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# Experimental and numerical study on the combustion of a 32 MW wood-chip grate boiler with internal flue gas recirculation technology

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**Abstract**

The objective of the present work is to evaluate the feasibility of reducing $NO_X$ emission while improving thermal efficiency in a 32 MW wood-chip grate boiler with the technology of internal flue gas recirculation (TIFGR). Both experiment and numerical modeling were conducted. Firstly, the experimental case with conventional over fired air (OFA) supply system was modeled as reference. Subsequently, the conventional OFA nozzles was modified to apply TIFGR. Two burner arrangements were considered, i.e. parallel and staggered. The internal flow dynamics, combustion temperature distribution and final NO emission were compared between the original case and the two modified cases. Reasonable agreement is achieved between numerical modeling and experimental measurement for the reference case, proving the adequacy of the present adopted numerical models. As compared to the conventional OFA arrangement, both parallel and staggered burner configurations are able to reduce $NO_X$ by establishing intense internal flue gas recirculation. Especially, the parallel OFA arrangement shows a greater potential for $NO_X$ reduction while improving the thermal efficiency. As a result, the parallel OFA arrangement is suggested for grate boilers to implement TIFGR.



*Keywords:* Wood-chip grate boiler; Internal flue gas recirculation (IFGR); Numerical modeling; NO reduction; Reduced order model.

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## 1. Introduction

In order to mitigate the world-shared problem of global warming, choice on fuel supply for combustion has been gradually shifted from fossil types to biomass. Biomass has higher moisture content than coal, and its lower calorific value (LCV) can vary in a wide range, which is highly subject to resources. Owing to the wide adaptability in fuel LCV, grate firing is currently regarded as one of the most promising ways to use biomass in combined heat and power (CHP) plants for waste-to-energy purpose [1].

Inside a grate boiler, fuel undergoes drying, pyrolysis, oxidation and cooling along with the grate chain. Subsequently, the released gaseous species from the grate will go through homogeneous reactions above the grate chain. This process is very different from that inside a pulverized coal boiler. To better understand the fuel conversion as well as pollutant formation processes inside a grate firing boiler, Santos et al. [2] developed a measuring program to characterize the species composition and temperature distribution on the grate. However, considering the advantages in obtaining the detailed in-furnace information with less cost, computational fluid dynamics (CFD) modeling approach has become a useful tool to predict the combustion performance of grate firing boiler since the last century. Using the measured profiles of species composition and temperature on the grate as initial boundary conditions for the upstream freeboard, Shin et al. [3] inspected the combustion performance of a waste incinerator by CFD modeling approach. Moreover, the impacts of various operating parameters on the combustion behaviors and pollutant evolution have been explored [4].

Despite the potential utilization of biomass in energy supply, some grate firing boilers have been reported to suffer from high $NO_X$ emission, which exceeds the national emission standard. For biomass, the formed $NO_X$ during combustion is mainly derived from the fuel-$NO_X$ route, namely the oxidation of fuel-bound nitrogen. While the thermal-$NO_X$ route accounts for the secondary role, which is formed by interaction between molecules of oxygen and nitrogen. Frankly speaking, it is hard to reduce fuel-$NO_X$ formation by altering the fuel conversion process on the grate, since the fuel conversion process is subject to primary air flow rate, temperature and grate moving velocity. These operating parameters will significantly affect the fuel burnout and the combustion above the grate. Therefore, it is expected to minimize $NO_X$ formation by suppressing the thermal-$NO_X$ route. For this purpose, the technology of internal flue gas recirculation (TIFGR) can be introduced, which is able to dilute the fresh air and result in lower combustion temperature. In industrial applications, this technology is called as moderate or intense low-oxygen dilution (MILD) combustion [5]. The TIFGR has previously attempted in grate firing boilers by Blasiak et al. [6] with CFD modeling. However, up to now, there is still little information available for applying this novel technology in grate firing boilers.

This paper is intended to examine the feasibility of implementing TIFGR in a 32 MW grate firing boilers for biomass by CFD numerical modeling. First, experimental case with a conventional air supply system will be modeled, and the measured data will be used to validate the adequacy of the present numerical models. Then, CFD numerical modeling will be conducted for different over fired air (OFA) arrangement cases which adopt TIFGR. Comparisons will be made in terms of flow dynamics, temperature distribution and $NO_X$ formation behaviors.

## 2. Grate boiler geometry

Fig. 1 shows the schematic diagram of the grate firing boiler investigated in this work. It can produce 38.12 ton steam per hour, which has an approximate 32 MW fuel input. Wood-chip is used as fuel in the boiler plant, and the specification of the fuel properties can be known from Table 1. Ambient temperature air is used and is sent into the boiler through four streams, namely the primary air (PA) below the grate, secondary air on the front wall (FSA), secondary air on the rear wall (RSA) and over fired air (OFA) on the front wall. The percentages of air amount of the four air streams are 47%, 22%, 22% and 9%, respectively. The PA is distributed in five zones, but the air flow rate varies from zone to zone, in order to control various fuel conversion processes in different zones. For instance, in zone 2 and zone 3, more PA is delivered to improve the combustion temperature above the grate, thus the pyrolysis and de-volatilization processes can be accelerated. As can be found in Fig. 1, three thermocouples are used to collect gas temperature near the furnace sidewall. Simultaneously, the gas composition ($O_2$, $CO_2$ and $H_2O$) as well as gas flow rate are measured at the outlet of the furnace.