

Imulation of temperature field in swirl pulverized coal boiler

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Abstract. In order to achieve the goal of energy saving and emission reduction and energy efficient utilization, taking a 58MW swirl pulverized coal boiler as the research object, the three-dimensional model of the rotor is established. According to the principle of CFD, basic assumptions and boundary conditions are selected, the temperature field in the furnace of 6 kinds of working conditions is numerically solved, and the temperature distribution in the furnace is analyzed. The calculation results show that the temperature of the working condition 1 is in good agreement with the experimental data, and the error is less than 10%, the results provide a theoretical basis for the following calculation. Through the comparison of the results of the 6 conditions, it is found that the working condition 3 is the best operating condition of the pulverized coal boiler.

1. Introduction

At present, the balance between environmental cleanliness and energy use is the guarantee of the sustained development of the national economy. Efficient use of energy and the reduction of pollutant emissions are two important ways for that[1]. In the 11th Five-Year Planning, the first proposed the policy of energy-saving emission reduction', that is, to reduce energy waste and reduce emissions of harmful pollutants[2]. In the past decade, the environment conditions have improved. Based on this, the country in the 13th Five-year Planning to further clear the proposed energy-saving emission reduction targets. Accelerate the construction of resource-saving and environment-friendly type of society[3]. Through these to improve policy mechanism, adjust the industrial layout, and enhance energy efficiency.

While actively responding to policy calls, we need to understand our energy conditions at first, China is the third largest energy-producing country and the second largest energy user in the world. We have a large amount of primary energy storage and low per capita share[4]. The more important thing is the primary energy structure in 76% are dominated by coal. Even the development of hydropower, wind energy and other resources of the country have improved, but the use of coal in the proportion of energy structure is still as high as 69.46%, this situation is more prominent in the boiler industry[5].

Industrial boiler is still the main heat and power equipment in our country. The heat energy contained in steam and high temperature water is directly served in social life and industrial production[6]. At present, China's industrial boilers at least more than 590 thousand units, and industrial coal-fired boilers about 500 thousand units, the annual consumption of coal in 700 million T or so, accounting for about 20% of the national annual coal consumption. More than 70% of coal-fired



industrial boilers in our country are layer combustion furnaces. Among them, the fixed grate boiler and chain grate based, less than 20t/h layer fired boiler weighted average thermal efficiency is only 68.72%, lower than the international similar level of 15% ~20% [7]. However, in the developed countries have applied pulverized coal full chamber combustion technology to the field of industrial boilers. Boiler's thermal efficiency is much higher than the traditional coal-fired boilers, especially industrial chain boilers. The full chamber combustion technology also has the advantages of environmental protection and high economic efficiency [8].

Taking a 58MW swirl pulverized coal boiler as the research object, the different operating conditions of the combustion temperature field in the furnace are studied. According to the principle of CFD, the physical model and mathematical model of the furnace are established, and reasonable basic assumptions and boundary conditions are selected. In six different conditions, the combustion temperature field in the furnace was calculated by Fluent software and collect field test data and compare it. Finally, verify the reliability of the simulation results. According to the calculation results, focus on the analysis of the temperature distribution and choose the best operating combustion conditions.

2. Simulation object and physical model meshing

Taking a 58MW swirl pulverized coal boiler as the research object, which has equipped with the same four swirl burners and the model is LTXL-15/-20/265-C2, the width, depth and height of the simulated boiler furnace are 55.393m, 16.923m, 6.110m. The boiler uses a membrane water wall and a circulating water pump system, mainly by adjusting the amount of coal and a second air flow method to achieve load thermostat, the powder feeding system is a ball mill with a hot air supply system. The pulverized coal is fed into a mixer with a Venturi tube structure, and pulverized coal is sent into the burner under primary air. The designed coal is AIII, and the industrial analysis and element analysis of its coal quality are shown in Table 1.

