1.1 Research object

1.400 MW unit boiler of a power plant adopts SG-1117/17.5-M749 type
2. Intermediate reheat natural circulation drum boiler,

3. Single furnace chamber and inverted U layout.

Boiler width, depth and height are 15.39 m, 13.64 m, 54.3 m respectively, the boiler chamber volume is 7754.1m3, the combustion mode of the furnace is four angles tangential combustion, the burner is 11 m, 14 layers of pulverized coal nozzles and 8 layer two air nozzles are installed, and the air nozzle area is 0.512 m * 0.512 m, two air spray. The oral area was 0512 m x 0.574 m. The boiler structure is shown in Figure 1. Selected coal type is Yima bituminous coal, and its coal quality characteristics are shown in Table 1.

Tab.1 analysis of coal of characteristics

w_{ad}/%				w_{daf} /%				
w(M)	*w*(A)	*w*(V)	*w*(FC)	*w*(C)	*w*(H)	*w*(O)	*w*(N)	*w*(S)
4.50	22.15	14.55	45.80	78.53	3.69	7.28	.95	1.55

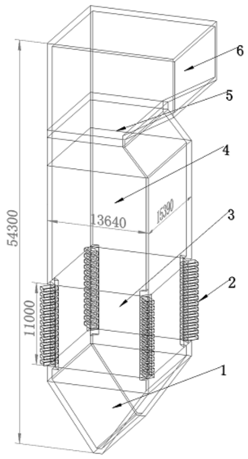

Fig.1 Boiler structure

1.2 Combustion process and theoretical basis

Measurements to reduce NOx pollutant in the air are taken seriously and many works in the industry has been under consideration to reduce NOx emissions. In the process air and fuel staged combustion with flue gas recirculation strategies are adopted by plants. Air staged combustion uses the grading air supply, resulting in the change of combustion dose to achieve the control of NO emission (for reduction purpose). The production of thermal & fuel nitrogen depends on the meditation of oxygen in incineration zone, that is, overkill air coefficient has great influence on NOx fabrication. When the surfeit air coefficient is <1, the first stage combustion zone is rich in fuel. The first period air can only provide some fuel, which not only reduces the temperature of the flame, but also has a large number of unburned and unfinished combustion harvest in the blaze, which not only inhibits the reaction of nitrogen and oxygen in the air, but also the intermediate products produced by the thermal cracking of nitrogen organic compounds in the fuel cannot be entered because of oxygen. The NOx is formed by one-step oxidation, so the combustion of fuel rich state in the first stage combustion zone can inhibit the formation of NOx. To ensure fuel burnout, a second stage wind must be supplied. Because the second stage wind is selected in the lower gas temperature position into the furnace, although alpha >1, although the air has surplus, but because of the low temperature combustion, so the second stage of combustion can also inhibit the generation of NOx.

Three layers of SOFA nozzles are added to the top two 5m of the foremost burner to bring out air staged combustion modification, and the SOFA nozzle area is 0.512 m 0.737 m. The reconstructed boiler structure and burner are shown in Figure 2. In the picture, A, B, C, D, E, and F are the wind blets before and after the transformation respectively, and AA, AB, BC, CD, DE, EF, etc. are respectively the two wind blets before and after the transformation.

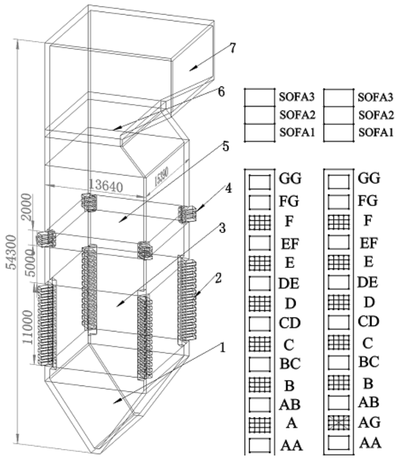

Fig.2 Boiler structure and burner arrangement

Biomass gas is a syngas formed by gasification of biomass in a gasifier. It mainly includes flammable and non flammable gases such as CO, H2 and CH4. After purification, the biomass gas enters the boiler to mix with the coal through the burner, and its mixing process. The biomass gasification characteristics of the unit mass and the characteristics of the biomass gas obtained at the highest gasification efficiency are shown in Table 2.

