Applied Energy 189 (2017) 133–141

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Anthracite combustion characteristics and NO_x formation of a 300 MW_e down-fired boiler with swirl burners at different loads after the implementation of a new combustion system

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HIGHLIGHTS

- Combustion and NO_x emissions of the boiler at different loads was investigated.
- The retrofitted coal/air flow could be all ignited in time at different loads.
- The fullness degree of coal flame in the furnace at different loads was different.
- The reheat steam reached the design temperature at middle and low loads after retrofit.
- NO_x reduction of 40% at different loads was achieved with no negative effects.

ARTICLE INFO

Article history:
Received 22 September 2016
Received in revised form 1 December 2016
Accepted 11 December 2016

Keywords:
Down-fired boiler
Swirl burner
Overfire air
Load
Pulverized coal combustion
NOx emissions

ABSTRACT

A new combustion system has been applied to a 300 MW_e down-fired boiler with swirl burners to reduce NO_x emissions. The unit provided the introduction of overfire air (OFA) and a decrease in the flow area of the inner and outer secondary air ducts of the swirl burners. Industrial experiments on the retrofitted boiler were performed at different loads. Full-scale measurements of the flue gas temperature distribution in the burner outlet region, the furnace temperature distributions measured by a pyrometer and the local mean gas species concentrations in the region near the sidewall were made at loads of 180, 250, and 300 MW_e. The results show that the ignition distance increased with decreasing load, especially as the load decreased from 250 MW_e to 180 MW_e. At three different loads, the retrofitted coal/air flow could be all ignited in time at a distance in the range of 0.6–1.4 m from the burner outlet. Compared with the original combustion system, the ignition distance of the coal/air flow was significantly reduced at a load of 300 MW_e. In addition, at a load of 300 MW_e, the temperature of the boiler hopper was much higher than that at loads of 180 MW_e and 250 MW_e. Compared with the original combustion system, the upper furnace temperature decreased slowly with increasing measurement height at a load of 300 MW_e after the retrofit. Measurements of the O_2 and CO concentrations in the region near the sidewall indicate that the fullness degree of the coal flame in the furnace at different loads was different. After the retrofit, the reheat steam temperatures reached the design temperature of 541 °C at loads of 180 MW_e and 250 MW_e, and the average reheat steam temperatures increased by approximately 13 °C. Compared with the original combustion system, a significant NO_x reduction (more than 40%) at different loads was achieved without increasing the levels of unburnt carbon in the fly ash.

1. Introduction

The reserves of low-volatility coal are abundant and globally distributed in China; however, these low-volatility coals, especially anthracite, usually present difficulties in achieving both timely ignition and favourable burnout, in addition to maintaining steady combustion [1–3]. Down-fired boilers have the advantages of high temperature and a long travel path of the pulverized coal particles in the lower furnace; as a result, down-fired boilers are widely applied in power plants to consume low-volatility coals [4,5]. However, down-fired boilers still suffer from the problems of high NO_x emissions and poor flame stabilization at a low load without oil support firing in practical operation [6–8].

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http://dx.doi.org/10.1016/j.apenergy.2016.12.063
0306-2619/

Nitrogen oxides (NO_x), which are one of the primary air pollutants, not only do great harm to the environment (considering their roles in, for example, acid rain formation, increasing ground-level ozone, photochemical smog generation, and forest deterioration) but also endanger human health [9–12]. In China, one of the main sources of NO_x is derived from the primary emissions of various types of coal-fired power plants into the air [13–15], among which the NO_x production of down-fired boilers is significantly higher than that of other types of boilers and can be as high as 2000 mg/m^3 (6% O_2) [16–19]. There are four main types of down-fired boilers: the Foster Wheeler (FW) down-fired boiler, the Babcock & Wilcox (B&W) down-fired boiler, the Mitsui Babcock Energy Limited (MBEL) down-fired boiler and the Stein down-fired boiler [20]. The FW, MBEL and Stein down-fired boilers all use direct flow burners, whereas the B&W down-fired boiler is equipped with swirl burners [21]. NO_x emission reduction is generally achieved using two approaches: low-NO_x combustion technology and the treatment of post-combustion flue gas [22]. Low-NO_x combustion technology is preferred as a low-cost and highly effective approach to reduce NO_x emissions [23–25]. Various low-NO_x combustion technologies for these down-fired boilers have been proposed. Among these NO_x control technical schemes, overfire air (OFA) technology is mature and is widely applied in low-NO_x retrofits of down-fired boilers. For FW down-fired boilers, the FW company introduced the declinational OFA in the lower part of the upper furnace, and in situ experiments indicated that NO_x emissions at the furnace exit decreased by more than 50% with slightly increased carbon content in the fly ash [26]. Moreover, Chinese researchers have performed substantial research on the low-NO_x combustion retrofitting of FW down-fired boilers. Liu et al. [19,27] and Fang et al. [28] investigated the FW down-fired boilers after the application of OFA technology through industrial experiments. The results indicated that NO_x emissions at the exit of the furnace decreased sharply with slightly increased carbon content in the fly ash. For MBEL down-fired boilers, Li et al. equipped MBEL down-fired boilers with OFA, and the results showed that the NO_x emissions decreased by approximately 50% and that the carbon content in the fly ash increased slightly [20,29,30]. To date, most reports on the effects of OFA retrofitting have focused on the FW and MBEL down-fired boilers that adopt direct flow burners. In contrast, there are very few reports in the literature concerning the application of OFA technologies to B&W down-fired boilers with swirl burners and burning anthracite coal.

