The Simulation and Optimization of Flow Field in the Low Temperature SCR Reactor

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Abstract. The uniformity of flue gas velocity at the inlet of selective catalytic reduction denitrification reactor can improve the denitrification efficiency, and the reasonable layout of guide plate can improve the flue gas flow rate. Fluent is used to analyze the flow field in the inlet flue of denitrification reactor, and the flue gas velocity in the guide plate reactor arranged in different ways is simulated. The optimized layout mode is the form of radian plus straight plate, which is helpful to uniform flue gas velocity, improve denitrification efficiency, and help students to improve the understanding of reactor flow field uniformity.

Keywords. Flue gas denitrification, SCR reactor, FLUENT simulation, flow field optimization.

1. Introduction
NOx is one of the main air pollutants. A large number of NOx emissions will bring a series of environmental problems, such as acid rain, photochemical pollution, ozone layer destruction and so on. Selective catalytic reduction (SCR) technology has been widely used for its advantages of simple operation and stable operation [1]. In recent years, low-temperature denitrification technology has become a research hotspot in the field of denitrification at home and abroad. The low-temperature denitrification technology can place the SCR denitrification device in the low-temperature and low-dust section at the end of the flue gas treatment system, which can reduce catalyst poisoning and mechanical wear while improving the economics of denitrification in coal-fired power plants [2-5]. FLUENT is at the forefront of CFD software technology and leads CFD software technology. It is the CFD commercial software package with the largest market share today. Its main function is to analyze and calculate the flow field of the built model and to post-process the calculation results. Gao et al. [6] used FLUENT software to model and numerically study the position, number and other structural parameters of the guide plate, and found that the mixing machine with plate guide plate and disc ring has better effect. Yao et al. [7] used Fluent porous media model to simulate the flow and chemical reaction process of NOx in honeycomb catalyst. The results showed that the combination of porous media model and reaction rate correction factor could compensate the deviation of reaction rate calculation and interface diffusion. Baek Shin et al. [8] with Fluent software to find used for selective catalytic reduction (SCR) of the application of new type whole channel geometry, found that compared with the conventional rectangular channel, elongated hexagonal channel in the NO conversion rate and pressure drop has better performance. However, there is no simulation on the structure and layout of the guide plate in low temperature SCR reactor. Guide plate of reasonable arrangement and design, can make the SCR reactor inlet flue flow field uniformity is improved. In this paper, fluent software will be used to simulate SCR reactor in low temperature and low dust environment. By simulating the
different layout of inlet flue guide plate, the reactor is optimized to make the flue gas flow rate more uniform. It is hoped that the low-temperature SCR denitrification reactor can be better applied in the future.

2. Numerical Simulation of SCR Denitrification Reactor

2.1. Numerical Simulation Method

CFD software can directly display the state of the simulated flow field by changing various set parameters in the system in a short time, so as to achieve the desired effect. In this paper, Fluent software is used to simulate the flow field in the reactor.

2.2. Governing Equation

In the flow field calculation of denitrification reactor, the flow is in turbulent state according to Reynolds number Re calculation. Therefore, the standard k-ε model is used to simulate the flow in the reactor. The general expression of the governing equation of the standard k-ε model is as follows:

\[ \frac{\partial (\rho \phi)}{\partial t} + \nabla (\rho \mu \nabla \phi) = \nabla (\Gamma \cdot \nabla \epsilon) + s \]  

In the equation, \( \rho \) is the density of the fluid, \( t \) is the time, \( \Phi \) is the general variable, \( u \) is the velocity vector, \( \Gamma \) is the generalized diffusion coefficient, and \( s \) is the generalized source term.

2.3. Geometry Model

This paper takes SCR denitrification reactor of 600MW coal-fired unit as the research object. The denitrification system installed by the unit includes reactor, catalyst layer, ammonia injector and flow sharing plate, among which ammonia ejector device is in the inlet flue of the reactor. The denitrification reactor of this unit is arranged behind the economizer. The inlet section size of the SCR reactor is 2.0m*6.11m, the ammonia ejector port is at the lower third of the inlet flue and the catalyst size is 5.7m*5.7m* 3.03m, the width of the reactor is 6.11m in the Z direction, and the geometric model of the reactor is shown in the figure 1.

![Figure 1. Model structure diagram.](image)

2.4. Meshing and Boundary Conditions

The model uses icem CFD in ANSYS to model and build the grid. According to the proximity relationship between the grid nodes, it can be divided into structured grids and unstructured grids. Due to the complex interface processing of the structured grid, the use is restricted. Therefore, in this paper, tetrahedral elements in the unstructured grid are used to divide the model, which can effectively shorten the initialization time. Scale factor is set to 5, Max element is set to 64, maximum size is set to 0.002, prism height limit factors is set to 0.0, curve mesh setup is set, In select curve (s), the maximum size is set to 0.0, mesh type is set to tetra/mixed, the number of grid elements is 1282685, and the total nodes is 217129. The grid is checked by Fluent, and the feedback window shows that the minimum grid size is positive. The model is correct and can be used for simulation calculation. The velocity inlet and pressure outlet are adopted as the boundary conditions. The inlet velocity of flue gas and the inlet velocity of ammonia are both 15 m/s, and the outlet pressure is set at 0Pa. The flue gas turbulence
intensity \( I = 0.0294 \). Hydraulic diameter \( D = 5.73 \text{m} \). The catalyst bed adopts a porous media model and flows in a laminar flow area. The viscous resistance coefficient was 1.34 \((1/\text{m}^2)\) in each direction, and the inertial resistance was 91 \((1/\text{m}^2)\) in each direction. The porosity was 0.68.