Table 1. Proximate analysis and element analysis of coal.

| Industrial analysis (%) | | | | elemental analysis (%) | | | | |
|-------------------------|-------|------|------|------------------------|------|------|-------|------|
| Var | Aar | Mar | FCar | Car | Har | Oar | Nar | Sar |
| 38.48 | 21.37 | 8.85 | 31.3 | 57.42 | 3.81 | 7.16 | 0.93 | 0.46 |
| Qnet,ar(KJ/kg) | | | | | | | 22211 | |

When the pulverized coal boiler is in actual operation, it requires a lot of auxiliary equipment, such as safety valves, spray, etc. Due to the complexity of the internal structure of the burner and the arrangement of the water wall in the furnace, some simplifications should be made in the physical modeling of the numerical simulation. In this paper, the following simplified and hypothesis is made when establishing a physical model:

- 1) Ignore the establishment of auxiliary equipment physical model.
- 2) Simplify the water wall, with the furnace wall instead of water wall, because the water wall to play the role of heat transfer.

In this paper, the physical modeling and mesh generation are carried out according to the structural dimension of the simplified calculation area of furnace. By dividing the furnace grid into blocks, and combining with the structural characteristics of the furnace, it is divided into 5 zones for mesh generation. For areas where the flow field in the furnace changes greatly, it should be encrypted to ensure the accuracy of the simulation. Taking into account the non-uniform mesh division principle of Gambit and the good quality of grid mesh, small amount of computation and convergence of structured mesh [9]. Thus, some of the complex structures of the block part of the burner are partially tetrahedral structures and the other are hexahedral structures. The total number of grids is about 2 million, and the grid distortion of each block area is less than 0.8, when the distortion does not exceed

0.97, the smaller the degree of distortion, the higher the quality of the grid, so that the furnace grid quality is good[10].The meshing of the furnace calculation area is shown in Figure 1.

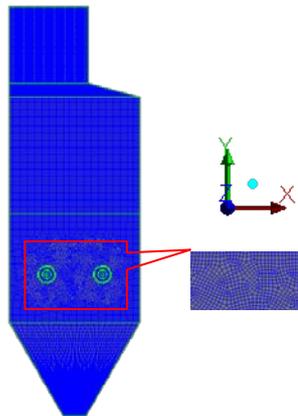


Figure 1.Physical model for solving temperature field.

3. Mathematical model

Pulverized coal burns in the furnace is a complex physical and chemical process that contains a series of changes, such as turbulent flow, mass transfer heat and combustion. It should conform to the law of conservation of mass, the law of conservation of momentum and the law of conservation of energy[11].In this paper, many mathematical models are involved in numerical simulation, the gas-phase flow model is based on the Realize model, gas-solid two phase flow model is used to select the random particle orbital model in the Lagrangian coordinate system, radiation heat transfer model using P-1 model, volatile thermal analysis model to select a two-step reaction model competition, the gas fraction combustion model uses the mixed fraction - probability density function model, Coke combustion model choose the power-diffusion control rate model.

4. Boundary condition

4.1. Inlet boundary condition

Table 2. Specific design parameters under various working conditions.

| working condition | load (MW) | Primary wind speed (m/s) | Internal two wind speed (m/s) | External two wind speed (m/s) | Central wind speed (m/s) | Air volume ratio between two internal and external air |
|-------------------|-----------|--------------------------|-------------------------------|-------------------------------|--------------------------|--|
| 1 | 58 | 11.8 | 39.10 | 24.09 | 8.0 | 3:1 |
| 2 | 58 | 11.8 | 41.60 | 19.27 | 8.0 | 4:1 |
| 3 | 46.4 | 11.8 | 35.35 | 16.48 | 6.8 | 4:1 |
| 4 | 46.4 | 11.8 | 36.83 | 13.65 | 6.8 | 5:1 |
| 5 | 34.8 | 11.8 | 29.03 | 11.06 | 5.2 | 5:1 |
| 6 | 34.8 | 11.8 | 29.86 | 10.45 | 5.2 | 6:1 |

