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Review

Gas/particle flow and combustion characteristics and NO_x emissions of a new swirl coal burner

Zhichao Chen*, Zhengqi Li, Qunyi Zhu, Jianping Jing

School of Energy Science and Engineering, Harbin Institute of Technology, Harbin, Heilongjiang 150001, PR China

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ABSTRACT

Due to the limits of reserves and price for the high rank coal, the low rank coal has been employed as fuel for power generation in China and will be eventually employed in the world. To burn low rank coal, centrally fuel-rich swirl coal combustion burner has been studied in Harbin Institute of Technology. This paper reviews and analyzes the major research results. The work has included both experiments and numerical simulation. The experiments were conducted using small-scale single-phase experimental equipment, a gas/particle two-phase test facility and 200- and 300-MW_e wall-fired utility boilers. For the burner, the primary air and glass beads partially penetrate the central recirculation zone and are then deflected radially. At the center of the central recirculation zone, there is high particle volume flux and large particle size. For the burners the local mean CO concentrations, gas temperatures and temperature gradient are higher, and the mean concentrations of O_2 and NO_x in the jet flow direction in the burner region are lower. Moreover, the mean O_2 concentration is higher and the gas temperature and mean CO concentration are lower in the side wall region. Centrally fuel-rich burners have been successfully used in 200- and 300-MWe wall-fired pulverized coal utility boilers.

1. Introduction

Coal is the most abundant reserves fossil fuel in the world, and the absolute amount of coal in average annual consumption will show an upward trend, especially in China [1]. Owing to relative plentiful supply and low price of coal, many countries in the world use coal as fuel for power generation, particularly adopt the pulverized coal boiler [2–5]. The ratio of pulverized coal power generation units to power generation units in China, US and the world is respectively about 75%, 50%, and 40% [6]. The coal combustion can cause serious air pollution [7–9], such as NO_x, SO_x, CO_2 and so on. As environmental protection requirements improving among countries around the world, clean coal technologies have been developed and used widely, such as coal combustion with CO_2/O_2 oxy-fuel combustion [10,11], the ultra-supercritical plant, the integrated gasification combined cycle and pressurized fluidized bed combustion. Some new coal-based power generation units have begun to adopt the above clean coal technologies. But most 100–300 MWe coal burning units in the world built in the past are subcritical units [12], especially some 600 MWe units in China are subcritical units. In 2004, the subcritical and supercritical units account for 39.4% of total capacity, super high-pressure units comprise 16.6%, and high-pressure units of 100 MW and below constitute 44% in China [13]. For these completed units, mainly adopt some new technologies to retrofit them, such as low NO_x burner [14–19], overfire air, wet and dry flue gas desulfarator, selective catalytic and non-catalytic reduction.

To lessen environmental pollution, the allowed NO_x emission from power plants has been lowered in many countries. In the European Union for example, the allowed emission concentration for power plants over 500 MWe is 500 mg NO/Nm^3 at 6% O_2 from 2008 to 2016. From 2016, the limit will be 200 mg NO/Nm^3 at 6% O_2 [8,20]. The strict limits on NO_x emissions has been given in China. The pulverized coal power generation units built after 2004 should have NO_x levels under 450 mg/Nm^3 at 6% O_2 (dry basis) when burning coals with more than 20% volatiles (dry ash-free basis) [21]. This encourages the development of a lower NO_x emission technique for wall-fired [14–19], tangentially fired [22–25], and down-fired [26–30] boilers. The low NO_x swirl burners are almost designed for bituminous coal, which have the high sensitivity to the type of coal.

In China, in view of continuous and persistent development strategy, the security of fuel supply and fuel cost, a lot of power station use low rank coal with low calorific value, low volatility and low ash fusion temperature. When burning low rank coal, it is difficult for low NO_x burners designed to burn high rank coal to meet power industry requirements such as flame stability and no

* Corresponding author. Tel.: +86 451 86 41 3231; fax: +86 451 86 41 2528.
E-mail address: chenzc@hit.edu.cn (Z. Chen).

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propensity for slagging [19,31–35]. Coal demand will increases from 38% between 2005 and 2015 to 73% by 2030 [36]. As coal is a kind of non-renewable resource, the global coal production from the existing coalfields is reaching quickly the peak, and coal production from these areas will fall by 50% in the next 40 years [2]. Due to the limits of reserves, supply and price for the high rank coal, the low rank coal or blends of different kinds of coals has been employed as fuel for power generation in some countries and will be eventually employed in the world in the future. The sub-bituminous coal is studied to be utilized in pulverized coal boilers designed for bituminous coal combustion in Japan [37]. For the energy development strategy, the low rank coal is used as fuel for power generation in China. To burner low rank coal, the requirements for such a lower NO_x emission technique are high flame stability, high efficiency combustion, and resistance to slagging and high-temperature corrosion. To meet the requirements, Prof. Li et al. proposed a new swirl burner, the centrally fuel-rich swirl coal combustion burner [18,34,35,38–48] (Fig. 1). For this burner both the inner and outer secondary airs are in a swirling state. The primary air–coal mixture duct is at the center of the burner and the primary air is non-swirling. Cone separators are installed in the primary air–coal mixture duct to concentrate the pulverized coal into the central zone of the burner.

