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Experimental study on flow and combustion characteristic of a novel swirling burner based on dual register structure for pulverized coal combustion

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ABSTRACT

A novel spout structure which contains dual-gear rings (DGR) and double conical flaring (DCF) for swirling burner is proposed. Flow field outside the novel burner (DGR–DCF burner) is studied in an unconfined environment comparing with a conventional one. The effects of DGR and DCF structures, secondary air distribution and swirling intensity on reverse flow and turbulence are discussed. Results suggest that the novel burner stabilizes reverse flow and enhances turbulence of the flow field under different air distributions and swirling intensities. The novel burner is further studied in a wall-fired pilot furnace. Gas temperature distribution, NO_x emission and unburned carbon in the fly ash are researched. Higher ignition temperature near the burner spout and a more stable temperature field in the furnace is formed with the novel burner. Reduction of NO_x emission and unburned carbon in the fly ash are achieved. The momentum ratio (M) of inner secondary air to outer primary air is defined to uniform the secondary air distribution. Increase of M raises the temperature level near the burner spout. NO_x emission and the unburned carbon in the fly ash both attain their minimum with $M = 4.428$ in the experiment range.

1. Introduction

Coal is the fundamental fossil energy source in the world. The pulverized coal burner is considered as an important combustion equipment which affects the coal combustion efficiency, safe and stable operation of boiler system and pollution emission. Researchers have done a lot of studies on coal combustion and pollution emission control, such as dense-dilute combustion [1], low-NO_x burner [2–6], flow field organization [4–7], flue gas desulfuration [8–11] and denitration [12,13]. Because of its convenient adjustment, lower cost and important effect on combustion, swirling burner of pulverized coal is always a hot topic for thermal engineering researchers. Smart et al. [14] presented the development of a coal fired precessing jet burner, the program of which began in 1994 because of the further incentive for the utility boiler market, and were performed in depth in 1999. They studied the effect of precessing jet momentum ratio and gun position on NO_x emission, heat flux and ignition distance in detail. The results showed a positive influence of the use of precessing jet on combustion characteristic. Costa et al. focused on the gas temperature and species in the burner region of a front wall fired boiler. They obtained temperature level in the burner region and NO_x concentration above the boiler nose in 1997 [15]. The work provided a considerable effort to minimum variations on boiler operating conditions and a reference for 3D mathematical model evaluation and development. Bollettini et al. [16] operated a study on scaling of natural gas burners and integrated substantial experimental data from scaling 400 projects with CFD simulation in 2000. In 2001 Milani and Saponaro introduced the dilute/flameless combustion technology and the high velocity burners, the emphasis of which is on fluid dynamic entrainment and mixing of flue gases. The temperature distribution of flameless combustion was different with conventional flame combustion and the NO_x formation was controlled [17]. Nettleton studied the effect of swirling angels of secondary air stream on flame stability and suggested some explanation for the existence of stability limits in 2004 [18]. Gu et al. analyzed the relation among the NO_x formation, gas flow and pulverized coal moving in a swirling burner with numerical simulation. The authors found that the maximum particle penetration depth into the internal recirculation zone (IRZ) L_{dav} and effective time of IRZ τ_{eav} lead to the minimum outlet NO emission [19]. Chacón et al. developed a new methodology for the design and optimization of a low NO_x-CO, natural gas burner by numerical simulation to comply with NO_x emission limits of European countries [2]. Jing et al. researched the effect rules of outer secondary air

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Nomenclature

DGR	dual-gear rings
DCF	double conical flaring
IPA	inner primary air
OPA	outer primary air
ISA	inner secondary air
OSA	outer secondary air

Symbols

R	dimensionless radial distance outside the burner (–)
r	radial distance outside the burner (m)
X	dimensionless axial distance outside the burner (–)
x	axial distance from the burner (m)
d	diameter (m)
u	axial velocity (m/s)
U	dimensionless axial velocity (m/s)
V	total air flow rates (Nm^3/s)
v	tangential velocity (m/s)
u'	axial velocity turbulence (m^2/s^2)
v'	tangential velocity turbulence (m^2/s^2)
ε	turbulence intensity (–)
ρ	density (kg/m^3)
Q	air quantity (kg/s)
f_{re}	dimensionless section reverse flow ratio (–)
M	momentum ratio of inner secondary air to outer primary air (–)
Ω	combination swirl intensity (–)
A	cross section area of pipe (m^2)
a	depth of furnace (m)
x', y', z'	depth, width and height coordinate of the furnace (m)
X', Y', Z'	dimensionless depth, width and height of the furnace (–)
w	mass fraction (%)

Subscripts

1,2,3,4	IPA, OPA, ISA, OSA
eq	Equivalent
ct	Axis
o	Outer
i	Inner
fh	Fly ash

vane angels and primary air ratio on flow, combustion characteristic and NO_x emission [6,20]. Li et al. studied the furnace temperature, heat flux and char burnout with double swirling flow burner at different loads [21].