The model of the furnace of the 58MW pulverized coal boiler has four burner nozzles, each nozzle has four entries,namely1,2,3,4.Before simulating the simulation, we need to set the parameters for each entry. For instance, the furnace inlet plane is set as the velocity inlet boundary condition, center air velocity, primary air velocity and the pulverized coal flow are set according to the operating

conditions, the inner and outer secondary winds are set by the speed vector file import. The specific parameters of each working condition are shown in Table 2:

For the setting of the particle phase and the conditions at the inlet:

- 1)Pulverized coal particle diameter distribution based on Rosin-Rammler law.
- 2)The physical characteristics such as quality and density of pulverized coal particles are set in real time according to different calculation conditions, the specific circumstances are shown in Table 3.
- 3)The initial velocity of pulverized coal particles is 0.8 times of the primary air velocity, The temperature setting of pulverized coal particles is the same as that of primary air.

4.2. Outlet boundary conditions

In the numerical calculation, it is difficult to measure the data of the outlet interface in the actual process. Therefore, the furnace outlet boundary conditions are simplified[12].It is assumed that the flow boundary condition at the exit of the furnace is Outflow, which means that the rate of change of all the variables in the flow direction is zero. Given the outlet pressure is atmospheric pressure, the setting of the outlet temperature is determined by the different operating load, as shown in Table 3.

Table 3. Correlation settings for each load.

| Load | 100% | 80% | 60% |
|---|---------------------|----------------------|----------------------|
| Pulverized coal per burner (t/h) | 2.13 | 1.73 | 1.31 |
| Pulverized coal particle temperature (K) | 293 | 293 | 293 |
| Furnace outlet temperature (K) | 1100 | 950 | 800 |
| Water wall heat flux density(W/m ²) | 2.0×10 ⁵ | 1.62×10 ⁵ | 1.23×10 ⁵ |

4.3. Wall boundary conditions

In the viscous layer near the wall boundary, the transport properties of the fluid vary greatly. In the actual process, in order to ensure the accuracy of the calculation, the fluid near the wall area should use Standard wall function.

5. Results and analysis

5.1. Verification of numerical simulation of temperature field in furnace

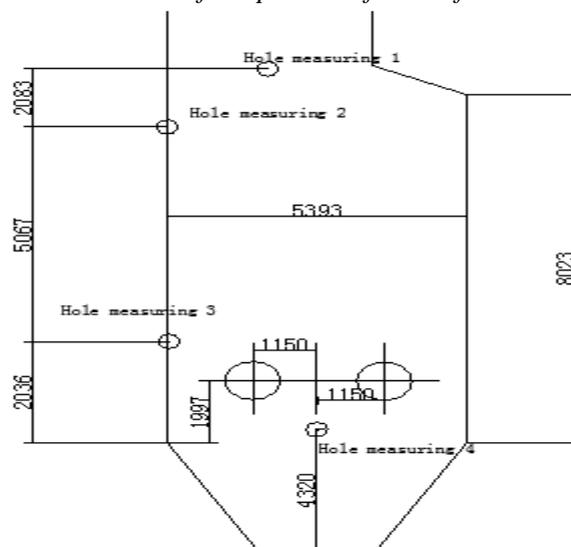


Figure 2. Simulation verification point.

In order to illustrate the correctness of the numerical simulation, the experimental data acquisition of the relevant points was carried out for the simulation results ,the test points of the numerical simulation are shown in Figure 2.

The experiment was carried out under the following conditions. The first is the 58MW boiler load 100%.The second is the ratio of the inner and outer secondary air is 3: 1.According to the relevant test method at the test point using the instrument to collect data, and organize the data, then compared with the simulation results under the same conditions. Figures 3, 4, 5 are the temperature distributions of points 1, 2, 4 about numerical simulation values and experimental values. According to the figure, there is some error between the experimental value and the numerical value, but the error is within the range of 10% acceptance. While the trend is consistent, indicating that the entire process of numerical simulation is correct, lay the foundation for the simulation of other working conditions.

