Simulation of Velocity Field in a Pulverized Coal Fired Boiler

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Abstract. This paper selects a 58MW pulverized coal boiler as the research object, three dimensional physical modelling and mathematical modelling are established for the boiler furnace, according to the set of reasonable hypothesis and boundary conditions, the Fluent software is used to simulate the velocity field in the furnace under six operating conditions. Through the numerical simulation results, the optimal operating conditions of this kind of boiler are discussed, which can provide data reference for improving the energy efficiency of small and medium-sized coal-fired boilers.

1 Introduction

In China’s energy structure, coal occupies a major position, in the current energy structure of coal has nearly 70\%\textsuperscript{[1]} share, which can be foreseen, coal in the future a longer period of time in China is still the main source of energy.

At present, coal-fired industrial boilers in our country, most are layer combustion furnace, accounting for more than 70\%, most of which are fixed grate boiler and chain grate, the average heat efficiency of less than or equal to 20th layer combustion furnace is only 68.72\%, less than the international level of 15\% ~20\%\textsuperscript{[2]}. The pulverized coal full chamber combustion technology has been applied in the field of industrial boiler, at the same time; the whole room combustion technology also has the advantages of environmental protection emissions, high economic benefits\textsuperscript{[3]}.

This paper selects a 58MW pulverized coal boiler as the research object, three dimensional physical modelling and mathematical modelling are established for the boiler furnace, according to the set of reasonable hypothesis and boundary conditions, the Fluent software is used to simulate the velocity field in the furnace under six operating conditions. Through the numerical simulation results, the optimal operating conditions of this kind of boiler are discussed, which can provide data reference for improving the energy efficiency of small and medium-sized coal-fired boilers\textsuperscript{[4, 5]}.

2 Mathematical Model of Pulverized Coal Combustion

Conservation of energy, the gas flow model realize $k - \varepsilon$ model is selected. The general formula of the equation is\textsuperscript{[7]}:

$$\text{div} \ p v \phi = \text{div} \Gamma_\phi \nabla \phi + S_\phi$$  \hspace{1cm} (1)

Where: $\phi$ is the common dependent variable, $\Gamma_\phi$ is the transport coefficient $S_\phi$ is the source term, $p$ is the airflow density, $v$ is the velocity vector.

3 Physical Modelling and Mesh Generation

The main research object of this paper is the 58MW hot water pulverized coal boiler equipped with four LTXL-15/-20/265-C2 Swirl Burners. The structure and size of the boiler are shown in Figure 1. The burner numbers shown in Figure 1 are 1\#, 2\#, 3\# and 4\#, respectively, among them, 1\# is relative to 3\#, and 2\# is relative to 4\#.

Figure 1. Schematic diagram of boiler structure and dimension.
The boiler adopts membrane type water wall and circulating water pump system, and the boiler load temperature is controlled by controlling the pulverized coal quantity and the one or two air flow. The pulverized coal feeding system of the boiler is a ball mill with a hot blast air supply system. The pulverized coal is transported into the mixer and the pulverized coal is sent into the burner under the action of primary air. The study selected AIII, an industrial analysis of coal quality as shown in Table 1.

Table 1. Proximate analysis and element analysis of coal.

<table>
<thead>
<tr>
<th></th>
<th>Proximate analysis (%)</th>
<th>Element analysis (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Var Aar Ar Ma r FC ar</td>
<td>Car Har Oar Nar Sar</td>
</tr>
<tr>
<td>38.48</td>
<td>21.37 8.8 31.3</td>
<td>57.4 2 3.81 7.16 0.93 0.46</td>
</tr>
<tr>
<td></td>
<td>Net calorific power of as received basis Qnet,ar(KJ/kg) 22211</td>
<td></td>
</tr>
</tbody>
</table>

In order to ensure the accuracy of the simulation, it is necessary to do the corresponding encryption processing for the larger area of the flow field in the furnace. Taking into account the non-uniform mesh division principle, the good quality of structured mesh, small amount of computation and convergence of structured mesh of Gambit, so there are some tetrahedral structural grids for some complicated structures in the block part where the burner is located, then the Cooper method is used to divide. The other blocks are hexahedral structured grids. The grid division of the furnace calculation area is shown in Figure 3.

