Numerical Simulation Analysis of Flow and Heat Transfer in Medium Temperature Boiler

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Abstract. Waste heat recovery by waste heat boiler is one of the important means to utilize secondary energy, which is widely used in metallurgical industry. However, due to the great influence of production technology and other factors in industrial process, it brings many difficulties to waste heat utilization. Based on the structural parameters and operating parameters of the waste heat boiler, combined with the basic principles of fluid mechanics, the numerical calculation model of the waste heat boiler is established. The flow field and temperature field inside the waste heat boiler are studied and analyzed by numerical simulation method, which provides the necessary basis for its structural optimization.

Key words. Waste heat boiler, flow field, temperature field, numerical simulation.

1. Introduction
In the process of converter steelmaking, oxygen blowing will produce a large amount of high temperature (1450 ℃ ~ 1650 ℃) Dust-containing converter gas. High-temperature dust-containing gas is collected by the movable hood above the converter, and then sent to the vaporization cooling flue for cooling. This part of gas discharged after preliminary cooling by the vaporization cooling flue is called medium-temperature converter coal, and the temperature is between 800 ℃ and 1000 ℃, containing a high concentration of CO and a large amount of metallic iron dust particles. Negative pressure operation is mostly used in the transportation of gas in the medium temperature section, which is easy to penetrate into air and explode [1]. This also brings difficulties to the treatment of converter gas in the middle temperature section.

The design of waste heat boiler is based on the composition of flue gas. Different metal smelting furnaces need different structures of waste heat boiler, which is non-standard design. Therefore, the structure of waste heat boiler needs continuous improvement and optimization, and numerical simulation method is an effective and economical measure [2]. Traditional metallurgical process research mainly relies on the combination of laboratory research and field test, and relies on long-term accumulated experience to a great extent. With the development of metallurgical technology and related technologies, market competition and higher requirements for process optimization, the traditional measured research methods can no longer meet the requirements of the new situation. Due to the large-scale and high-temperature environment of the waste heat boiler, some required data cannot be obtained through experiments and field observation methods. Therefore, this paper relies on numerical simulation methods to study the flow field and temperature field inside the waste heat boiler, and carries out numerical simulation analysis. It is beneficial to optimize the structure of the waste heat boiler.
2. Numerical Simulation of Flow and Heat Transfer in Waste Heat Boiler

Based on the complexity of the structure of the waste heat boiler itself and the changeable actual working conditions during operation, it is a feasible method to establish a simplified mathematical model to solve the internal complex flow and heat transfer problems and multi-field coupling problems. Mature numerical simulation technology can make up for the shortcomings in the experiment and replace the experiment to a certain extent. Under the measured conditions, it is difficult to fully reflect the three-dimensional flow and temperature distribution in the whole furnace. Numerical simulation can provide this information. Using the established mathematical model and software, the waste heat boiler is simulated [3]. The influence of different grid division schemes, turbulence models and radiation models on the simulation results is analyzed, and the most reasonable simulation scheme is determined. The distribution of the internal flow field and temperature field of the waste heat boiler is obtained.

The actual flow and heat transfer process in the running waste heat boiler is very complex. This paper makes the following assumptions for the simulated flow and heat transfer process:

- The parameters of the waste heat boiler system do not change with time, and the flow and heat transfer in the furnace are running under steady conditions
- Does not consider internal complex chemical reactions and changes;
- Ignore the complex components of the flue gas, and fit the physical properties of the flue gas according to the physical characteristics of the average composition flue gas.

2.1. Geometric Model and Mesh Generation

2.1.1. Establishment of Model. This paper uses Fire tube (also known as shell boiler) waste heat boiler carry out that flue gas Recovery and utilization of waste heat. The basic structure is that a small cylinder, a tube (called fire tube) or a shell of other shapes (called furnace liner) is installed in a large cylinder (pot shell). The fire tube is isolated from the large cylinder and forms a jacket. The jacket contains water, while the fire tube and the furnace liner are used as combustion chambers and flue ducts to contain flame or flue gas. The heat generated by combustion or brought by flue gas is transmitted to the fire tube wall Water [4], water Evaporation enters the steam drum for flue gas utilization, established in this paper. The boiler structure mainly includes: Import Smoke box, Steam drum, flue gas pipeline, outlet flue gas box Wait. The overall structure diagram and internal structure diagram are shown as figure 1 and figure 2.

![Figure 1. Whole waste heat boiler Structural diagram.](image1)

![Figure 2. Internal structure diagram of waste heat boiler.](image2)

2.1.2. Grid Division. In simulation, the division of computational grid is an important part and the basic condition of computational fluid dynamics. The quality of grid directly affects the calculation accuracy and convergence of numerical simulation results. It can be seen that mesh division is the first
step in numerical calculation, and only reasonable mesh division can ensure the accuracy of numerical calculation.

