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Influence of primary air ratio on flow and combustion characteristics and NO_x emissions of a new swirl coal burner

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ABSTRACT

Cold airflow experiments on a small-scale burner model, as well as *in situ* experiments on a centrally fuel-rich swirl coal combustion burner were conducted. Measurements were taken from within a 300 MW_e wall-fired pulverized-coal utility boiler installed with eight of centrally fuel-rich swirl coal combustion burners in the bottom row of the furnace during experiments. Various primary air ratios, flow characteristics, gas temperature and gas species concentrations in the burner region were measured. The results of these analyses show that with decreasing primary air ratio, the swirl intensity of air, divergence angles and maximum length and diameter of the central recirculation zone all increased, and the turbulence intensity of the jet flow peaked but decayed quickly. In the burner nozzle region, gas temperature, temperature gradient and CO concentration increased with decreasing primary air ratio, while O_2 and NO_x concentration decreased. Different primary air ratios, the gas temperatures and gas species concentrations in the side-wall region varied slightly.

1. Introduction

Coal-fired plants account for a great proportion of the energy capacity in the international energy production and consumption structure, with the power industry being one of its major consuming industries. However, the ever-present problem of high NO_x emissions is of prime concern in the operation of thermal power units and the regulation of which has become increasingly strict globally in recent years. The objective of the Cost Abatement for Effective NO_x Reduction in PF Coal-fired Power Plants project is to check the ability of primary techniques to attain exhaust NO_x emission levels imposed by the European Union. Since 2008, the allowed concentrations for power plants rated over 50 MW_e has been set at 500 mg NO_2/Nm^3 at 6% O_2. From 2016, the limit for power plants rated over 500 MW_e will be 200 mg NO_2/Nm^3 at 6% O_2 [1]. In China, the permissible NO_x emission limit was set in 2004 at 450 mg/m^3 for existing power plants.

With this background, intensive research has been conducted around the world to reduce pollutant emissions generated during combustion [2–5]. Li [2008, 2010, 2002] proposed a new low-NO_x pulverized-coal burner technology, the centrally fuel-rich (CFR) swirl coal combustion burner, based on a radial-bias combustion burner and an enhanced ignition dual-register burner [6–8].

Industrial experiments performed on full-scale boilers have revealed coal combustion characteristics and the mechanism of NO_x formation. Costa et al., [1997, 2003, 2007] measured local mean gas species concentrations (*viz.* O_2, CO, CO_2, and NO_x), gas temperatures and char burnout at several ports in a 300 MW_e, front-wall-fired, pulverized-coal utility boiler [9–11]. Vikhansky et al., [2004] measured heat fluxes in a 550 MW_e, opposite-wall-fired, pulverized-coal utility boiler [12]. Experiments have been performed in pulverized coal, tangentially-fired, down-fired and wall-fired boilers [13–22], but few detailed measurements have been taken in the burner region to acquire flow dynamics.

Different aerodynamic fields lead to variations in the coal combustion process. To analyze the interplay between aerodynamic behavior and the combustion of the pulverized coal, researchers have studied the aerodynamic behavior of full-scale furnaces by performing experiments with small-scale models [23–25]. Changes in the primary air ratio of a swirl burner have the same effect as changes in the secondary air ratio. The secondary air ratio, which greatly affects the aerodynamic field and combustion characteristics within a swirl burner, is defined relative to the variation in the mass flow rate of over-fire–air. Thus, it is necessary to study the dependence of the flow and combustion characteristics and NO_x emissions of swirl burners on primary air ratios.

In the present work, cold airflow experiments were performed with a small-scale burner model as well as *in situ* experiments on a CFR burner. Measurements were conducted with a 300 MW_e wall-fired pulverized-coal utility boiler in the No. 4 burner in the

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bottom row on the rear wall of the furnace. Local mean concentrations of O_2, CO and NO_x and gas temperatures were recorded at positions within the CFR burner for different primary air ratios.

2. Utility boiler

The B&W B-1025/16.8-M boiler with a 300 MW_e unit was made by Babcock & Wilcox Beijing Co. Ltd. This opposite-wall-fired, pulverized-coal boiler with a dry-ash type furnace is equipped with 20 enhanced ignition dual-register burners, of which 12 are arranged in three rows on the front wall of the furnace. The other eight burners are arranged in two rows on the rear wall, opposite to the eight burners in the top and bottom rows on the front wall. A schematic view of the boiler and burners is shown in Fig. 1. Five medium-speed mills and a positive-pressure direct-fired system are used to supply pulverized coal to the burners. To increase boiler combustion stability, eight enhanced ignition dual-register burners in the bottom row of the furnace were replaced with CFR burners.

Fig. 2 is a schematic diagram of a CFR burner with 16 bent-shaft vanes in the inner secondary air duct and 12 tangential vanes at the entrance of the outer secondary air duct. Table 1 lists the design parameters for the burner. Compared with the enhanced ignition dual-register burner, the CFR burner has cone separators instead of a particle deflector and a conical diffuser in the primary air tube to affect the distribution of pulverized coal in the primary air. Under the influence of the cone separators, pulverized coal carried by primary air is concentrated into the central zone of primary air, which results in a coal-rich flow within this zone and a coal-lean flow peripheral to it.

