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Effect of Rectifier Grid on Flow Field Upstream of Ammonia Injection Grid

Yuhao Wu, Yuan Tie, Yan Zhang, Lei Deng*, Defu Che
State Key Laboratory of Multiphase Flow in Power Engineering, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, 710049, China (leideng@mail.xjtu.edu.cn)

ABSTRACT

In this study, with a rectifier grid upstream of ammonia injection grid (AIG), a three-dimensional CFD model was established to optimize the flow field. The effect of the installation height, rectifier grid spacing and plate height on the flow field were investigated. The results show that the uniformity of flow field is improved as the distance between rectifier grid and AIG upstream section decreases. Reducing the grid spacing at high-velocity region is also a valid way to improve the flow field. In addition, the plate height of 200 mm is selected for better performance in optimizing the flow field. Besides adding curved plates at the corner, a suitable rectifier grid arranged upstream of AIG can effectively improve the flow field as well.

Keywords: rectifier grid, flow field optimization, CFD, SCR

1. INTRODUCTION

Nitrogen oxides (NO_x) are common air pollutants in industrial exhaust gas. The massive emission of NO_x is responsible for the formation of smog, acid rain and photochemical smog, which causes great harm to the environment and human health[1,2]. According to the relative policy, the NO_x emission is limited to 100 mg·Nm^{-3} for the pulverized coal boiler in China[3-5]. Therefore, valid denitration technology is in urgent need. With high efficiency, selective catalytic reduction (SCR) systems have been widely used to reduce NO_x emission.

There are many corners and internals in the long flue of SCR system, which affects the distribution of velocity and reducing agent significantly. Many researchers have explored how to optimize the flow field in the SCR system. Zeng et al.[1] found that installing small-sized baffles upstream of the facility was helpful to improve the uniformity of flow field. Yu et al.[6] and Zhong et al.[7] paid their attention to the effect of gas-solid flow on catalyst erosion. In general, most of previous studies were mainly focused on the effect of flow on the catalyst in the SCR system[8-10]. Actually, the velocity distribution upstream ammonia injection grid (AIG) is also an important indicator to measure the system performance[11-13]. However, the optimization of flow field upstream of AIG was concerned by a small portion of research, which are mainly focused on the use of perforated plate[14] or baffle[15]. The rectifier grid, composed of vertically staggered plates, is always arranged before catalyst. The effect of rectifier grid height on catalyst was studied by some researchers[16]. Since the rectifier grid upstream of the catalyst can effectively optimize the flow field upstream of catalyst[17], installing it upstream of AIG should also have a good performance. Unfortunately, there are few reports on the arrangement of the rectifier grid upstream of AIG.

In this study, a flue gas denitration system of a 260 t·h^{-1} oil-gas boiler was chosen as the simulation object. Computational fluid dynamics (CFD) was used to simulate and optimize the flow field upstream AIG. The effects of installation heights, rectifier grid spacing and plate heights were analyzed to better improve the flow field. To the best of the authors' knowledge, it is the first time to investigate the effect of parameters of rectifier grid on the flow field upstream of AIG. This work is a good reference for industrial design and optimization.

2. MODELLING METHODOLOGY

2.1 *Physical model*

The simulations were based on a flue gas denitration system of a 260 t·h^{-1} ultra-high pressure oil-gas boiler, with the geometry schematic shown in Fig 1. The inlet gas flow rate is 35.355 kg·s^{-1}. The flue gas enters the

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economizer hopper, passes through AIG and rectifier grid in turn, finally reach the SCR reactor. For convenience, the section 400 mm below the horizontal axis of the ammonia injection pipe is named as AIG upstream section, as shown in Fig 1. In this study, only the area from flue gas inlet to AIG upstream section is analyzed and discussed.

