Numerical simulations of the combustion characteristics for a 660MW tangentially fired boiler with different closing-to-wall air velocities

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Abstract. To solve the problem of high temperature corrosion of water-cooled wall of power station boiler, this paper proposes a new type technology of closing-to-wall air. Taking a 660MW tangentially fired boiler as the research object, numerical simulations were conducted to study the influences of closing-to-wall air velocity on the combustion characteristics in the boiler. The results show that \( O_2 \) concentration in the flowing region is significantly increased, \( CO \) concentration is significantly reduced, and the oxidizing atmosphere in the near-wall region is enhanced. As the closing-to-wall air velocity increases, the rigidity of the airflow is gradually stronger, and the penetration depth of the airflow increases, so that the coverage area of the airflow is increased. The influence of the closing-to-wall air velocity on the combustion effect of the boiler is negligible.

1. Introduction
About 80% of China's utility boilers burning lean coal suffer from the problem of the high temperature corrosion of water-cooled wall with different degrees. In recent years, low NOx combustion technologies were generally adopt on the utility boilers to control the amount of NOx generated during the combustion process by reducing the oxygen atmosphere in the main combustion zone, but at the same time, the reducing atmosphere aggravate the high temperature corrosion of the water-cooled wall.

Closing-to-wall air technology is an effective means to alleviate high temperature corrosion of water-cooled wall in the furnace [1-2]. In this paper, a new type of closing-to-wall air technology suitable for tangentially fired boiler is proposed. Taking a 660MW tangentially fired boiler as a research object, the influence of the closing-to-wall air velocity on the combustion characteristics in the furnace, especially near the water-cooled wall, was studied.

2. The new type of Closing-to-wall air technology
The new type of closing-to-wall air proposed in this paper is shown in Figure 1. The closing-to-wall air nozzle is placed at the position where the water-cooled wall is prone to high-temperature corrosion. Some water-cooled wall tubes are bent toward the inside of the furnace. The gap between the inner wall and the furnace wall forms a double of the closing-to-wall air nozzles. The closing-to-wall air box is arranged outside the furnace wall, completely covering the bended tubes, and is connected with the secondary air box through the connecting pipe. The amount of the closing-to-wall air is controlled by the adjusting valve on the connecting pipe.
3. Object and research method

3.1. Research object
The research object in this paper is a 660MW wall-type tangentially fired boiler. The section size of the furnace is 20.402 meters (width) × 20.072 meters (depth), and the overall height of the furnace is 68 meters. A group of burners are arranged on each side of the furnace wall. The burner is arranged in two stages, with a total of 6 layers of nozzles. A four-layer over-fire air is placed at the four corners of the furnace above the burners. The design fuel of the boiler is lignite.

3.2. Research method
The numerical simulation is performed on a computer equipped with the Fluent 6.3.26 software. The selection of the calculation model is shown in Table 1. The velocity inlet and the pressure outlet are selected as the inlet and outlet boundary conditions respectively. A "no-slip" boundary condition was employed for fluid along the wall. A mesh independence test is conducted. An initial mesh with about 3036812 nodes was first created in the computational domain. The number of mesh nodes was then increased to 3561648, 4052674, 4634352 and 5034782. Mesh independence was checked by comparing the O₂ concentration in the flue gas at the furnace outlet. As shown in Figure 2, the finest mesh (5034782 nodes) and medium-density mesh (4032674 nodes) yield similar results. For this reason, we chose a mesh density of 4634352 nodes and have applied it to all further work reported in this study.

