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A novel coal combustion technology for a down-fired boiler: Aerodynamic characteristics

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ABSTRACT

A new combustion technology, the hot air packing (HAP) technology, was proposed and researched to improve the coal burnout and control NO_x emission in down-fired boilers. Compared with the prior technology, HAP technology necessitates the addition of special secondary air ports added in the furnace ash hopper (SA-H) and the furnace bottom (SA-B). Cold-air-flow experiments in a 1:4 scale model and fluid dynamics numerical simulations were carried out to reveal the aerodynamic characteristics in a furnace with HAP technology. The experimental and simulation results coincided well with each other; and both showed that HAP technology had rational aerodynamic characteristics in the furnace. Compared with a base case, common down-fired combustion technology, HAP technology forms a larger W shape and bigger recirculation zones, as well as a larger penetration depth of primary air flow. Moreover, HAP technology destroys the dead recirculation zones and avoids air flow washing against the wall. The angle and location of SA-H have great impacts on the aerodynamic characteristics in the furnace, especially in the ash hopper. Within the six cases, the SA-H configuration with an angle of 0° and the upper-located position yielded optimal results.

1. Introduction

Pulverized coal combustion in utility boilers is the most utilization of coal in the world, and it provides the prime electricity and power supply, especially in China. To reduce the pollutants from coal combustion, combustion optimization has attracted and still is attracting the endeavor of researchers and engineers. Besides the online combustion optimization [1,2], the redistribution of coal and air flows, particularly air staging is the emphasis [3–7]. These works include the modification and optimization of overfire air [7,8], secondary air [9] and primary air [5,6] in industrial boilers, tangentially fired boilers, opposed swirling boilers, down-fired boilers, and circulating fluidized bed boilers. There are a large amount of anthracite and lean coal reserves all over the world, which provide more than 20% of the generated electricity. In China the number can be as much as 40%. Down-fired boilers are more suitable than tangential-fired boilers for burning low volatile coal including anthracite and lean coal [10]. Moreover, down-fired boiler technology has been developing very quickly and has become a leading process for anthracite firing in the ever increasing power station market. However, the operations of down-fired boilers still suffer from the problems of poor stability, low burnout (8–15% of unburned carbon in fly ash typically), and high NO_x emission (1100–2000 mg/m^3 at 6% O_2) [11,12]. Air staging embedded in combustion modification and optimization is one of the effective and promising ways to solve these problems.

Focusing on these problems, many innovative air-staging technologies have been proposed to decrease unburned carbon content and NO_x emission. Li and his colleagues devised and validated a retrofit modification [13] which had a declined angle of secondary air through cold-flow experiments within small-scale furnaces designed by both Foster Wheeler Co. (FW) and the Mitsui Babcock energy limited Co (MBEL). It was also demonstrated by the full-scale experiments and numerical simulation [14,15] that declination of secondary air resulted in the flame center moving down, unburned carbon content decreasing and NO_x emission reducing. A new technology based on the concept of multi-injection and multi-staging combustion was proposed and verified by experimental investigations on the flow field, combustion characteristics and NO_x reduction [16]. Researches on Babcock and Wilcox (B&W) and Stein boilers have been reported by Fan et al. [17,18] and Burdett [19]. Fan conducted the numerical simulation of a 300 MW boiler with focus on the combustion characteristics and NO_x formation, and Burdett performed industrial tests to investigate the effects of air staging on NO_x emissions from a 500 MW boiler unit. Furthermore, other studies were carried out on aerodynamic and combustion characteristics [20,21], slagging [22], and NO_x reductions by parametric tuning of operating conditions [12,23] and by overfire air application [24,25] in down-fired boilers.

It has been found out by Ren [26] and Fang et al. [14] that the original horizontal-fed direction of the F-layer secondary air can not only block the primary air, but also impel the flow to form a dead recirculation zone in the furnace hopper zone. This solitary recirculation zone adversely affects burnout and decreases utilization rate. However, most of the attention has been focused on the impact of burners, secondary

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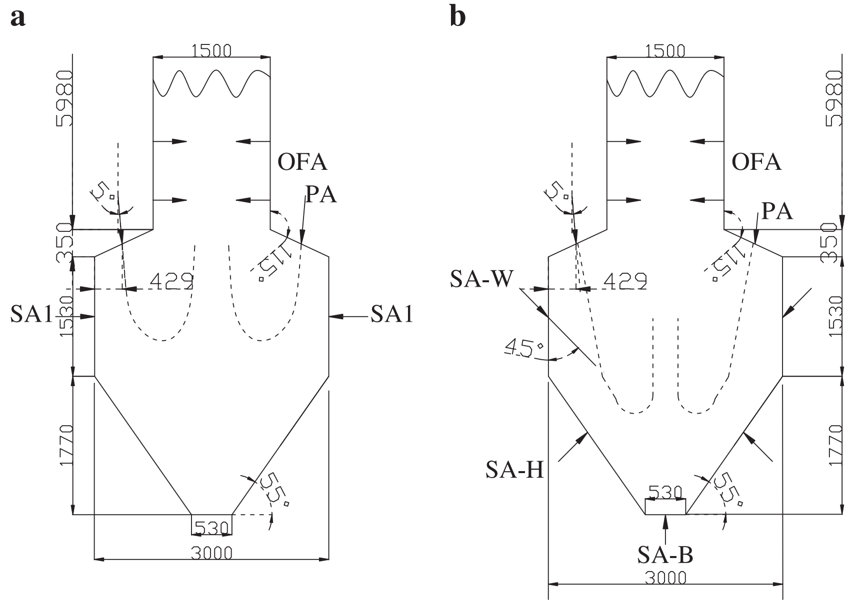