2.5. Solution Method
Fluent computer simulation software adopts the pressure solver based on discrete finite volume method. The numerical simulation of turbulent flow adopts indirect simulation. The indirect simulation methods are divided into large eddy simulation (LES), Reynolds average method (RNS) and statistical average method, among which RNS method is widely used. The discrete format adopts the first-order upwind style, and the under-relaxation factor keeps the system default value.

3. Flow Field Analysis of Inlet Flue of SCR Denitrification Reactor

3.1. The Influence of the Guide Plate on the Flow Field of the Inlet Flue
The denitrification efficiency is affected by the residence time of flue gas in the reactor. The appropriate residence time of flue gas in the reactor can fully react with reducing agent in the pore of catalyst, so as to improve the denitrification efficiency. SCR system to achieve a reasonable design speed of flue gas flow, through the catalyst speed is between 4 to 6 meters. The reasonable layout of the guide plate not only helps to reduce the separation caused by fluid flow through the bend, but also reduces the secondary flow resistance caused by it, which can effectively improve the SCR denitrification efficiency in the flue flow field [9-10]. Due to different structures and different SCR denitrification systems, the layout scheme of guide plate is different. In the following, the simulation is carried out on the condition that there is no guide plate, a guide plate and a guide plate at the upper and lower corners, found that the installation of curved straight edge guide plate is the most effective and reasonable form.

3.2. Flow Field Distribution without Optimization Measures
Without optimization, the velocity distribution in the reactor is shown in figure 2. In the empty tower without guide plate, the velocity distribution in the flue is uneven, and there is almost no flue gas flow on the left side. At the entrance and the corner of the flue, the local velocity is high, which is easy to cause wall abrasion and is not conducive to mixing with reducing agent, which affects the denitrification efficiency.

![Figure 2](image)

Figure 2. Flow velocity distribution in the reactor without optimization.

3.3. Equipped with a Guide Plate
Equipped with a guide plate when the velocity distribution as shown in figure 3, the corner on the SCR reactor flue equipped with a guide plate, guide plate assumes the circular arc formed, radius of one meter, can see on the corner flue has certain effect, velocity to the scattered among them, the wall friction is reduced. Studies have shown that the installation of radian plus straight edge guide plate is the most effective and reasonable form.
3.4. The Arrangement of the Guide Plate up and down the Corner
In order to make the flow velocity in the rising flue evenly distributed, different number of guide plates are set at the corner of the flue, and the guide plates are set at 1/4, 2/4 and 3/4 of the inner wall at the first corner, so that the rising flue gas can be evenly distributed. At the second corner, the airflow distribution changes in a right-angle direction, which causes uneven flow velocity. Setting guide plate at 1/4 and 3/4 of the inner wall can effectively eliminate this phenomenon (figures 4-5).

It can be seen from the figures 4-5 that the low-speed area on the left side and the high-speed area on the right side of the flow field through the rectifying grid are significantly reduced when the guide plate with radian and straight plate is used. At Y=15 m, the cross-section of the reaction device on the upper layer of the catalyst, the velocity deviation coefficient is Cv=10.75% . Compared with the non-rectifying grid, the uniformity of the flow velocity is greatly improved, the velocity deviation is small, and the velocity direction. It is also basically parallel to the Y axis, which meets the requirements of optimization. Compared with that without rectifier grid, the velocity uniformity is greatly improved, the velocity deviation is very small, and the direction of velocity is basically parallel to y axis, which meets the optimization requirements.
4. Comparison of Denitrification Reactors of Different Units

4.1. Optimization of 300mw Unit Denitrification Reactor
The size of SCR denitrification reactor will be affected by different flue gas outlet volume of different size units. According to the known flue gas quantity, the denitrification system size of 300MW unit is 6.43m * 6.43m * 16.62m. In the 300MW unit SCR denitrification reactor, the optimization scheme in 2.4 is adopted, and the same number of guide plates are used, which has achieved good results (figures 6-7).

![Figure 6](image1.png) **Figure 6.** Speed cloud diagram of SCR denitrification reactor without optimization.

![Figure 7](image2.png) **Figure 7.** Optimized cloud diagram of denitrification reactor of 300MW unit.

4.2. Optimization of Denitrification Reactor for 1000mw Unit
In a 1000MW unit, the shape of the reactor was changed on the basis of keeping the original size of the reactor. The arc-shaped scheme was adopted at the corner of the inlet flue, and the upper and lower layers were staggered in the layout of the guide plate. The guide plate was arranged at different angles in the flue, such as 90-180 ° and 80-150 ° respectively. Good results were obtained after this arrangement (figures 8-9).

![Figure 8](image3.png) **Figure 8.** Flow velocity cloud diagram when SCR reactor of 1000MW unit is not optimized.
Figure 9. Flow velocity cloud diagram after optimization of SCR reactor of 1000MW unit.

5. Conclusion
In this paper, the simulation and analysis of different guide plate at the inlet flue of SCR reactor are carried out. The results show that the combination of arc guide plate and direct flow guide plate can make the flue gas more evenly distributed in the reactor, so that it can contact with the catalyst more fully, so as to improve the denitrification efficiency. The results show that the arrangement of the guide plate has good effect in 300 MW, 600 MW and 1000 MW units. This intuitive and clear flow field distribution map helps students deepen their impression and understand the importance of flow field uniformity.

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