4 Boundary Condition

4.1 Entrance Boundary Condition

There are 4 burner nozzles in the model of the pulverized coal boiler furnace have studied in this text. Before the simulation, it is necessary to set parameters for each entrance. For the setting of the particle phase, the conditions at the inlet:

1) The particle size of pulverized coal is distributed according to Rosin-Rammler law [8].
2) Other physical characteristics such as mass and density of pulverized coal particles are set in real time according to different calculation conditions.
3) The initial velocity of pulverized coal particles is 0.8 times of the primary air velocity. [9]

In this paper, the inlet boundary of the furnace is set as the boundary condition of the velocity inlet. The specific parameters of each working condition are shown in Table 2.

4.2 Exit Boundary Condition

For the setting of the furnace exit boundary condition, it is difficult to know the information on the exit interface because it is difficult to measure in the actual process, therefore, in the numerical calculation; the exit boundary condition should be simplified. It is assumed that the Outflow condition for the flow boundary conditions at the exit plane of the furnace is that the rate of change of all the variables in the flow direction is zero, and that the given outlet pressure is atmospheric pressure.
Table 2. Specific design parameters under various working conditions.

<table>
<thead>
<tr>
<th>Working condition</th>
<th>Load (MW)</th>
<th>Primary wind speed (m/s)</th>
<th>Internal auxiliary air (m/s)</th>
<th>External auxiliary air (m/s)</th>
<th>Central wind speed (m/s)</th>
<th>Air volume ratio between two internal and external auxiliary air</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58</td>
<td>11.8</td>
<td>39.10</td>
<td>24.09</td>
<td>8.0</td>
<td>3:1</td>
</tr>
<tr>
<td>2</td>
<td>58</td>
<td>11.8</td>
<td>41.60</td>
<td>19.20</td>
<td>8.0</td>
<td>4:1</td>
</tr>
<tr>
<td>3</td>
<td>46.4</td>
<td>11.8</td>
<td>35.35</td>
<td>16.48</td>
<td>6.8</td>
<td>4:1</td>
</tr>
<tr>
<td>4</td>
<td>46.4</td>
<td>11.8</td>
<td>36.83</td>
<td>13.65</td>
<td>6.8</td>
<td>5:1</td>
</tr>
<tr>
<td>5</td>
<td>34.8</td>
<td>11.8</td>
<td>29.03</td>
<td>11.06</td>
<td>5.2</td>
<td>5:1</td>
</tr>
<tr>
<td>6</td>
<td>34.8</td>
<td>11.8</td>
<td>29.86</td>
<td>10.45</td>
<td>5.2</td>
<td>6:1</td>
</tr>
</tbody>
</table>

4.3 Wall Boundary Condition

In the viscous layer near the wall boundary, the transport characteristics of fluid vary greatly. In order to ensure the accuracy of calculation, Standard wall function is chosen in the near wall region of fluid.

5 Results and Analysis

The numerical simulation of combustion in the furnace under the above 6 conditions is analyzed, working conditions 1 and 2, working conditions 3 and 4, working conditions 5 and 6 are divided into three groups under different operating load conditions, numerical simulation of boiler operation and combustion. Each group under the same operating load condition, air volume ratio between two internal and external auxiliary air is different, which influences the flow field in the furnace. The difference of velocity flow field between the 3 groups under the same load and different air volume ratio is analyzed, and the difference of the flow field in the furnace under the different loads and air volume ratio is also discussed. Figure 4 is the velocity flow field distribution vector under the working condition 1 and the working condition 2.

Figure 4. Vector diagram of velocity field distribution under working condition 1 and working condition 2.

