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Numerical Simulation and Optimization of Flow Field in the SCR Denitrification System on a 600 MW Capacity Units

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Abstract

The fluid flow in the selective catalytic reduction (SCR) system of a 600MW power plant was simulated and optimized to reduce oxides of nitrogen(NO_x) emanated from a coal-fired boiler. Some configuration parameters such as the location and number of guide plates as well as the shape of Mixer were modeled and studied numerically. It shows better effectiveness using the plate-type guide plate and disc-ring Mixer. The conversion of NO_x increases from 67% to 96% with the increase of NH_3/NOx, but decreases from 98% to 82% with the increase of velocity. The deviation of velocity distribution at the entrance to the catalyst bed and NH_3 slip can satisfy the demand in Engineering.

Keywords: SCR; flow field; numerical simulation; optimization

1. Introduction

Numerical modeling is an economically effective design and analysis tool for the simulation of flow, heat transfer and combustion phenomena surrounding boiler components and auxiliary equipment. It permits the study of an increased number of geometric arrangements or modifications in a more timely manner than is possible with physical flow modeling due to its flexibility. Optimization of the SCR system to maximize deNO_x performance and to minimize NH_3 slip is one of the main challenges [1-4]. In this paper, CFD modeling was used to provide a numerical simulation of flow field and evaluate NO_x

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reduction performance of a SCR system in a 600 MW B&W, coal-fired furnace.

2. Simulation details

The geometric configuration of the CFD model is shown in Figure 1. The commercial package,Gambit 6.2 has been chosen to generate a digital model of SCR. Fluent 6.3 was used to conduct numerical simulations. All vanes, turning or splitter, were modeled as infinitely thin surfaces. The geometry of the catalyst layers were not modeled explicitly. Instead, a porous media assumption was made, and an appropriate pressure loss correlation was applied to each of these regions [5-6].

The boundary conditions were as follows:

- A uniform velocity profile was specified at the inlet.
- A static pressure boundary was specified at the exit of the domain.
- All walls were assumed to be smooth with a no slip velocity condition.

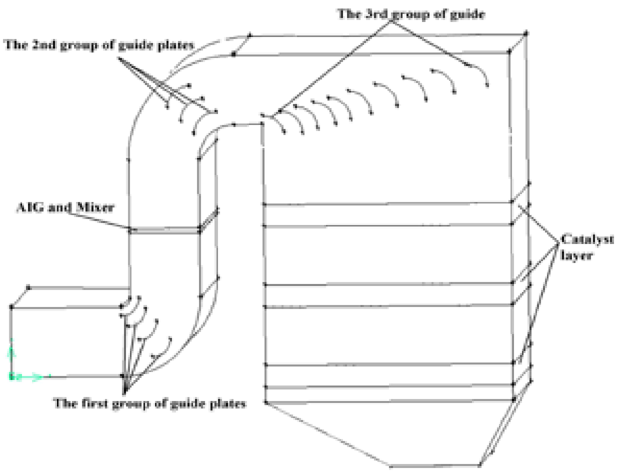


Fig.1 Layout of SCR $deNO_X$ system

3. Results and discussion

Figure 2 illustrates simulation results in one plane after the first group of guide plates with two kinds of guild plates. By contrast, the first scheme(a) is adapted for its less material consumption with the similar mixing effect.

In a full scale system, the ammonia distribution is the most important process condition as it relates to SCR performance. The ammonia-injection equipment is fitted in the vertical duct of the SCR reactor. The NH_3/NO_x molar ratio is carefully selected at design stage on the basis of the type of catalyst applied so as to ensure high efficiency of NO_x reduction and very low NH_3 slip. As one of the important equipments in the $deNO_x$ system, the mixing results of AIG and Mixer will affect the distribution of ammonia, thus chemical reaction in catalyst and the efficiency of NO_x reduction. The mixing effects of disc-ring Mixer and grid-type Mixer are plotted in Figure 3. Disc-ring Mixer is adapted as a new guiding device for its simple structure and better mixing effect. Hot air and reduction agent will be sprayed to disc-ring Mixer through every nozzle, which creat a eddy zone at the downstream side of the Mixer, so ammonia and exhaust gas can be stirred well.

