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Research Paper

Numerical simulation of the combustion characteristics and NO_x emission of a swirl burner: Influence of the structure of the burner outlet

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HIGHLIGHTS

- The prediction shows a good agreement with experimental results.
- Burner performance increases as primary air cone length decreases.
- Burner NO_x reduction capacity increases as inner secondary cone length increases.
- Burner performance increases as outer secondary air cone length increases.

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ABSTRACT

Numerical simulations on coal combustion and NO_x emissions were performed for a centrally fuel-rich pulverized-coal swirl burner. By varying cone lengths of primary air, inner secondary air and outer secondary air, the burner outlet structure effect was disclosed in detail. The new findings which can deepen the understanding of the swirl burner performance are as follows. The ignition performance and NO_x reduction capacity of burner increases as primary air cone length decreases. As the inner secondary air cone length increased, ignition performance of burners becomes poor and the NO_x reduction capacity increases. The ignition performance and NO_x reduction capacity of burners become stronger with increases in outer secondary air cone length. Under the conditions including that (i) outer secondary air cone length is three times of the outer secondary air duct diameter, (ii) inner secondary air cone length is 50–100% of outer secondary air cone length and (iii) primary air cone length is 0 mm, the burner presents an excellent performance on NO_x emissions and pulverized-coal combustion characteristics with air-staging conditions.

1. Introduction

Nitrogen oxide (NO_x) is produced in the coal combustion process by coal-fired power plants. NO_x can result in many unfavorable environmental effects, such as smog and acid rain, and has been an important issue for some time. Selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) are the most efficient methods for controlling NO_x emissions, but these methods are costly. Low NO_x burners and air staged technology has been popular due to the simplicity and cost-effectiveness of retrofitting burners and the significant reductions in NO_x.

There has been extensive work on the effects of primary stoichiometric ratio [1–4], over fire air location [5–7], air temperature [8], different coal types [9] and swirl number and fuel equivalence ratio [10] on NO_x emission carbon burnout characteristics in laboratory furnaces or industrial boilers. However, due to the limitations of existing measurement technologies, a complete view of coal combustion cannot be measured using laboratory furnaces or industrial boilers. Computational fluid dynamics (CFD) can provide a wide range of information regarding combustion characteristics [11–13]. Several simulation studies have focused on the combustion process and NO_x emissions in a single swirl burner. Zeng et al. investigated the influences of outer secondary air vane angle on NO_x emissions for a 300 MW boiler. Results showed that the NO_x concentrations increased from 861.41 to 912.87 mg/N m^3

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(O_2 = 6%) as the angle increased from 35° to 45° [14]. Li et al. simulated the particle sticking behavior near the throat of a swirl burner and found that the relationship between outer secondary air vane angle and sticking-particle ratio is non-linear [15]. Zhou et al. studied the effect of the primary air pipe of a low NO_x swirl burner on NO_x emissions and found that the optimized swirl burner results in an increase in NO_x reduction of approximately 175 mg/N m^3 (O_2 = 6%) compared with a prototype burner [16].

The performance of a swirl burner depends on how to form a moderate central recirculation zone which entrains high temperature gas to guarantee timely ignition and stable flame. After adopting air staging technology, the secondary air mass flow rate of the burner decreases by about 37% when the designed over fire air (OFA) ratio is 25%, resulting in the swirl intensity of the burner decreases sharply. Regulating a moderate central recirculation zone for swirl burners is a huge challenge after adopting air staging technology to reduce NO_x emissions. The main factors that affected the swirl burner performance are its geometry and operating parameters. The available literature on the swirl burner performance mainly focuses on the swirl angle [14,16], primary air pipe structure [16–18], swirl generator location [19], swirl number [10,20,21], outer/inner secondary air ratio [22]. These mentioned parameters are adjustable according to the boiler load and coal variation in practical operations, whereas the burner outlet cone is fixed. Apparently, evaluating the burner outlet structure effect on NO_x emissions and combustion characteristics is necessary for a swirl burner, especially with the circumstances adopting the air staging technology. The published literature provides no any information in this academic field. Accordingly, in this paper effects of various outlet structure parameters of an air-staging swirl burner on combustion characteristics and NO_x emissions are evaluated, including the primary air cone length (L_p), inner secondary air cone length (L_i), and outer secondary air cone length (L_o).