Tab.2 Characteristics of pine gas at high temperature

/%					
CO	H_2	CH_4	CO_2	N_2	H_2O
21.2	18.02	1.39	5.89	39.9	4.6

The ratio of combustion to biomass is equal to the percentage of heat input to total boiler input. Therefore, the volume flow of biomass gas at x (c) is:

$$V_q = \frac{\alpha B_0 \times Q_{net,ar}}{Q_{syngas}} \qquad (1)$$

In the formula: Vq - the flow of pine gas at the temperature of X (c), m3/s, alpha blending ratio,%, this article selects 10%; B0 - coal consumption per unit time under the burning condition of pure coal, kg/s; Qnet, ar - coal powder low calorific value, kJ/kg; Qsyngas - under the condition of combustion, the single

Volume pine gas is at the temperature x (c). The total heat, kJ/m3;
The pine gas is injected into the furnace from the lowest primary air vent, and its speed is as follows.
:The pine gas is injected into the furnace from the lowest primary air vent, and its speed is as follows.:

$$v_{syngas} = \frac{V_q}{4S_1} \qquad (2)$$

Type: vsyngas - the pine wood gas velocity at high temperature, m/s, S1 - lowest primary air nozzle area, m2; This paper mainly studies the export NOx emission, and the proportion of NO is the largest in NOx, and the mass concentration of NOx is calculated by 0.95 occupation ratio and 6% dry oxygen content, while NO2 and N2O are less. The formula of NOx mass concentration in dry flue gas is as follows:

$$NO_x = \frac{NO}{0.95} \times 2.05 \times \frac{21-6}{21-O_2} \qquad (3)$$

Formula: NOx - dry flue gas NOx mass concentration under standard condition, mg/Nm3; NO - dry flue gas measured NO volume content, %; O2 - dry flue gas measured oxygen content,%.

In order to analyze the effects of pure coal combustion and pine gas mixing on Combustion Characteristics and NOx emission of coal-fired boilers under the same SOFA conditions, the following 5 working conditions are studied: working condition 1 is no SOFA pure coal combustion condition, working condition 2 is SOFA pure coal combustion condition with air distribution ratio of 15%, and 3 is SOFA pure coal combustion worker with air distribution ratio of 20%. The condition 4 is SOFA with air distribution ratio of 15% and burning 10% pine gas combustion conditions. The working condition 5 is SOFA with air distribution ratio of 20% and blended with 10% pine gas combustion conditions. The initial parameters of the 5 simulated operating conditions are shown in Table 3.

Tab.3 Initial parameters

Parameters	*Condition 1*	*Condition 2*	*Condition 3*	*Condition 4*	*Condition 5*
B_0/kg·s^{-1}	31.45	31.45	31.45	32.30	32.30
V_q /m^3·s^{-1}	1	1	1	9.97	9.97
V_z /N m^3·s^{-1}	256.2	256.2	256.2	256.2	288.8
β_{SOFA} /%	0	15	25	15	25
v_1/ m·s^{-1}	20.5	20.5	20.5	20.5	20.5
X_1 /℃	312	312	312	312	312
v_2/ m·s^{-1}	51	31.57	30.12	31.01	32.67
X_2 /℃	313	313	313	313	313
v'_{SOFA} / m·s^{-1}	0	45.57	66.77	44.04	61.72
X_{SOFA} /℃	0	341	341	341	341
v_{syngas}/ m·s^{-1}	0	0	0	51.86	51.86
x/℃	0	0	0	580	580

1.3 Mathematical model and its verification

Combustion process is complicated and full of new experiments especially with pine gas and pulverized coal in furnace it generated heat transfer and mass transfer chemical reaction. One experience flow and two flows in furnace are applied through coal powder and pine gas.

Realizable k- epsilon model is used to simulate the turbulent flow of gas phase, and the two-phase mixture fraction / probability density function (PDF) is used to simulate the gas phase turbulent combustion process, and the P1 model is used to simulate the radiation heat transfer process in the furnace, and the random trajectory tracking model is used to simulate the discrete phase particle trajectories.

A dynamic diffusion limited model was used to simulate the combustion process of coke. The two step reaction model was used to simulate the pyrolysis process of the coke. The simulation results show that the full load pure coal combustion simulation is carried out after the remolding of the unit. When the SOFA air distribution ratio is 25%, the mass concentration of NOx emission in the furnace outlet is 586.5 mg/Nm3, and the measured export NOx emission concentration is 656.69 mg/Nm3 to [20] under the full load hot state test. It is known that the numerical simulation calculation method is more accurate.