In modeling, Grid division requires a large amount of work, but also the accuracy of calculation. In a certain range, the calculation accuracy will increase with the increase of the number of grids, but at the same time the calculation scale will also increase accordingly. When it increases to a certain number, the calculation accuracy will no longer be affected by it. Therefore, the calculation accuracy and the calculation scale should be considered when determining the number of grids.

In this paper, Fire tube the type waste heat boiler has been carried out. The model is simplified and carried out Multi-grid division and final synthesis. Considering computational timeliness and computational efficiency, one of them is selected for numerical simulation [5].

Before the simulation, the inner runner of the fire tube waste heat boiler was extracted and named. The extraction results are shown as figure 3 and figure 4.

![Figure 3. extraction channel.](image1)
![Figure 4. Grid division.](image2)

### 2. 2. Numerical Simulation

#### 2.2.1. Boundary Condition Setting.

The calculation condition is selected as 100% flue gas flow. The standard working conditions of furnace flue gas calculation involved in this project are as table 1.

| Flue gas flow (Nm³) | Evaporation output(T/H) | Flue gas temperature change( °C) | The flue gas composition |
|---------------------|-------------------------|---------------------------------|-------------------------|
| 25000              | 10                       | 1000                             | SO₂  SO₃  CO₂  H₂O  O₂  N₂  CO |
|                     |                          |                                 | 9.354  0  0  3.654  9.101  77.891  0 |

#### 2.2.2. Numerical Simulation.

In this paper, the software separate solver is used for numerical simulation, the upwind difference scheme with second-order accuracy is adopted for the governing equations, and the pressure is applied-SpeedSIMPLEC. The algorithm solves discrete equations. The internal calculation area of waste heat boiler is discretized by hexahedral structured grid. Because the calculation domain of waste heat boiler is very large, the influence of water wall on the flow region is ignored, and the standard wall function is adopted [6].

The flow state of flue gas in the furnace affects the heat transfer process. The flow of flue gas in the waste heat boiler is turbulent. The accuracy of the velocity field and temperature field in the furnace cavity largely depends on the turbulence model. Therefore, when software is used to simulate the flow and heat transfer in the waste heat boiler, the selection of turbulence model is very important. In this project, only one of the turbulence models is selected to simplify the simulation process based on the turbulence model established in Chapter 2 Accuracy Higher Model Numerical simulation is carried out, and the temperature and temperature of the system are obtained Speed Distribute the results [7].

- Temperature characteristic analysis
Import Temperature set to 1000°C in actual simulation. The resulting outlet temperature is 394°C. The results are shown in the following figure 5 and figure 6. The temperature distribution is uniform, which is in line with the actual situation. The temperature of the lower part of the radiation chamber in the furnace is higher when the Realizable k-ε model is adopted. The temperature distribution changes greatly due to the flow field, which is quite different from the other two turbulence models, indicating that the heat intensity distribution on the heat transfer surface is not uniform.

**Figure 5.** Simulation results of temperature field.  
**Figure 6.** Velocity field simulation results.

- Analysis of flow characteristics
  From figure 5 it can be seen from the furnace flow field distribution shown in, that the velocity distribution in the flue pipe is relatively uniform, there is no obvious back flow phenomenon, the heat transfer trend in the convection area is relatively uniform, and the flow field distribution can reflect the internal information.

3. Conclusion
On the basis of analyzing and summarizing the research of typical waste heat boilers, this paper uses the structural parameters and operating parameters of waste heat boilers provided, and combines the basic principles of fluid mechanics to establish a numerical calculation model of waste heat boilers, and analyzes the flow field and temperature field of waste heat boilers. It provides necessary information for its structural optimization. In this paper, the basic theory of numerical simulation of waste heat boiler is summarized, the mathematical model of flow field and temperature field simulation calculation of waste heat boiler is established, and the models used in turbulence calculation and radiation heat transfer calculation are analyzed.

By determining the boundary conditions of numerical simulation of waste heat boiler, the emissivity and absorption rate of flue gas are analyzed in detail, and the soot deposition on the wall is considered. The numerical simulation method of furnace process is expounded, the model used in the simulation is verified, and the appropriate turbulence model and radiation heat transfer model are selected through comparative analysis. The numerical simulation of fire tube waste heat boiler is carried out, and the distribution of internal flow field and temperature field under standard operating conditions is obtained, and the overall law of internal flow and heat transfer is preliminarily grasped, which has guiding significance for the specific direction of analysis and optimization.

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