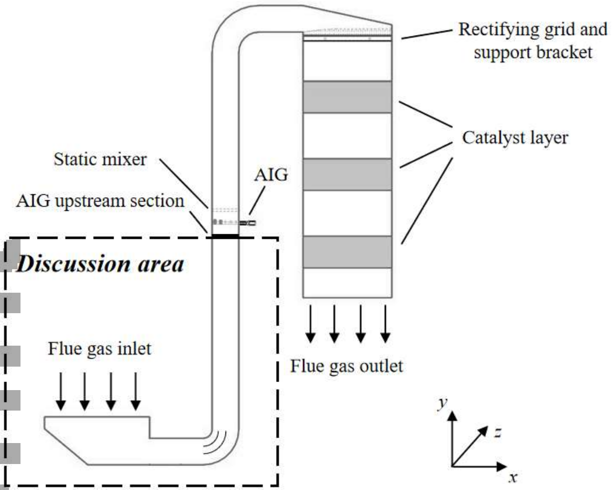

Fig 1 geometry schematic of the SCR system

2.2 Analysis method

The coefficient of variable of velocity C_v is considered as the main evaluation standard:

$$C_v = \frac{\sigma}{\bar{x}} \times 100\% \tag{1}$$

$$\sigma = \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2} \tag{2}$$

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \tag{3}$$

In addition, the velocity contour is also used to characteristic the velocity distribution. Moreover, in this study, the optimization is based on the case 0 with two 90° curved plates at the corner, as shown in Fig 1. These plates are set to optimize the flow field preliminary, which can reduce C_v on the AIG upstream section from 21.84% to 19.84%. However, the C_v at the AIG upstream section is generally required below 15%[1]. Therefore, the rectifier grid is used to further optimize the flow field.

2.3 Grid independence test

The grid independence was firstly verified. The total grid number in discussion area of 91854, 132204 and 187534 were primarily calculated. Their pressure drop, from the flue gas inlet to the AIG upstream section, are 80.7 Pa, 76.5 Pa and 76.2 Pa, respectively. Considering the accuracy and cost of the simulation, the mesh with 132204 cells is chosen.

3. RESULTS AND DISCUSSION

3.1 Effect of the installation height

In this section, the rectifier grid is composed of fourteen plates spaced 80 mm in x direction, with nine plates spaced 400 mm in z direction. All plates are non-thickness and 200 mm high. To investigate the best installation height, in the following five cases, the y-direction axes of the rectifier grid are located 300, 1300, 2300, 3300 and 4300 mm below the AIG upstream section, respectively. In this order, they are named case 1 to 5. Fig 2 shows the simulation results of five cases.

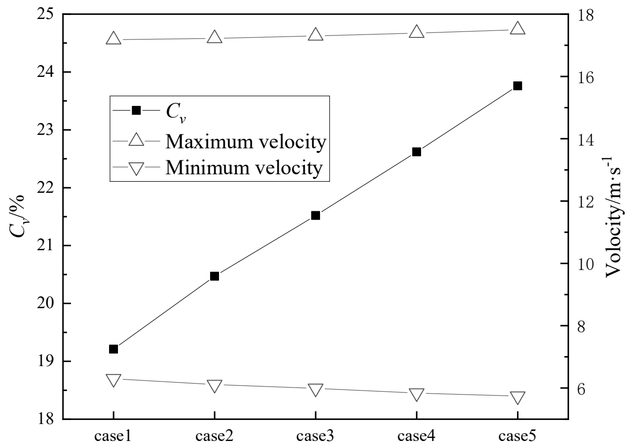

Fig 2 C_v and velocity on the AIG upstream section with different installation heights

In Fig 2, with approaching the AIG upstream section, C_v and minimum velocity increase, while maximum velocity has the opposite trend. In actual engineering, it is difficult to repair or replace if the rectifier grid is very close to AIG. Taking practice and simulation results into account, 300 mm below the AIG upstream section is taken as the apposite installation height. The following simulations are based on it. However, the smallest C_v is 19.21% in case 1, which is only a little lower than 19.84%. So further optimization is still needed.

3.2 Effect of the rectifier grid spacing

In this section, three optimization methods are provided: 1.Reducing the spacing to 40 mm in right seven plates (adding one plate between every two plates, as shown in Fig 3);2.Reducing the spacing to 20 mm in right seven plates;3. Reducing the spacing to 40 mm in left seven plates. These three cases are named case 6-8, respectively.