To improve both the combustion performance and NO_x emission, optimizations of swirling burner structure for pulverized coal are proposed and studied continuously. The Babcock & Wilcox Company in New Orleans, LaRue and Wolf [22] proposed an improved burner with a splash plate, deflector and a diffuser to decrease the nozzle pressure drop and NO_x formation in 1983. Babcock-Hitachi Kabushiki Kaisha in Tokyo [23] provided a coal combustion apparatus for NO_x reduction which comprises coal pipe, multi-air passageways and bluff body in 1985. Stein Industrie in France [24] provided an axial conduit for feeding fuel in 1987, which is adjustable for varying the preliminary mixing chamber length and supports the ignition and combustion. The Babcock & Wilcox Company also in 1989 proposed a flame stabilizing ring and retractable gas element to create a low oxygen/fuel rich flame resulting in reduced NO_x formation [25]. Tenova also started in 2002 a research program, which led to a new family of low NOx burners named FlexyTech® TSX based on the flameless technology which allows to reach a low NO_x emission [26]. Orfanoudakis et al. have studied the effect of swirl number on flow and particle characteristic especially near internal recirculation zone (IRZ) in the near-burner region of a multi-fuel laboratory burner in 2005 [27]. Li et al. in 2008 made a comparison between an enhanced ignition-dual register (EI-DR) burner and centrally fuel rich (CFR) swirling burner experimentally on combustion characteristic, and found that CFR burners have higher combustion efficiency, less NO_x emission and more stable flame at low load in a 300 MW(e) wall-fired utility boiler [3]. To burn low rank coal centrally-fuel rich swirling coal combustion burner was proposed and studied both experimentally and numerically by Chen et al. [5]. They focused on the gas-particle flow analysis to control the gas temperature level and NO_x formation. With development of measurement technology and numerical calculation, the investigations on swirling burners become more comprehensive. Allouis et al. proposed a new diagnostic tool based on fast infrared imaging to test the combustion stability for burners and help adjusting flame [28]. Khanafer et al. used computational fluid dynamics simulation coupled with chemical equilibrium calculation to analyze NO_x formation in swirling burners [29]. All the studies on the swirling burner mentioned above have mainly focused on the effects of air distribution, swirling intensity and retrofit structures on combustion and NO_x emission.

However, little study of novel flame ring and flaring effect on the swirling burner, which have significant impact on flow and combustion, has been reported. In this paper, a novel burner spout with dual-gear rings (DGR) and double conical flaring (DCF) is proposed as shown in Figs. 1 and 2. Cold air test and combustion experiment are carried out under different secondary air distributions, swirling intensities and coal types. The flow characteristic, combustion performance and NO_x emission are discussed. Comparing with a conventional one, the novel burner is proved to be helpful to obtain stable, efficient and clean combustion for pulverized coal.

2. Novel burner model

The proposed novel structures were installed on a radial dual register burner, which is geometric similarity with the ratio of 1:6 to the prototype, the dual register swirling burner of

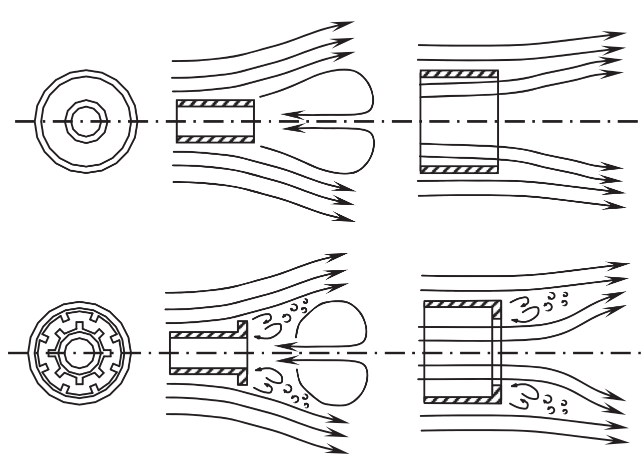

Fig. 1. Design concept of DGR in inner primary air pipe (a) traditional inner primary air spout (up); (b) DGR in the inner primary air spout (down).