Fig. 1. Air ports arrangement of both HAP technology and the base case: (a) base case, (b) HAP technology.

air, and OFA. All of them are located in the upper furnace or the upper part of lower furnace. Hardly has any research been carried out or reported with focus on the ash hopper zone which is nearly equal to one third of the lower furnace.

This paper proposes an innovative deep air-staging technology for down-fired pulverized-coal utility boilers. The technology is called hot air packing (HAP) technology which adds some special secondary air ports in the ash hopper zone. The prospective advantages of HAP technology are improving the aerodynamic characteristics in the down part of lower furnace and ash hopper and promoting flow filling in ash hopper by deep air-staging. Since cold small-scale model experiment [13,16,27,28] is a common way to understand aerodynamic behavior in a real furnace, an experiment on a cold small-scale model as well as fluid dynamics numerical simulations were conducted to evaluate the HAP technology's feasibility. Furthermore, the HAP was compared with common down-fired technology to reveal its advantages.

2. Experimental facility

2.1. Introduction of HAP technology

HAP technology is a deep air-staging combustion technology which suits the need of high burnout and low NO_x emission in down-fired boilers. Compared with prior down-fired technology, HAP technology necessitates the addition of special secondary air ports in the furnace ash hopper (SA-H) and in the furnace bottom (SA-B). With the help of primary and secondary air ports, the air flows through these special ports pack pulverized coal particles inside the furnace efficiently, which is benefit for staging combustion, NO_x reduction and preventing from slagging. Moreover, the new ports which located in the ash hopper and furnace bottom improve the flow velocity in ash hopper and increase the utility ratio of ash hopper, which is helpful for coal burnout and gas temperature homogeneous distribution in the lower furnace. With a novel rational distribution of both air ratio and flow velocity among all ports, HAP technology will have a good performance on NO_x emission, combustion efficiency and slagging by both deep air-staging and the improvement of ash-hopper utility ratio. HAP technology can be applied in new down-fired boilers and implemented as a retrofitting technology in in-service down-fired boilers. In the latter case, the main modification only includes all burners and its correlative things, such as hot air flue pipes and tube-wall opening. It is not necessary to modify the furnace body deeply. Thus the retrofitting is easy to adopted and implemented in a short term.

Table 1
Air arrangement of small-scale cold model (m/s).

	HAP technology case	Base case
PA	28.88	34
SA1	/	20.6
SA-W	7.36	/
SA-H	7.36	/
SA-B	7.36	/
OFA	31.06	31.06

Fig. 1 presents a schematic diagram of a 3.5 MW furnace with HAP technology as well as a common down-fired technology as the base case. All experimental research was planned to be done with the down-fired 3.5 MW pilot facility and its cold small-scale model. The cross-section of upper facility furnace is 1500 × 1200 mm and the lower furnace is 3000 × 1200 mm. The primary air (PA) is channeled at an angle of 5° vertically downwards through double cyclone burners. Besides two layers of OFA, there is one layer of secondary air ports (SA1) on the vertical wall at the base case, as Fig. 1a shows. HAP technology retrofits the secondary air ports arrangement and adds three ports: two hot-air ports in the furnace ash hopper (SA-H) and one hot-air port on the bottom (SA-B). Simultaneously, horizontal secondary air ports are inclined with an angle of 45° and are renamed the SA-W at HAP technology case. Due to additional ports and the unchanged OFA rate, hot air flow injected through SA1 has to be distributed to SA-W, SA-H and SA-B. Inclined SA-W is supposed to balance the primary air penetration depth and the slagging risk. The purpose of the SA-H is to destroy the dead recirculation zone in the ash hopper zone. The function of SA-B is to make the whole flue gas flow upwards and protect the wall near the bottom from slagging. SA-H, SA-B and inclined SA-W pack the primary air flow and pulverized coal along the penetration route, which will cause a longer primary air penetration depth and a larger utilization rate of the lower furnace.

2.2. Cold model and measurement

To investigate the aerodynamic characteristics and the impact of SA-H's angle and position in a down-fired furnace with HAP technology,