In China, the interval between the peak load and the valley load has increased year by year, and the change frequency of the loads has increased. The operating time of the boilers under middle and low loads has prolonged, and the valley load has declined further. As a result, it is particularly important to investigate the combustion and NO_x emission characteristics of down-fired boilers at different loads, especially at low and middle loads. Li et al. completed an industrial experimental study of a 660 MW_e FW down-fired boiler without OFA; the results showed that, with decreasing load, the NO_x emissions decreased from 2448 mg/m^3 (6% O_2) to 1610 mg/m^3 (6% O_2) and that the boiler efficiencies were all higher than 92% at three different loads [6]. Li et al. investigated a 300 MW_e MBEL down-fired boiler without OFA; the industrial measurements showed that there was asymmetric combustion was not achieved in the furnace at loads of 250 and 300 MW_e; however, asymmetric combustion at a load of 150 MW_e. Simultaneously, with decreasing load, the NO_x emissions decreased from 1180 mg/m^3 (6% O_2) to 880 mg/m^3 (6% O_2), and the carbon content in the fly ash decreased from 10.5% to 5.5% [31]. Fan et al. studied the combustion and NO_x emission characteristics of a 300 MW_e B&W down-fired boiler without OFA using numerical simulation; their results showed that the NO_x emissions for a 50% load were below the value for a full load and that the NO_x production was higher than 1700 mg/m^3 (6% O_2) in the local region of the furnace at a full load [32,33]. Research on the combustion and NO_x emission characteristics of down-fired boilers at different loads would be beneficial for environmental protection and the economical and safe operation of the boilers. In particular, full-scale industrial experimental research studies are highly desirable and a necessity because they can provide precise understanding of the pulverized coal combustion process and the NO_x emission characteristics of real combustors. Currently, industrial experimental research on the combustion and NO_x emission characteristics at different loads is mainly performed for FW and MBEL down-fired boilers without OFA. However, for B&W down-fired with swirl burners, only numerical simulation investigations regarding combustion and NO_x emission characteristics at different loads exist. There are very few industrial experiments related to the combustion and NO_x emission characteristics of B&W down-fired boilers at different loads, especially for a boiler equipped with OFA technology.

A new and comprehensive low-NO_x combustion technology was applied to a 300 MW_e B&W down-fired boiler with swirl burners and burning anthracite coal to reduce NO_x emissions. The technology mainly involved introducing OFA and decreasing the flow area of the inner and outer secondary air ducts of the swirl burners. In the present study, the influence of the load on the combustion and NO_x emission characteristics of the retrofitted boiler was investigated. Full-scale industrial experiments were performed on the boiler at loads of 180, 250, and 300 MW_e. Measurements of the flue gas temperature distributions in the burner outlet region, the furnace temperature distributions measured by a pyrometer and the local mean gas species concentrations in the region near the sidewall were made at different loads for the full-scale boiler. The wealth of data can be used to investigate the combustion and NO_x emission characteristics of the boiler at different loads. The results will be of benefit in the design and operation of similar boilers and can also be used to support relevant theoretical analyses and numerical calculations.

2. Experimental section

2.1. Utility boiler

The experimental object is a B&WB-1065/17.5-M 300 MW_e down-fired boiler produced by Babcock & Wilcox Beijing Company Ltd. The boiler is a single-chamber, balanced ventilation, once intermediate reheated, subcritical parameter, natural-circulation and single-steam drum boiler. The coal pulverizing system of this boiler is a double-inlet and double-outlet, positive-pressure, direct-blow steel ball mill system, and the boiler adopts the "W" flame combustion mode. Fig. 1 presents the combustion configuration of the 300 MW_e down-fired boiler with the new combustion system. The height and width of the boiler furnace are 52.7 m and 21.9 m, respectively. The arches separate the furnace into two regions, the upper furnace and the lower furnace. There are sixteen enriched enhanced ignition-axial control low-NO_x (EI-XCL) burners arranged on the front and rear arches, and the burners are perpendicular to the arches. The internal structures of the burner and other structures of the boiler were described in detail in a previous report [34].

2.2. New combustion system

As illustrated in Fig. 1, the process involved in this new combustion system is as follows. (1) A part of the secondary air was separated from the secondary air box to be directed as OFA to form a low-oxygen reducing atmosphere in the lower furnace. The direct-flow OFA nozzles were arranged symmetrically on the front