Fuel 88 (2009) 1720–1731

Contents lists available at ScienceDirect

Fuel

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

Numerical investigation on the flow, combustion and NO_x emission characteristics in a 500 MW_e tangentially fired pulverized-coal boiler

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ARTICLE INFO

Article history:
Received 25 June 2008
Received in revised form 24 March 2009
Accepted 1 April 2009
Available online 18 April 2009

Keywords:
Tangentially fired pulverized-coal boiler
Combustion simulation
Nitrogen oxide (NO_x) emissions

ABSTRACT

The characteristics of the flow, combustion, temperature and NO_x emissions in a 500 MW_e tangentially fired pulverized-coal boiler are numerically studied using comprehensive models, with emphasis on fuel and thermal NO_x formations. The comparison between the measured values and predicted results shows good agreement, which implies that the adopted combustion and NO_x formation models are suitable for correctly predicting characteristics of the boiler. The relations among the predicted temperature, O_2 and CO_2 mass fractions are discussed based on the calculated distributions. The predicted results clearly show that NO_x formation within the boiler highly depends on the combustion processes as well as the temperature and species concentrations. The results obtained from this study have shown that overfire air (OFA) operation is an efficient way to reduce the NO_x emissions of the pulverized-coal fired boiler. Air staging combustion technology (OFA operation) adopted in this boiler has helped reduce fuel NO_x formation as well as thermal NO_x formation under the present simulated conditions. The decrease in the formation of fuel NO_x is due to the decreased contact of the nitrogen from the fuel with the oxygen within the combustion air, while the decrease in thermal NO_x formation is caused by a decrease in temperature. The detailed results presented in this paper may enhance the understanding of complex flow patterns, combustion processes and NO_x emissions in tangentially fired pulverized-coal boilers, and may also provide a useful basis for NO_x reduction and control.

1. Introduction

Tangentially fired pulverized-coal boilers are the most widely used type of boiler for industrial coal combustion because of their good flame distribution and uniform heat flux to the furnace walls, but still have some problems such as large amounts of combustible matter in fly ash, combustion instabilities at low loads, heat imbalance and gas temperature deviation in super-heaters and re-heaters, and slagging in the furnaces [1]. Moreover, although nitrogen oxide (NO_x) emissions from the boilers are comparatively low, NO_x emission has a significant impact on the environment. The control and reduction of NO_x emissions from coal combustion has become an international concern, because NO_x forms acid rain and is involved in the generation of photochemical smog. As a consequence, governments around the world and international organizations, which support limiting air pollution, have established restrictive legislation that suppresses the emission of NO_x into the atmosphere [2].

Several technologies such as burner design modification, air/fuel staging, over fire air (OFA) operation, flue gas recirculation and reburning have been used to reduce and control NO_x emissions. The main objective of these technologies is to minimize the reaction temperature and the contact between nitrogen from the fuel and oxygen in the combustion air, while creating a fuel-rich zone in which NO_x can be reduced to N_2 [1,3–5]. The simplest technique is to introduce the OFA operation because this requires a simple air duct modification along with straightforward management of the air streams.

Since the NO_x emissions are strongly related to complex physical and chemical processes such as turbulent flow, combustion, temperature, heat transfer, and NO_x formation mechanisms, understanding these complex processes is a prerequisite for reducing NO_x emissions, as well as resolving the previously mentioned problems including large amounts of combustible matter in fly ash. Several numerical studies have been completed in order to better understand the complicated phenomena, including gas–particle flow, combustion, heat transfer and NO_x formation in boilers [1,3–18]. These studies have been focused on the investigation of

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doi:10.1016/j.fuel.2009.04.001

causes and methods for decreasing gas flow and temperature deviation in the boilers [1,6–8]. Some studies have been carried out in order to predict NO_x emissions from boilers under several operation conditions [3–5,13–16,18]. Their results show that the prediction of NO_x emissions is affected by the used combustion and NO_x formation models, and the amount of NO_x formed is highly sensitive to the temperature and oxygen concentration distributions as well as fluid flow. Despite the remarkable progress shown in literature, there are still significant uncertainties surrounding the control and reduction of NO_x that necessitates further research due to the complicated phenomena in furnaces involving complex physical and chemical processes that need to be precisely modeled [1]. There are very few studies that are focused on how NO_x formation is affected by changes in operating conditions. Deep insight about the influence of operating conditions on NO_x formation could provide useful guidelines for controlling NO_x formation.

In this study, the characteristics of the flow, combustion, temperature and NO_x emissions in a 500 MW_e tangentially fired pulverized-coal boiler are numerically studied with emphasis on fuel and thermal NO_x formations. In order to generate accurate predictions, additional attention is given to selecting the calculation domain, generating mesh, and choosing numerical models, since NO_x formation is affected by fluid flow, temperature and oxygen concentration distributions. The predicted results are compared with available measured data and operating data. A calculation is also carried out for the case with OFA operation, which allows some combustion air to be supplied through OFA ports, and is compared with the case without OFA operation in association with the reduction of NO_x emissions.