As shown in Figure 4, the cut plane is close to the burner nozzle position. The internal and external auxiliary air passes into the furnace through the internal and external auxiliary air ducts with the internally oriented swirl vanes, at the same time the primary air and the central air are wrapped inside the auxiliary air to enter the furnace. In this way, under the influence of the cyclone of the internal and external auxiliary air, the furnace gradually spread to form a vortex, and the flow velocity direction has reflux and expansion. Under the action of the furnace arch, the airflow will rotate, and then the flue gas will enter the next link through the furnace outlet. Two cases are compared in Figure 4, the working condition 2, the airflow from the burner nozzle diffuses into the furnace, forming the effect of circumfluence and expansion, meanwhile, there is a disturbance to the airflow in the lower part of the furnace burner to form a swirl. In the upper part of the furnace, the effect of airflow disturbance is also obvious, and the effect of vortex formation by air turbulence is more obvious. The working condition 2 shows that when the air volume ratio is 4:1, the aerodynamic field in the furnace is obviously better, and the turbulence of the airflow in the furnace is obviously better, which is beneficial to the preheating and combustion of the pulverized coal particles into the combustion chamber.

Figure 5 is the velocity field distribution vector under the working condition 3 and the working condition 4.

Figure 5. Vector diagram of velocity field distribution under working condition 3 and working condition 4.

The two operating conditions is compared in Fig. 5, it is found that the swirl effect near the burner nozzle is basically the same. The flow field in the upper and lower parts of the furnace, the effect of working condition 4 is obvious, indicating that when the air volume ratio is 5:1, for the flow field, the disturbance is great. But compared with figure 4, when the same air volume is 4:1, the working condition 3 is basically the same as the working condition 2, but also weakens. It shows that when the air volume ratio is 5:1, the disturbance effect of the flow field is better.

The velocity field distribution vector under the working condition 5 and the working condition 6 are showed in Fig. 6.

Comparing the two working conditions in Fig. 6, it is found that the influence of air volume ratio on the flow field inside the furnace is less obvious than that in the preceding condition. The effect of condition 6 and condition 5 is basically the same, but under the condition of equal air volume ratio, the working condition 4 is better than the working condition 5, that with the increase of air volume ratio, the flow field in furnace is less affected.
Figure 6. Vector diagram of velocity field distribution under working condition 5 and working condition 6.

In summary, through the comparison of the above 6 working conditions, it is found that the internal and external auxiliary air injection into the furnace in the swirl burner has a disturbance effect on the flow field in the furnace. The difference of the air volume ratio between the internal and external auxiliary air makes the radiation range of the disturbance different. At full load operation, the air volume is 4:1 better than the air volume ratio is 3:1, when the load changed to 80%, the working condition 4 was obviously better than the condition 3, the effect of working condition 3 is almost the same but weaker than that of working condition 2. When the load is 60%, the air flow ratio has little influence on the flow field. For the same volume of air ratio than 5:1, the disturbance effect of working condition 4 is better than that of working condition 5. It can be concluded that when the load is 100% and 80%, with the increase of air volume ratio, the disturbance effect of the flow field is better, but at the same air volume ratio, with the decrease of load, the convection field also has certain influence. When the load is 60%, the air flow ratio has little influence on the flow field, and tends to be the same. But for the same air volume ratio of working condition 4 and condition 5, the load drop has a great influence on the flow field disturbance.

Conclusion

By comparing the simulation results of the above conditions, the following conclusions are drawn: In the swirl burner, internal and external auxiliary air injection into the furnace for the disturbance of the flow field in the furnace is very obvious; the internal and external auxiliary air flow ratio is different, so that the radiation range of the disturbance is different. When the load is 100% and 80%, with the increase of the air volume ratio, the disturbance effect is better. When the load is 60%, the air flow ratio has little influence on the flow field, and tends to be the equal. When the air volume ratio is the same, the disturbance on the flow field will decrease with the decrease of load.

Acknowledgement

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