II. Result Analysis

2.1 Analysis of velocity field of burner region

Gas velocity field of the first wind, the top two winds, the burnout wind and the flaming angle of the burner under different working conditions are analyzed. The velocity field varies with the furnace height under different working conditions, as shown in Figure 4.

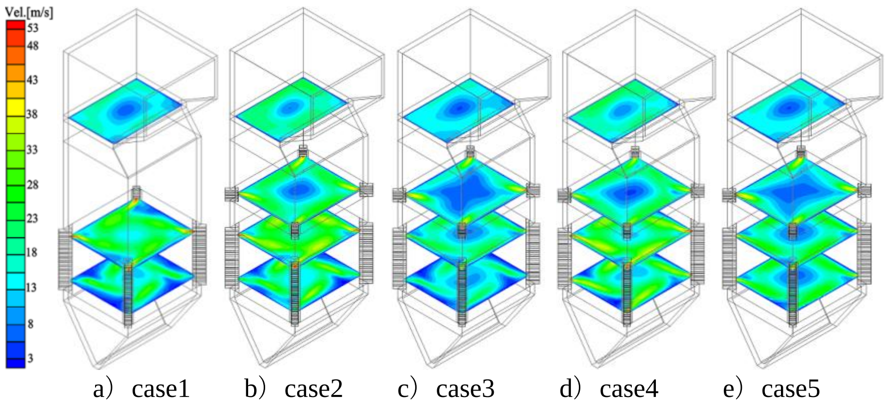

Fig.4 Distribution of velocity fields along furnace height

From Figure 4, it can be seen that under the situation of no SOFA and 15 to 25% SOFA, the first wind (blended with pine gas), two wind and SOFA can all shape a high-quality digression circle, and the swiftness field is stable. It is proved that under the ratio of 15% air distribution, the combustion of the SOFA is stable and the scheme is feasible. Under the ratio of 25% to the on fire wind, there is no debate about the arrangement of unadulterated coal combustion or doping, SOFA formation. The peripheral circle is not very model, which may cause unbalanced combustion in the heating system, when the SOFA condition is applied, the span of the minor level pine wood gas swiftness tangent circle increases.

2.2 The temperature distribution of the central section of the furnace with the height of the furnace

At the center section y =7.6m of the furnace depth, the distribution of the average temperature of the flue gas on the horizontal section of the boiler is shown as Figure 5 in different working conditions.

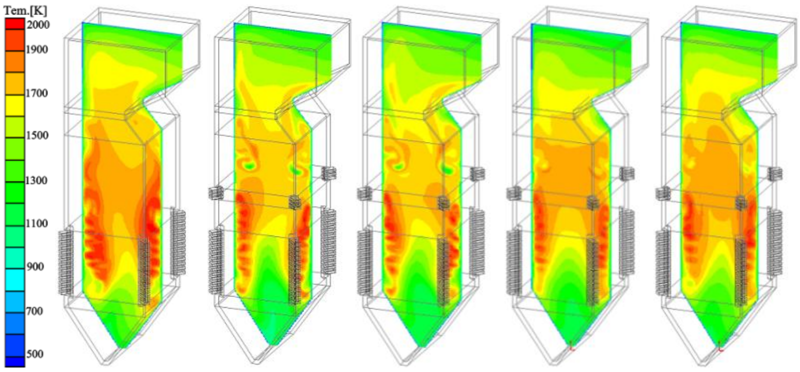

Fig.6 Distribution of temperature on vertical cross-sections along furnace height

From Figure 6, it is known that the average hotness of the furnace underneath is low below different operational conditions, but SOFA causes the combustion center of the furnace to shift up, causing the average temperature of the non SOFA circumstance to be advanced than that of the SOFA. The average temperature decreased progressively without SOFA, while the SOFA working stipulation reached succeeding peaks at about 28m height, and when the ratio of SOFA air allotment was 15%, the limited excess air coefficient of the main combustion area was 1.02, and the effect on the burnout of the pulverized coal was little, so the typical hotness of the furnace center of the working condition 1, working condition 2 and working condition was similar, respectively. For 1815.9K, 1812.6K and 1809.1K, the local excess air coefficient of the main combustion zone is 0.96 when the ratio of the air distribution ratio of the SOFA to 25% is increased, and a certain amount of oxygen affects the burnout of the pulverized coal, which leads to the decrease of the maximum average temperature of the working condition 3 and the working condition 5, respectively, 1788.4K and 1776.8K; at the furnace outlet, the furnace outlet smoke at different operating conditions. The temperatures were 1348K, 1353K, 1386K, 1321K and 1315K respectively.