This low NO_x burner burning low rank coal have been studied by Prof. Li et al. from 2003 in Harbin Institute of Technology. Firstly, the structure of the burner was optimized using single-phase test facility. Secondly, the optimal gas/particle flow field for the burner was gotten using gas/particle two-phase test facility and numerical simulation. Finally, for different types of coal, we investigated the performance of the burner on wall-fired utility boilers. The research results have been published in some international journals in energy field, such as Fuel, Fuel Processing Technology, Energy Conversion and Management, Applied Energy, Energy and Fuels, Combustion Science and Technology. In this paper, authors review the research work about this new swirl burner in detail. The work has involved measurements of the characteristics of the single-phase and gas/particle two-phase flows and coal flames in the near-burner region in small-scale single-phase experimental equipment and a gas/particle two-phase test facility and 200- and 300-MWe wall-fired pulverized coal utility boilers. Some of the published results, together with more-recent work and continuing research, are reported here.

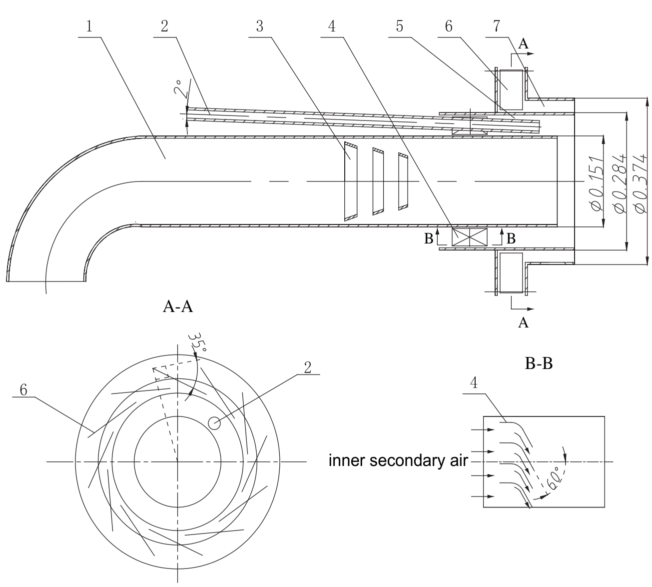

Fig. 1. Centrally fuel–rich swirl coal combustion burner and position of the monitoring pipe (dimensions in meters): 1. primary air–coal mixture duct, 2. monitoring pipe, 3. cone separators, 4. radial vanes, 5. inner secondary air duct, 6. tangential vanes, and 7. outer secondary air duct.

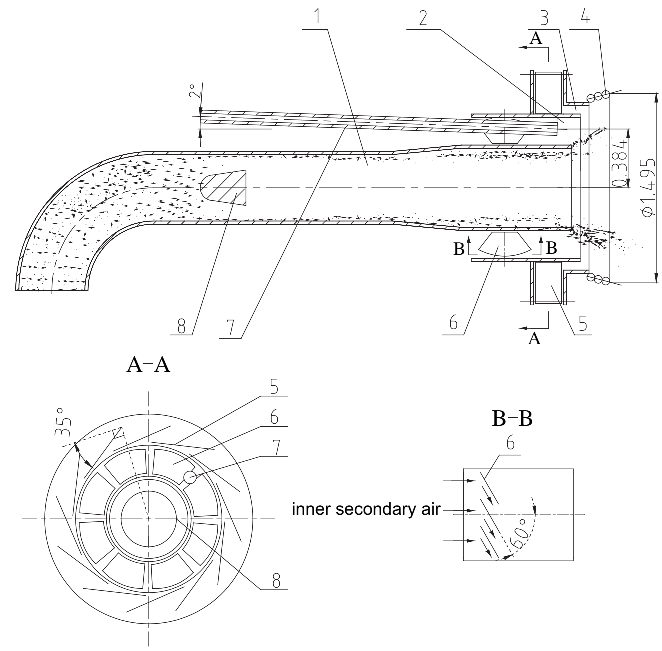

Fig. 2. EIDR burner in a bituminous coal-fired 1025-tph boiler and position of the monitoring pipe (dimensions in meters): 1. primary air–coal mixture duct, 2. inner secondary air duct, 3. outer secondary air duct, 4. water-cooled wall, 5. tangential vanes, 6. radial vanes, 7. monitoring pipe, and 8. conical diffuser.

2. Single-phase flow characteristics

The single-phase test facility [39,40] consists of a wind box, valve, dynamic pressure meter, model burner, coordinate frame, and an IFA300 constant temperature anemometer system. The three-dimensional flow field, the jet borders and the central recirculation zone boundary of the burner were measured. It is virtually impossible to replicate all the physical and chemical processes of a full-sized industrial burner in a scaled down model used in research. On the other hand, it would be too expensive to do experiments in a full-sized burner. However, results from a great number of different small scale cold-flow tests compared to those of full-size burner tests show reliable predictions can be made from the scaled down model tests [49–51]. For example, Pickett et al. [51] found the velocity profiles for reacting flow showed similar trends and patterns to those observed in cold flow experiments.

2.1. Effect of outer secondary air vane angles of the burner

Using isothermal modeling technology, a cold experiment was carried out in the laboratory using a centrally fuel-rich burner model one-quarter of the size of the prototype. The model's geometric sizes and operational parameters were obtained using scaling criteria: (1) geometric similarity; (2) secondary self-modeling flows; (3) boundary condition similarity; (4) unaltered momentum ratios with scale reduction. 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 centrally fuel-rich burner. The error in velocity measurements was less than 5%. To get the influence of vane angles on the performance of the burner, different