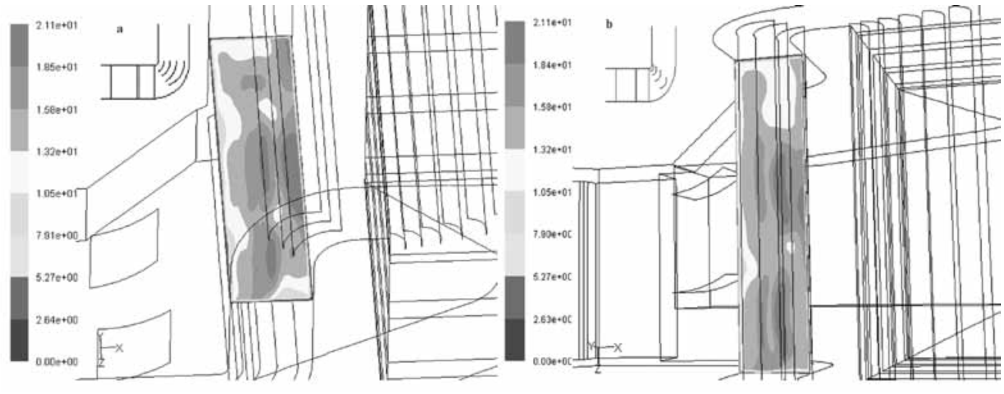


Fig.2 Simulation results in one plane after the first group of guide plates with two kinds of guild plates

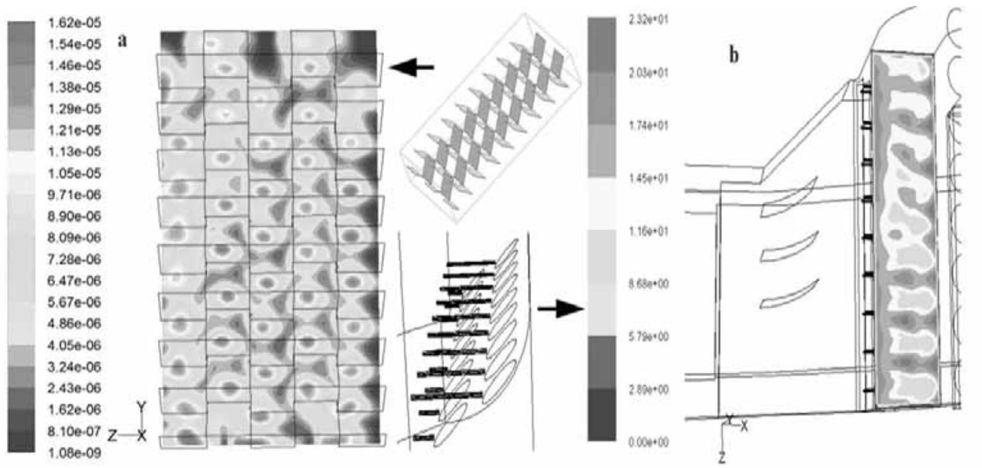
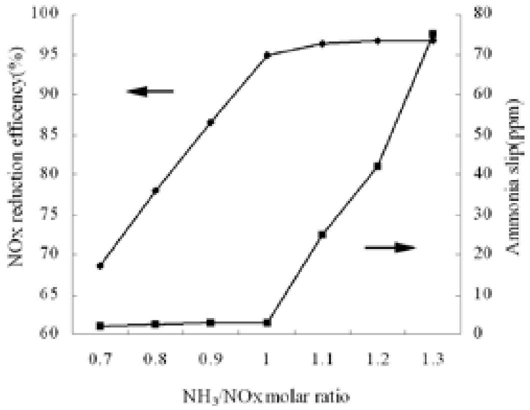


Fig.3 (a) Grid-type Mixer and its mixing effect; (b) Disc-ring Mixer and its mixing effect

3.1. Effect of NH_3/NO_x mole ratio upstream of the first catalyst layer on the NO_x reduction efficiency

For high performance SCR design, the NH_3/NO_x molar ratio distribution is typically the most critical distribution parameter influencing reactor efficency, outlet ammonia slip, and outlet NO_x variance. As shown in Figure 4, the higher the NH_3/NO_x molar ratio for a given SCR system, the better the NO_x reduction efficiency. When the NH_3/NO_x molar ratio is over 1.0, the variation of the NO_x reduction efficiency is inconspicuous. When it reaches 1.1, the NO_x reduction efficiency keeps mostly unchangeable. However, the corresponding ammonia slip increases exponentially and reaches unacceptable concentrations very quickly.