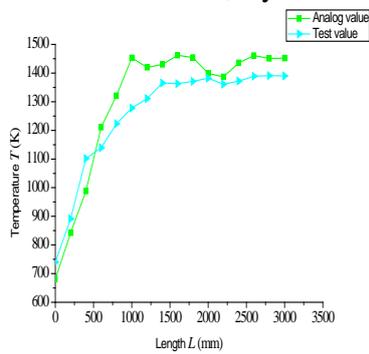


Figure 3.Hole measuring 1 Temperature distribution.

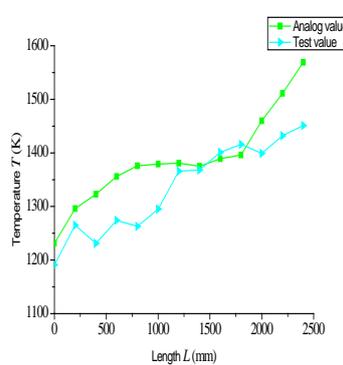


Figure 4.Hole measuring 2 Temperature distribution.

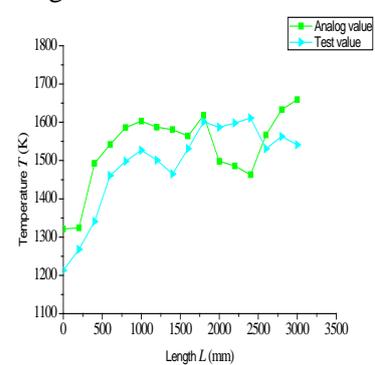


Figure 5. Hole measuring 4 Temperature distribution.

5.2. *Temperature distribution characteristics of furnaces in various working conditions*

The numerical simulation results of the above six combustion conditions in the furnace are analysed, the longitudinal section is selected in the Z direction at a distance of 950mm from the burner interface, its purpose is to intuitively understand the size of the secondary air swirl. By comparing the temperature distribution of the section under different conditions, in order to better show the changes in the internal variables of the furnace and provide a more direct reference for future research, we also focus on the average of the variables along the height of the furnace. The unit of temperature is Kelvin.

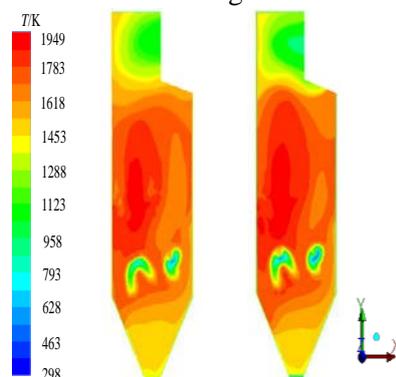


Figure 6. Temperature profile of longitudinal section of furnace in working condition 1 and working condition 2.

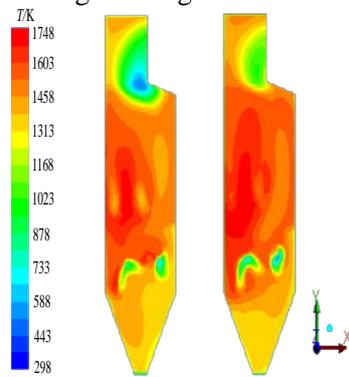


Figure 7. Temperature profile of longitudinal section of furnace in working condition 3 and working condition 4

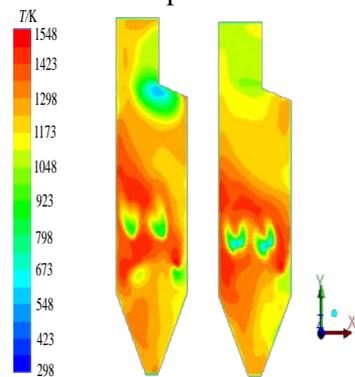


Figure 8. Temperature profile of longitudinal section of furnace in working condition 5 and working condition 6.

The temperature field distribution nephogram of each working condition is shown in Figure 6 to Figure 8.

Figure 6 is the temperature field distribution of the longitudinal section of the furnace under the condition of load 100% and air volume ratio 3:1 and 4:1 corresponding to working condition 1 and working condition 2.