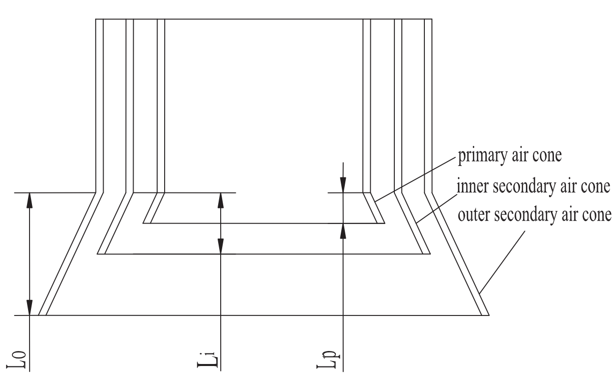

Fig. 1. The centrally fuel-rich swirl burner.

2. Numerical simulation

For this study, we considered a model burner (Fig. 1) one eighth of the size of the prototype designed for a 600 MW pulverized-coal utility boiler. In Fig. 1, L_p is the primary air cone length, L_i is the inner secondary air cone length, and L_o is the outer secondary air cone length of the model burner.

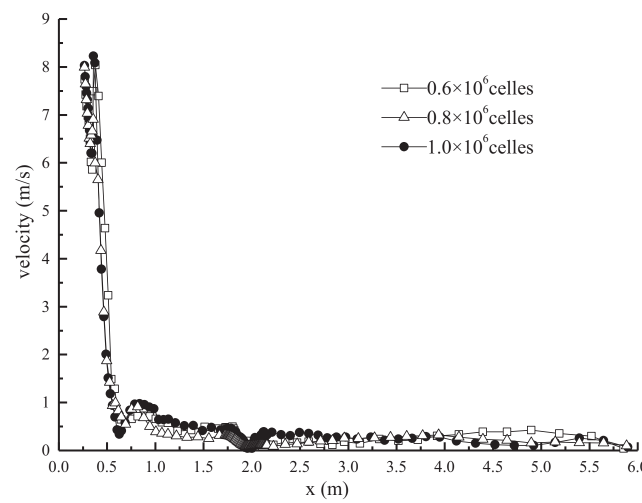

Fig. 3. Mesh-independence test based on gas axial velocities in the furnace centerline.

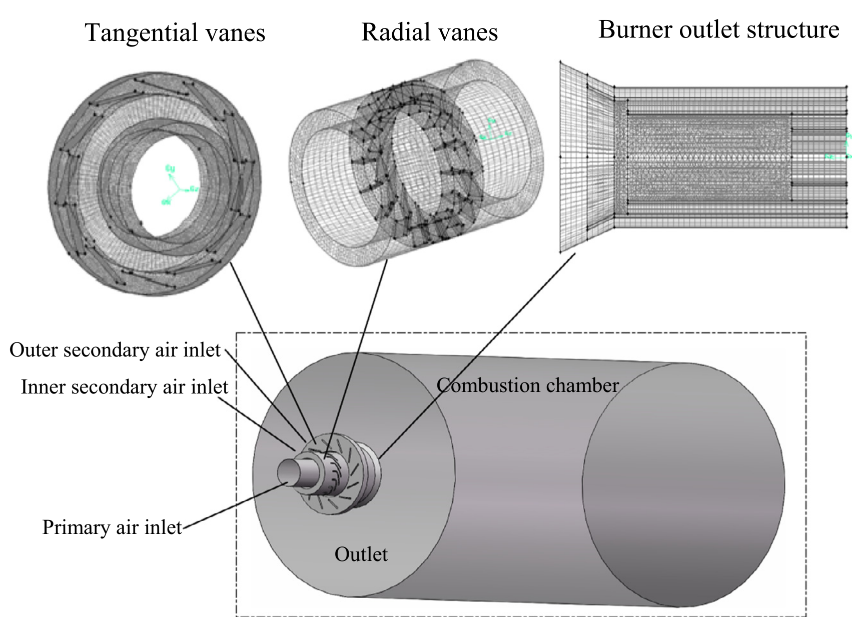

Fig. 2. Schematics of computational domain and centrally fuel-rich swirl burner.