2. The tangentially fired pulverized-coal boiler

The tangentially fired pulverized-coal boiler considered in this study is a 500 MW_e unit, and is shown schematically in Fig. 1. The height up to the furnace exit is approximately 51 m, and the horizontal cross section in the furnace has both a width and depth of 16.5 m. In order to make up a concentric firing system within the furnace, as shown in Fig. 1c, twelve burner sets are installed in the four corners ranging from the lower group A to the upper group C. Each burner set consists of two coal burners with different air to fuel ratios (a fuel rich burner (CONC) and a fuel lean burner (WEAK)) and two oil burners. The coal burners are of a low NO_x burner type (pollution minimum (PM) type) and their injection angles can be controlled ±30°. It is known that this type of burners help an effective mixing of pulverized coal and air prior to injection. The oil burners are only used during start-up. Therefore, this boiler is operated with 24 low NO_x burners during normal operations. Each burner set is treated as one module in the present study and the burner arrangement explained above is shown in Fig. 1b. OFA ports are installed above the burners.

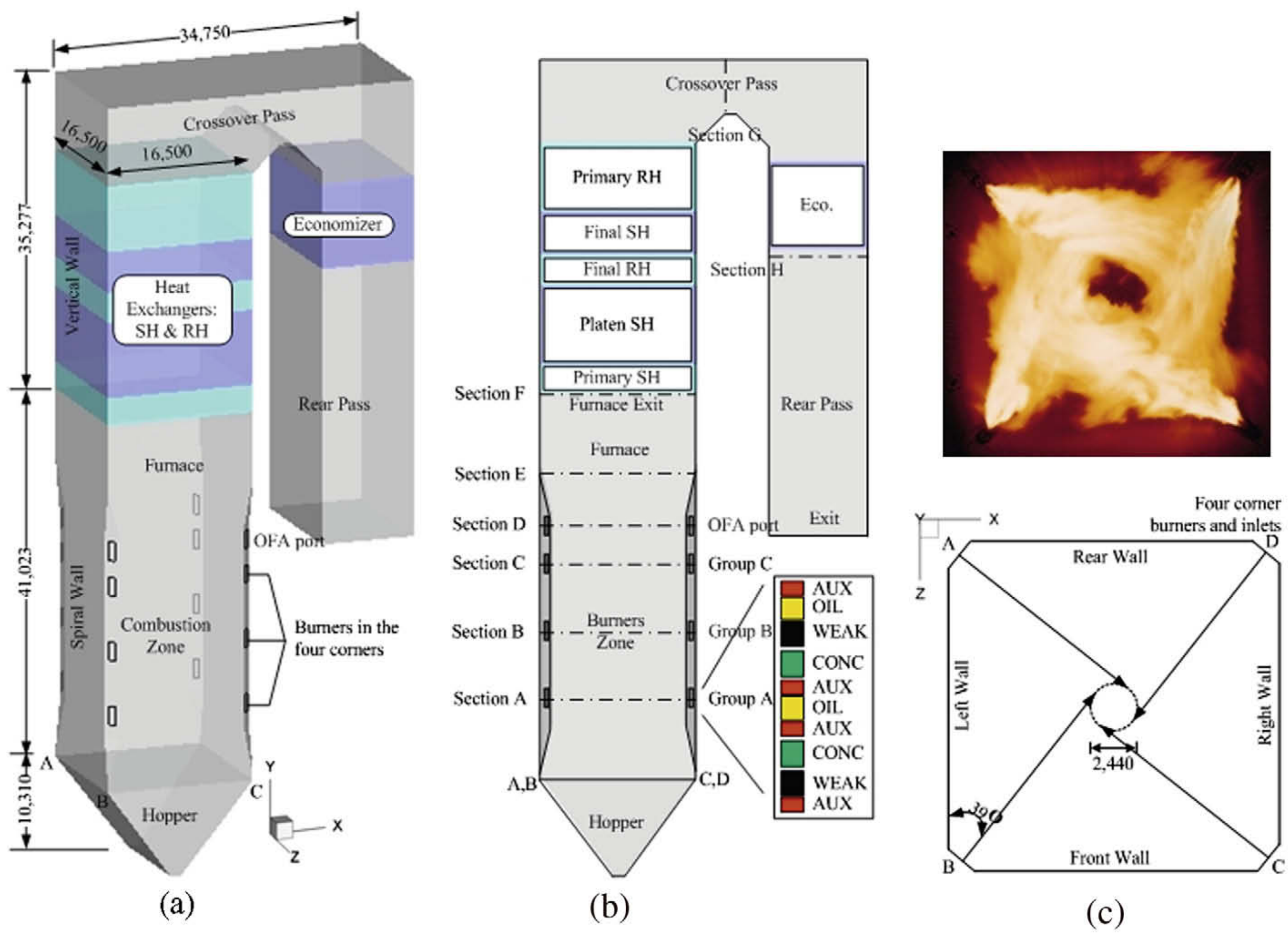

Fig. 1. Schematic configurations of the tangentially fired pulverized-coal boiler.