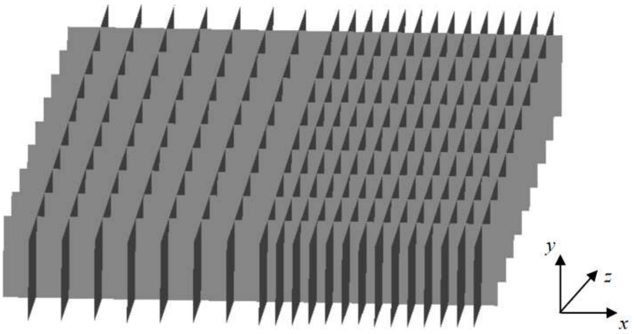

Fig 3 dense rectifier grid in case 6

Table 1 shows the C_v results, Fig 4 presents the velocity distribution on the AIG upstream section. In Fig 4, the most uniform velocity distribution is observed in case 6. A slight increase in C_v results from adding plates in low-velocity region in case 8. Compared with case 0 and case 6, the obvious decrease of C_v is caused by reducing the spacing of high-velocity region. However, when the spacing decreases from 40 mm to 20 mm, there is a 2.07% increase in C_v. It can be inferred that the flow field is improved significantly by adding dense rectifier grid in the high-speed area. But as shown in case 7, excessively reducing the spacing is negative for the reduction of C_v, similar to the study of Gao et al[16]. Since reducing the grid spacing means more plates and more costs, it is vital to find the optimal spacing.

Table 1 C_v with different spacing

example	Case 0	Case 6	Case 7	Case 8
C_v/%	19.71	15.38	17.47	20.51

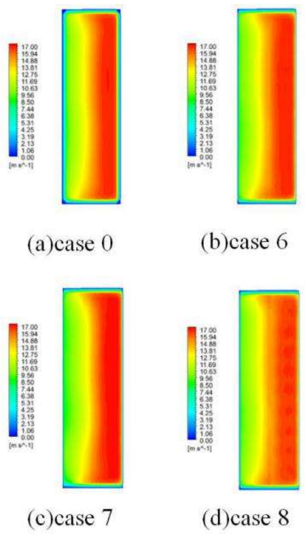

Fig 4 velocity distribution contours

3.3 Effect of the plate height

While remaining the axis height in y direction constant, five plate heights, including 100, 200, 300, 400 and 500 mm, are tested to optimize the flow field. The effect of different plate heights on flow field is shown in Fig 5. As the plate height increases, the velocity C_v on the AIG upstream section has a tendency of "decrease-increase-decrease". The best performance is taken by 200 mm high plates (case 6), with a minimum C_v of 15.38%. From the previous discussion, the addition of the rectifier grid has two sides. On the one hand, it can guide the airflow to improve the flow field. On the other hand, a negative impact is also shown on the flow, because the original flow field is destroyed by the plates. When increasing the plate height from 100 to 200 mm, the dominance is occupied by the positive effect, leading to a great improvement of uniformity of velocity distribution. On the contrary, the stronger negative effect results in the rise of C_v as the plate height increases from 200 to 300 mm. But When the plate height exceeds 300 mm, the higher the plate, the lower the C_v, indicating that the positive effect dominates again. Therefore, higher plates better guide the flow after the height over a certain value. However, a substantial increase in plate height will lead to higher costs. Considering the cost and reduction of C_v, the height of 200 mm is the best choice in this study.

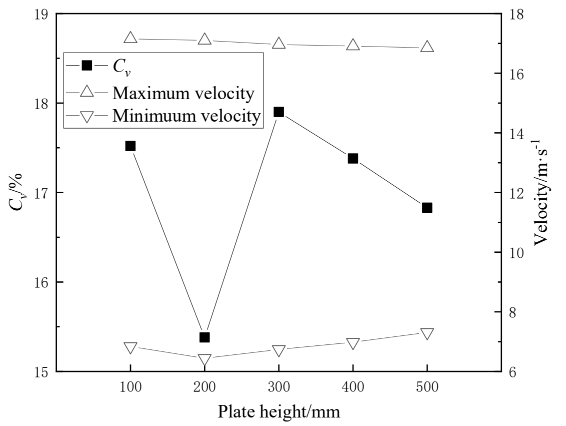

Fig 5 C_v and velocity on the AIG upstream section with different plate heights

4. CONCLUSION

(1)By approaching the AIG upstream section, the rectifier grid has better performance in reducing the C_v of velocity.

(2)The flow field upstream AIG can be optimized by reducing the rectifier grid spacing at high-velocity region.

(3) An appropriate plate height is helpful to improve the flow field. Compared with different designs, the 200 mm high rectifier grid located 700 mm below the horizontal axis of the ammonia injection pipe performs best, with a minimum C_v of 15.38%.

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