As shown in Figure 6, from the two temperature nephogram under conditions 1 and 2, two temperature-dependent areas can be seen. The low temperature zone is located below the burner nozzle, indicating that in the Z direction of this section, the flue gas is down due to the suction of the secondary air. When the interior of the furnace is treated as a whole, the degree of flame burning is roughly the same, the flame is full of the furnace. When the air volume ratio is 3: 1 and 4: 1, the temperature of the furnace along the longitudinal height is basically the same, and the high temperature area of the working condition 2 is larger. In the condition 1 and the condition 2, the temperature of the cold hopper is about the same, which is lower than the temperature of the main combustion zone. In the two conditions, with the flue gas upstream, the flue gas temperature gradually reduced, furnace outlet temperature is around 1100K, which meets the initial outlet temperature setting. The temperature of the flame angle position is higher than the outlet position. The temperature distribution of the water wall around the longitudinal section of the two kinds of working conditions is all reasonable, and no local high temperature area is generated, which is consistent with the safety of the water wall material.

After comparison of case 1 and condition 2, the overall furnace temperature distribution is roughly the same, the only difference is the high temperature range of radiation range. It is shown that the difference of the air volume ratio has a great influence on the velocity field at 100% of the load, but because of the operation at full load, the overall effect on the furnace along the height of the furnace is small and only affects the local area.

Figure 7 is the temperature field distribution of the longitudinal section of the furnace at the load 80% and the air volume ratio of 4:1 and 5:1 corresponding to the working condition 3 and the working condition 4.

As shown in Figure 7, the figure shows that there are two low-temperature zones in the lower part of the furnace section, for the same reason as when the load is 100%. While the minimum temperature of the low temperature zone at 5: 1 is slightly lower than the air temperature ratio of 4: 1. Condition 3 and condition 4 of the furnace temperature fullness are better, in the condition 4, the temperature of the furnace in the longitudinal height direction is slightly higher than the temperature under the condition 3, and the position of the high temperature region is higher than the condition 3. Under the condition 3 and the condition 4, the temperature of the cold hopper is the same and lower than the temperature of the main combustion area of the furnace in a reasonable temperature range. The temperature of the furnace outlet is low, the temperature of the flare angle is higher than the temperature of the outlet position, and the temperature distribution of the water wall around the longitudinal section of the furnace is reasonable and no local high temperature area is generated.

In contrast to condition 3 and condition 4, both of which use a swirl burner, resulting in a suction action around the nozzle, forming a low-temperature region. The increase in the air flow ratio results in a larger range of suction, the vortex is formed during the flow of the air in the furnace, resulting in a disturbing effect on the area of the upper part of the furnace. A low temperature zone will be formed in this area. The air volume ratio of 5: 1 is higher than that of the air volume ratio of 4: 1 in the position, so that the outlet temperature of the furnace is slightly higher than the air volume ratio of 4: 1. Thus, with the decrease of the load, the overall temperature of the furnace is reduced. As the air flow ratio increases, the high temperature region of the furnace can be moved upwards. The temperature distribution in the hearth of the two working conditions is different. It is beneficial to the combustion of the boiler when the boiler operates under this load condition, which has great influence. But the upward movement of the high temperature region is not conducive to the operation of the boiler, this will lead to an increase in the content of pollutants in the flue gas, so when the air flow ratio of 4: 1, the boiler operation in relatively good condition.

Figure 8 is the temperature field distribution of the longitudinal section of the furnace at the load 60% and the air volume ratio of 5:1 and 6:1 corresponding to the working condition 5 and the working condition 6.

As shown in Figure 8, when the load is 60%, the Flue gas reflux position near the burner nozzle along the furnace height direction shift. This shows that when the load is 60% and the air flow ratio of 5: 1 and 6: 1, in the Z direction of this section, the secondary air into the furnace, the flue gas in this position is upward. When the air volume ratio is 6:1, the capacity of the smoke suction is stronger.