Experiments were conducted within the utility boiler to analyze the flow and combustion characteristics and NO_x emissions for different primary air ratios within the CFR swirl burners.

3. Cold air experiments of the CFR burner model

Using isothermal modeling technology, a cold experiment was performed in the laboratory using a CFR burner model one-quarter of the size of the prototype. A schematic view of the test facility is illustrated in Fig. 3, where x is the distance to the exit of the burner

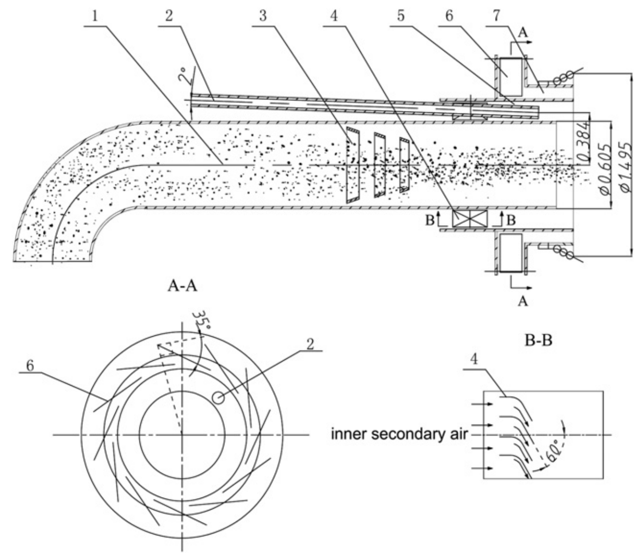

Fig. 2. Cross-section of CFR burner and position of the monitoring pipe (dimensions in meters): (1) primary air duct, (2) monitoring pipe, (3) cone separators, (4) radial vanes, (5) inner secondary air duct, (6) tangential vanes, and (7) outer secondary air duct.

along the jet flow direction, r is the distance to the chamber axis along the radius direction, and d is the diameter of the outer secondary air duct (d = 0.374 m). Table 2 lists experimental parameters. An IFA300 constant temperature anemometer system was used to measure the air velocity at various measurement sites. Using a probe with hot-film sensors, we measured the three-dimensional flow field at the exit of the CFR burner [7]. The error in velocity measurements was less than 5% [26].

Fig. 4 shows various profiles of the axial mean velocities after the outlet of the CFR burner, with different primary air ratios. In the panel for the x/d = 0.25 cross-section, two peaks can be seen in each of the velocity profiles. The peak values further away from the central line increase with decreasing primary air ratio. When the primary air ratio is low, the peak value in the axial mean velocities is high within the secondary airflow zone and mixing between primary and secondary air develops quickly. Swirl ability at the

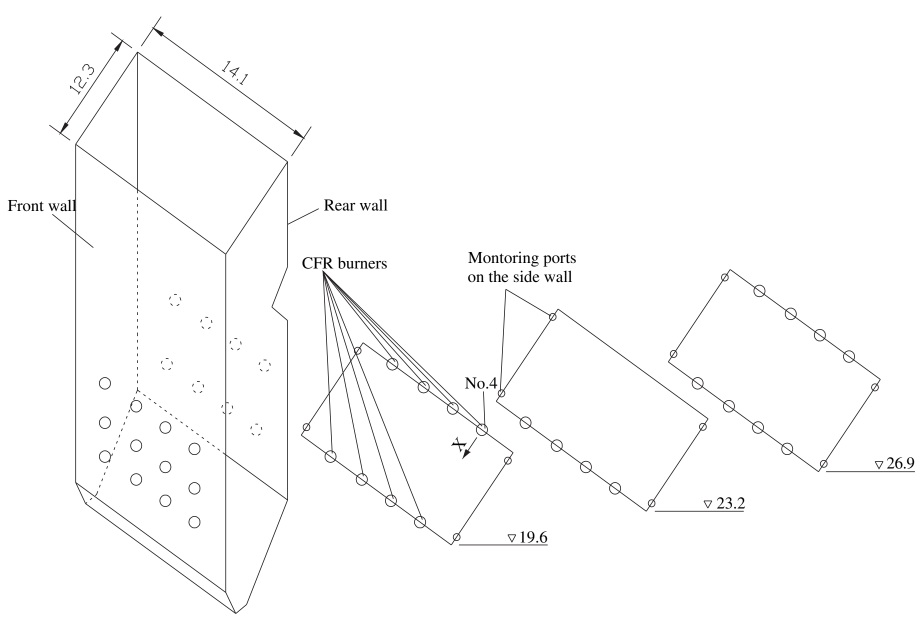

Fig. 1. Schematic view of the boiler with the burners (all dimensions in meters).