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Factors affecting the downward flame depth in a 600 MW down-fired boiler incorporating multiple-injection and multiple-staging technology

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ABSTRACT

Considering the excessively deep flame depth existing in a 600 MW down-fired boiler incorporating multiple-injection and multiple-staging technology, 1:20 scale aerodynamic tests were conducted to incrementally improve factors responsible for the deep flame depth. These trials demonstrated that, in all cases, the downward velocity near the wing walls decayed more rapidly than that near the furnace center. Increasing the mass ratio of pulverized coal in fuel-rich flow to that in fuel-lean flow and reducing the secondary air ratio while simultaneously increasing the tertiary air ratio was found to increase the penetration depth. Increasing the distance between adjacent burners, optimally lowering the fuel-rich and fuel-lean flow velocities, and reducing the secondary air velocity all decreased the penetration depth. The comprehensively improved downward airflow depth and air flux into the furnace hopper were reduced by 6.3% and 14.9%, respectively. Cold-state airflow tracing tests were performed in an actual boiler, the improved downward airflow depth reduced apparently, which was consistent with the results from modeling tests. Industrial-scale hot-state experiments determined improved hopper near-wall temperatures of 700–800 °C near the furnace center (values that were lower than those of 800–900 °C near the wing walls). These values were approximately 450 °C less than the prior temperatures at the same location, indicating the flame penetration depth was greatly reduced.

1. Introduction

At present, coal-fired power plants generate approximately 70% of the total power used throughout China [1,2]. In addition, as the result of current energy policies, these power plants are encouraged to burn low-rank coals such as lean coal and anthracite [3]. When combusting fuels with low volatility and poor reactivity, the application of arch-fired technology shows to both increase the heat flux and extend the flame travel [4,5]. However, various problems arise during the actual operation of down-fired boilers, such as late coal ignition [6–8], poor combustion stability [9], asymmetric combustion [10], heavy slagging [11], insufficient burnout (carbon in the fly ash is generally in the range of 8–15%) [12,13] and especially high NO_x emission levels (typically in the range of 1100–2000 mg/m^3 at 6% O_2) [14,15]. In addition, various issues can lead to uneven heating of the water wall, including asymmetric combustion causing a large downward flame depth on one side (as typically occurs in Mitsui Babcock Energy Ltd. down-fired boilers [16]), heavy slagging causing the water wall near the slagging region to absorb more heat, and the prolonged use of firing oil to stabilize coal combustion. This uneven heating in turn results in localized areas vulnerable to overheating, leading to water wall fin cracks and tube blast [17], which is a critical problem that must be addressed when working with supercritical down-fired boilers.

To reduce NO_x emissions and enhance coal burnout, Li has proposed a system known as multiple injection and multiple staging combustion (MIMSC) [18]. In the early stages of this technology, a louver concentrator [19] with minimal operational resistance was used to divide the primary coal/air mixture into fuel-rich and fuel-lean coal/air flows, such that the mass ratio of pulverized coal in fuel-rich flow to pulverized coal in fuel-lean flow was 6:4. Because a large downward flame penetration depth tends to prolong the residence time of pulverized coal in the

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furnace and thus enhances coal burnout, a relatively high secondary air ratio and velocity were adopted to entrain the coal/air flow downward to a greater depth. Furthermore, the adjacent burners on arches were placed in a centralized layout pattern with the intent of slowing the downward velocity decay. The first industrial application of this technique was to two 600 MWe supercritical down-fired boilers. Industrial-scale studies found reduced slagging in conjunction with symmetric and stable combustion in the furnace, and determined that the NO_x emissions at the furnace exit were 878 mg/m^3 at 6% O_2 [18] under the optimal operational setting at full load. Unfortunately, the hopper water-cooled wall was vulnerable to overheating over prolonged periods of operation, and consequently accidental water wall tube blasts sometimes occurred. This was attributed to excessive penetration of the downward coal/air flow, such that the high temperature flame met the hopper wall, raising the wall to high temperatures (1200 °C or above) and leading to significant heat absorption [20]. Despite the extended residence time of pulverized coal resulting from the increased flame penetration depth, the fuel-rich coal/air flow (containing 60% of the total coal) ignited at a distance of approximately 2 m from the nozzle. In addition, the fuel-lean coal/air flow (with 40% of the total coal) primarily combusted in the furnace bottom [20], raising the carbon in the fly ash to a high level of 9.81% under optimal operational settings [18].