By comparing the conditions 5 and 6, in the load 60% operating conditions, the temperature distribution of the water cooled wall of the two are roughly the same, they are within the safe range. While the high temperature area inside the furnace mainly concentrates on the middle and front wall of the furnace, and the rear wall is relatively high, back wall temperature is not very high relative to the previous two. Under the condition 5, the bottom of the furnace and close to the area on the cold ash hopper, the temperature is significantly lower than the condition 6, this shows that when the air flow ratio is 5: 1, where the turbulence of the flow field is obvious, the effect of preheating on incoming air and pulverized coal particles is better. At the same time, near the flare angle of the furnace outlet, the temperature of the condition 5 is significantly lower than the temperature of the condition 6 under the same operating load condition. On the whole. The temperature distribution of the two working conditions is almost the same, and there are differences in the individual local area, that is, when the load is 60%, the air volume ratio is different, and the furnace has little influence along the furnace height direction.

Figure 9 shows the average temperature distribution in the height direction of the furnace in 6 conditions. Under the 3 load operation conditions, the temperature is the inflection point near the 6.078m height of the furnace height. This is near the burner nozzle. Under the action of the swirling flow, it is necessary to preheat the pulverized coal and air, so it should be low. When the load is 60%, the height of about 6.078mm temperature fluctuations does not load at 100% and 80% of the large, the temperature fluctuation of 6.078 m is less than the temperature fluctuation at 100% and 80% of the load. This also shows that when the secondary air into the furnace, the flue gas in this position is upward, while the furnace high temperature area moves down to about 8.106m. Under other load conditions, the temperature reaches a maximum at a height of 8.782 m and then decreases gradually. When the load is 80%, with the air flow ratio increases, the temperature distribution along the height of the furnace moves upward. This is consistent with the results of the previous analysis.

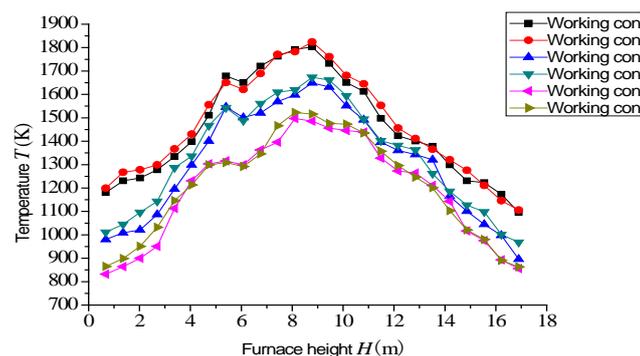


Figure 9. Average temperature distribution of furnace height in different working conditions.

6. Conclusion

1) The effect of operating load and air flow on the combustion in the furnace is different. With the decrease of the load, the temperature in the furnace decreases as a whole. The impact of different air flow on the same operating load is also different. When the load is 100% and 80%, in the Z direction of this cross section, the suction flue gas of the secondary air in the burner nozzle is down. When the load is 60%, in the Z direction of this cross section, the suction flue gas of the secondary air in the burner

nozzle is upward. Under the same load conditions, with the increase of air volume ratio, the capacity of suction smoke is stronger.

2) In the load 100%, when the air flow ratio is different, the temperature distribution of the longitudinal section of the furnace along the height direction is approximately the same, only partially different. When the load is 80%, when the air flow ratio is 5: 1, the temperature distribution of the furnace section is higher than 4: 1, this will be harmful to the treatment of flue gas pollutants. When the load is 60%, the air flow ratio has little effect on the temperature distribution of the furnace section along the height direction. At the same time under the two conditions, furnace temperature fullness is bad. As the high temperature concentrated in the front wall, making the water wall uneven heating.

3) Under different operating load conditions, the temperature distribution of the furnace along the height direction is basically the same. When the load is 60%, the high temperature zone of the furnace moves relatively downward. When the load is 80% and 60%, the temperature change of the high temperature region of the furnace is very slow and basically unchanged, this avoids the temperature sharply increased adverse impact on the water wall.

4) Combined with the local analysis of the temperature of each section and the analysis of the average value along the furnace height direction, from the angle of the boiler overall operation, the working condition 3 is the best operation scheme.

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