2.3 Distribution field with the height

the volume fraction of O2 in the bottom of the furnace is higher than that in the case of SOFA (except for the 15%SOFA mixing condition), in which the 15%SOFA mixing condition is far greater than the lowest two air supply, and the excess O2 flows into the bottom of the furnace, so the O2 volume fraction of the working condition 4 is the highest, while CO and CO2 are the highest. The volume of the generation is related to the concentration of O2, so the CO volume fraction of the SOFA working condition is lower in this area. In the main burner area, the O2 volume fraction reaches the peak at the furnace height about 18m, and the pulverized coal is not completely burned near the primary air nozzle, and the peak value of the CO volume fraction is about 20m at the height of the furnace, but the peak value of the SOFA pure coal condition is the peak value. It is obviously higher than no SOFA and SOFA mixing conditions. To the furnace outlet, the volume fraction of O2 and CO decreases gradually in the non SOFA condition due to the burnout of pulverized coal, and for the SOFA condition, the partial excess air coefficient and the continuous combustion of coke in the burnout wind area make the number of O2 and CO body integral to second peaks at about 28 m at the furnace height. At the outlet of the furnace, the volume fraction of O2 is 0.022%, 0.039, 0.052%, 0.391% and 0.318% respectively at the outlet of the furnace. It is known that the volume fraction of O2 in the outlet of the furnace is obviously greater than that of the pure coal, and the volume fraction of CO is 1.68%, 2.48%, 2.82%, 2.43% and 2.86%, respectively. The total combustion loss and the change of CO2 volume fraction are negatively correlated with the change of CO volume fraction, and the CO2 volume fraction of the furnace outlet at different working conditions is 16.65%, 15.84%, 15.80%, 15.98% and 15.57%, respectively.

Compared to the pure coal condition, the average mass concentration of the whole NOx in the burning condition is lower than that of the pure coal, and a small amount of NOx is generated at the bottom of the hearth, and a large number of NOx are generated and reached the peak in the main combustion area. The peak value of the average mass concentration of NOx without the SOFA condition is not at the same level as the peak of the SOFA condition. The degree is because SOFA moves the furnace flame center up and changes the position of thermal nitrogen formation. To the furnace outlet, the average mass concentration of NOx decreases gradually without the SOFA working condition, and the SOFA working condition begins to fall after the second peak of the furnace height about 32m. At the furnace outlet, the average mass concentration of NOx under different working conditions is 676.3 mg/Nm3, 603.5 mg/Nm3, 586.5 mg/Nm3, 500.46 mg/Nm3 and 483.95 mg/Nm3 respectively. Compared with the non SOFA pure coal condition, the average mass concentration of the export NOx decreases with the increase of the SOFA distribution ratio, and the separation decreases 10.76%, 13.28%, 26% and 28.4%.

III. Conclusion

1. Compared with the non SOFA pure coal condition, when the ratio of SOFA air distribution ratio is 15%, each velocity field forms a better tangent circle. With the increase of the air distribution ratio to 20%, the fluid disturbance in the main combustion zone is weakened, and the burning wind tangential circle is not very ideal, which may cause the unstable combustion in the furnace.
2. Compared with the non SOFA pure coal condition, under the same SOFA condition, the average temperature drop of the furnace center in the furnace center is higher than the pure coal condition, and the decrease amplitude is 39.1K and 27.5K respectively when the air distribution ratio is 20%. The volume fraction of O2 and CO in the furnace outlet of the furnace is increased and the CO2 volume fraction is reduced.
3. under the same SOFA conditions, the average mass concentration of the export NOx at the burning condition is lower than that of the pure coal, and the NOx reduction degree of the NOx is 26% and 28.4% respectively when the ratio of the SOFA air distribution ratio is 15% and 20% respectively, and the degree of NOx emission reduction under the pure coal condition is 10.76% and 13.28% respectively.
4. Considering the safe operation of the boiler and the effect of NOx emission reduction, the air graded combustion scheme is more reasonable by using the SOFA air distribution ratio and the 10% pine gas, which can not only maintain stable combustion in the furnace, but also achieve better effect of NOx emission reduction.

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