Table 1. Mathematical model for numerical simulation.

| Project                  | Model                                    |
|--------------------------|------------------------------------------|
| Turbulence model         | Can be realized k-ε model [3]            |
| Gas-solid model          | Lagrangian particle trajectory model [4] |
| Radiative heat transfer model | P-1 model [5]             |
| Volatile pyrolysis       | Dual competition model [6]               |
| Volatile combustion      | Mixing fraction PDF method [7]           |
| Coke combustion          | Power - diffusion model [7]              |
3.3. Arrangement of conditions

Four cases are arranged with different closing-to-wall air velocity: 10m/s, 15m/s, 20m/s and 25m/s. The remaining parameters of the four cases are the same. The number of the closing-to-wall air nozzle is 20, and the closing-to-wall air ratio accounts for 2% of the total air supplied into the furnace. The distribution of pulverized coal particle size follows the Rosin-Rammler rule, the average particle diameter is 50 microns.

4. Results and discussion

Figure 3 shows the temperature field near the wall under different closing-to-wall air velocities. It can be seen that the flue gas temperature in the flowing region is significantly reduced, which is basically less than 1000K. In the region that the closing-to-wall air uncovered, the flue gas temperature is generally in the range of 1300K to 1800K. With the increase of the closing-to-wall air velocity, the area of the low temperature region is gradually enlarged.
Figure 4 and 5 show the O$_2$ and CO concentration field in the near wall area under different closing-to-wall air velocities. The O$_2$ concentration in the flowing region is significantly increased to be greater than 2%, while the CO concentration was reduced to be less than 1%. Because of the poor diffusivity of airflow, in the region upper and lower the closing-to-wall air nozzle, the O$_2$ concentration is still less than 2% and the CO concentration is higher than 1%. Due to the influence of the main airflow in the furnace, the penetration depth of the closing-to-wall air jet on the left and right sides is not the same, one in the same direction as the main airflow in the furnace has greater penetration depth. As the closing-to-wall air velocity increases, the rigidity of the airflow is gradually stronger, and the penetration depth of the airflow increases, the coverage area of the airflow is increased, so that the area with oxidizing atmosphere near the water-cooled wall also increases accordingly.

Figure 4. O$_2$ concentration near the wall under different closing-to-wall air velocities.

Figure 5. CO concentration near the wall under different closing-to-wall air velocities.
Figure 6 shows the temperature field in the central cross-section of the upper layer of closing-to-wall air nozzles. The temperature distribution on the cross-section is similar for the cases with different closing-to-wall air velocities. The airflows from the burners are quickly mixed with the high temperature flue gas, forming a relatively complete tangential circle in the furnace center. The flame in the furnace is not skewed, not attached to the wall, and the fullness is good. The heat load distributes uniformly near the four water-cooled walls. As the closing-to-wall air velocity increases, the rigidity of the airflow is gradually stronger, and the penetration depth of the airflow increases, the area with lower temperature near the wall also increases.

![Temperature field in the central cross-section of closing-to-wall air nozzles.](Image)

Figure 6. Temperature field in the central cross-section of closing-to-wall air nozzles.

Table 2 shows the average value of the flue gas temperature and component concentration at the furnace outlet. The flue gas temperature and component concentration are basically the same under different working conditions, indicating that the change of the closing-to-wall air velocity does not affect the combustion effect in the furnace. The combustibles content in the fly ash and flue gas at the exit of the furnace is not much different, indicating the influence of the closing-to wall air velocity on the combustion effect of the boiler is negligible.
5. Conclusions
Taking a 660MW tangentially fired boiler as the research object, numerical simulations were conducted to study the influences of closing-to-wall air velocity on the combustion characteristics in the boiler. The following conclusions can be drawn:

1. The new type of closing-to-wall air proposed in this paper has good penetrability, can flow along the water wall to a distant location, and protects the water-cooled walls in the flowing region.

2. The closing-to-wall air make the oxidizing atmosphere near the water-cooled wall more strengthen. The O$_2$ concentration in the flowing region is significantly increased to be greater than 2%, while the CO concentration was reduced to be less than 1%, which can effectively alleviate high temperature corrosion of water wall.

3. As the closing-to-wall air velocity increases, the rigidity of the airflow is gradually stronger, and the penetration depth of the airflow increases, so that the coverage area of the airflow is increased.

4. The influence of the closing-to-wall air velocity on the combustion effect of the boiler is negligible.

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