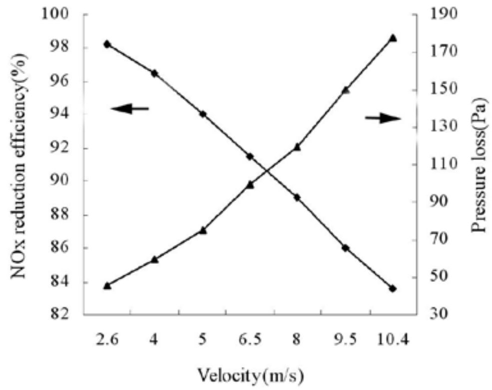


Figure.4 NO_x reduction efficiency and ammonia slip as a function of NH_3/NO_X molar ratio

Fig.5 Simulation result of NO_x reduction efficiency and pressure loss in catalyst under defferent velocity

3.2. *Effect of Velocity upstream of the first catalyst layer on the deNO$_x$ efficiency*

Effect of different Velocity on deNO$_x$ efficiency is simulated by fixing NO_x content and change NH_3 content(NH_3/NO_x=1:1). As illustrated in Figure 5, the efficiency of NO_x reduction ranges gradually from 98% to 83% as the velocity increases from 2.6 to 10.4. The corresponding pressure loss change from 46 to 178. It is explained that high space velocity yields bad reagent utilization.

3.3. *Velocity distribution upstream the first catalyst layer*

When the inlet conditions and catalyst activity characteristics are accurately known, the velocity distribution in every plane can be predicted. Figure 6 shows the velocity deviation upstream the first catalyst layer (with a total of 143 zones). As can be seen, better results will be obtained by using guide plate and disc-ring Mixer. Only a few values of velocity are more than the mean. Standard deviation is about 6.6% and can satisfy the demand of <15% in Engineering.

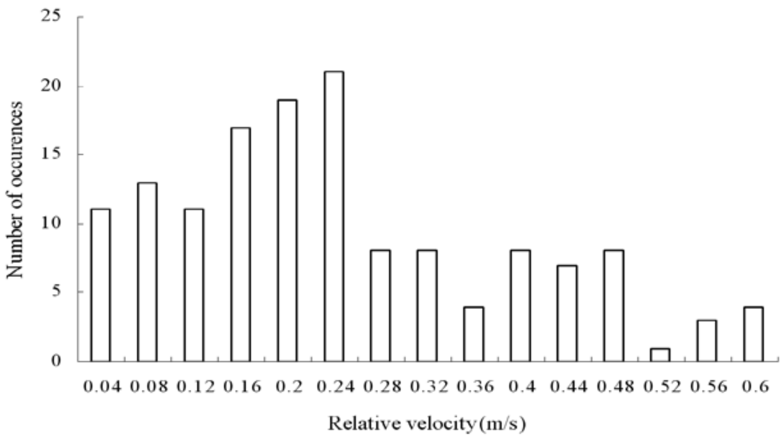


Fig.6 Relative Distribution upstream of 1st catalyst Layer

The resulting ammonia slip is shown in Figure 7. As in the design the average ammonia is 2.2 ppm. The maximum local ammonia slip is 4ppm, which is acceptable.

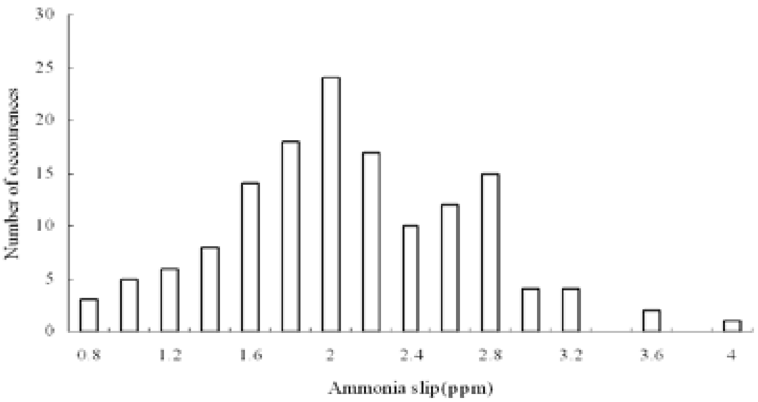


Fig.7 Ammonia slip upstream as a result of velocity distribution

4. Conclusion

Based on the results, the present work shows useful guidelines to achieve the optimum design of a SCR system for improving deNO$_x$ performance and reducing ammonia slip. It shows that better mixing effects can be obtained by plate-type guiding vanes and disc-ring Mixer. The NO$_x$ reduction efficiency increases with the increase of NH_3/NO_x molar ratio. However, when NH_3/NO_x molar ratio exceeds 1.0, the corresponding ammonia slip increases exponentially. So it is proper that NH_3/NO_x molar ratio should be 1.0. In addition, NO$_x$ conversion is reduced gradually due to the decrease in reaction time in the catalyst with the increase of velocity when NH_3/NO_x molar ratio is 1:1 and pressure loss keeps up going up. The deviation of NH_3 concentration and velocity distribution upstream the first catalyst layer can satisfy the demand in Engineering.

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