Many studies of MIMSC technology have been performed to date [16,18,21,22] and some valuable results have been obtained. It has been found that reducing the secondary air ratio and simultaneously increasing the tertiary air ratio gradually decreases the airflow downward penetration depth. As well, gradually increasing the tertiary air ratio (to a value equal to or greater than 25%) generates a highly asymmetric distribution pattern in the flow field [21]. In addition, a relatively low velocity and high pulverized-coal concentration both promote advance ignition of the primary fuel/air mixture [22]. Based on the above research findings, various means of reducing the downward flame penetration depth were proposed: reducing the secondary air ratio and simultaneously increasing the tertiary air ratio, lowering the secondary air velocity to decrease the downward airflow momentum, and increasing the distance between adjacent burners to facilitate the downward velocity decay. As noted above, a reduced flame penetration depth will shorten the residence time of pulverized coal in the furnace and thus negatively impact coal burnout. For this reason, several measures have also been proposed to enhance coal burnout, including increasing the pulverized coal concentration of the fire-facing fuel-rich coal/air flow and reducing the velocities of the fuel-rich and fuel-lean coal/air flows.

In the present work, 1:20 scale cold aerodynamic tests were conducted to incrementally improve the above factors found to modify the downward airflow penetration depth. Having determined an optimized burner structure and design parameters, these were applied to an actual boiler with the prior furnace size unchanged. In-furnace, cold-state airflow tracing tests were carried out to obtain a better understanding of the downward airflow penetration depth and flow state, and the results were compared with the airflow tracing trajectory prior to these

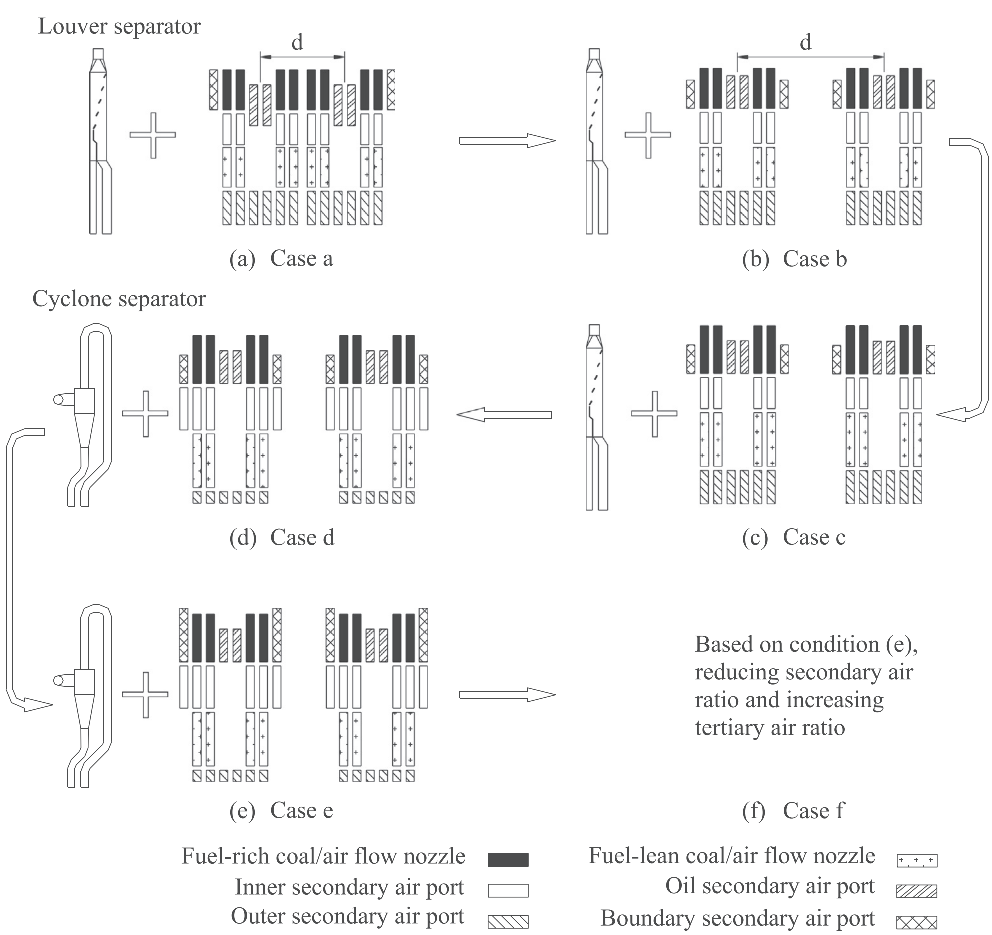

Fig. 1. The incremental improvements on MIMSC technology.