Fuel Processing Technology 152 (2016) 430–437

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Influence of external flue gas recirculation on gas combustion in a coke oven heating system

Stanislaw Gamrat, Jakub Poraj, Jakub Bodys, Jacek Smolka *, Wojciech Adamczyk

Institute of Thermal Technology, Silesian University of Technology, Konarskiego 22, 44–100 Gliwice, Poland

ARTICLE INFO

Article history:
Received 29 February 2016
Received in revised form 4 June 2016
Accepted 8 July 2016
Available online 19 July 2016

Keywords:
Coke oven battery
Heating flue
Coke oven gas
NOx reduction
External flue gas recirculation

ABSTRACT

In this study, external flue gas recirculation was considered to reduce nitrogen oxides (NOx) emissions in the heating flues of a coke oven battery. The thermal and prompt NO formation was numerically investigated employing an accurate 3-D representation of the heating flue geometry that the most popular Polish coke oven battery. Originally the developed model was experimentally validated as a transient coupled model for the representative heating flue and the two coke ovens. Then the coupled model was simplified to the heating flue model only with realistic boundary conditions on the heating flue and coke oven interface. As a result of the heating flue model simulations, the range of the reversed flue gas ratio was found for typical thermal loadings of the heating wall to effectively reduce NOx formation. The obtained results showed the significant effect of the considered flue gas recirculation on NOx formation reduction. Namely, the recirculation ratio of 0.2 resulted in 50% of the NOx reduction efficiency.

1. Introduction

Coke is a fuel that is used in various technical processes, e.g., in iron production in the blast furnace [1]. Thus, the coke production technology in coke ovens is still an important branch of industry. However, those production processes may be fairly harmful for the environment. Therefore, it is important to monitor and reduce the emissions from coke oven gas (COG) combustion.

The coke oven battery, where the coke is produced, consists of coke chamber charged by blends of coking coals and adjacent heating flues. In the combustion chamber, the thermal energy, which is necessary for the process of the dry distillation of coal, is produced by burning gaseous fuel. The blast furnace gas (BFG) or purified COG is often used in this application [2]. In the coking process, the most important problem is to obtain the appropriate final value and uniform distribution of the coke temperature within the whole space of the entire coking chamber. The desired coke temperature in the centre of the coking chamber is 1273 K, which requires a high temperature combustion process. Such conditions generate a large amount of NOx, which is harmful to the environment.

Numerical simulations of thermal processes in coke oven batteries using computational fluid dynamics (CFD) modelling have been used in various works. A great deal of attention has been paid to modelling the coking chamber, where the coal-to-coke conversion occurs. Guo and Tang [3] presented numerical results of the COG flow pattern and profiles of the temperature, density and porosity for a semi-coke bed. However, this approach does not accurately include the impact of the combustion process in a combustion chamber. Therefore, numerical coupled models of the coke and combustion chambers have also been developed. Smolka et al. [4,5] introduced a numerical model with time-dependent heat flux profiles transferred from the heating flues to the coke bed. Jin et al. [6] also developed a three-dimensional transient mathematical model that included coupled coking and combustion chambers.

In coke oven operations, in addition to effective coke heating, a low-emission combustion process is essential. To predict the quantity of generated NOx, an appropriate mathematical model of NOx formation needs to be employed. Loffler et al. [7] considered the influence of different mechanisms of NOx generation on the overall NOx emissions for the premixed combustion of natural gas in a one-dimensional plug flow reactor. As a result, a simplified model of thermal NOx was presented. The NOx content was computed based on the temperature and species distribution. Weiss et al. [8] ran calculations of NOx generation in a coke oven using BFG and COG as a fuel. For this purpose, the prompt and thermal NOx fields were predicted, and a non-premixed combustion model was employed. The aim of that work was to examine the impact of various combustion conditions on NOx generation. Rieger et al. [9] modelled the formation of NOx in a blast stove for the combustion of enriched blast furnace gas. That work considered two methods for modelling the turbulence-chemistry interaction: the eddy dissipation concept (EDC) and a PDF-flamelet model. The NOx emission simulations using EDC produced more accurate results when compared to the actual plant emission values.

* Corresponding author.
E-mail address: jacek.smolka@polsl.pl (J. Smolka).

http://dx.doi.org/10.1016/j.fuproc.2016.07.010

The methods that have been applied for reducing NOx emissions can be mainly divided into primary and secondary methods [10,11]. Among the primary methods that relay on a proper operation of combustion process, the most significant are staging air in the combustion process, reburning and flue gas recirculation processes [12–15]. Currently, recirculation is applied in the considered coke oven battery as an internal process that occurs through the recirculation window between the upward and downward heating flues. This method of recirculation works well, however, the amount of recycled flue gas cannot be controlled. Usually, this process does not allow for the effective reduction in the generation of NOx. Another problem is the uncontrolled mixing of flue gas with air and COG. To overcome these deficiencies, external flue gas recirculation (EFGR) can be considered. This method is used in many different industrial units [16–18]. These authors reported a positive impact on the NOx emission reduction and temperature uniformity in the combustion domain. This technology can be installed on an existing object, which is an additional advantage.

In this paper, a numerical model of NOx reduction using EFGR in the heating system of a coke oven battery is proposed. Hence, the main contribution of this paper is to provide the results of an application of a well-established method of NOx emission reduction to the most popular coke oven battery in Poland. To predict the influence of the coking chamber on the combustion chamber operation, the heat flux profile was introduced as a boundary condition. Typical values of the heat flux were obtained from previous work [4] using coupled models at various instants of the coking process, and the model was finally formulated as a steady-state process. Due to the high temperatures that occur in the combustion chamber, the model described by Loffler et al. [7], in which the thermal mechanism of the NOx generation has a prevailing role, was also employed in this study. In EFGR, changes in flow, species and the temperature of the air and flue gas mixture are taken into account. The presented results of this work demonstrate some tendencies and potential of the EFGR technology. In particular, the results with a gradually modified amount of the recycled flue gas are discussed and compared with cases without EFGR. In general, this primary NOx reduction method exhibited a very promising effect in the coke oven heating system for recirculation ratios ranging from 0.2 to 0.25.

2. Numerical model

2.1. Heating flue model

In general, a coke oven battery consists of a series of heating flues arranged in rows on both sides of the coke ovens. Heating flues are supplied from the bottom with air and the purified COG. The air and COG are preheated in a ceramic heat exchanger that works as a regenerator by accumulating heat from the hot flue gases from the combustion chamber. As shown in Fig. 1, a single combustion chamber is divided into two heating flues: an upward heating flue, where air and fuel are supplied, and a downward heating flue, where the flue gas outlet is located.

In the upper part of chamber, there is a bridge window, where the gases change their flow direction. In the lower part of the heating flue, there is a recirculation window designed for internal recirculation between both flues. The combustion cycle for one direction inside the chamber lasts approximately 20 min. Then, the flow direction is reversed, i.e., the air inlet becomes the flue gas outlet and vice versa. The whole coking process takes approximately 15 to 20 h.

Therefore, every numerical analysis of the heating system operation in the coke oven battery should be performed as a time varying case. This type of approach was presented in the previous authors' work [4]. The developed model the whole heating system was formulated as a transient coupled model of the heating flue and coke oven. On the other hand, the combustion process itself can be a

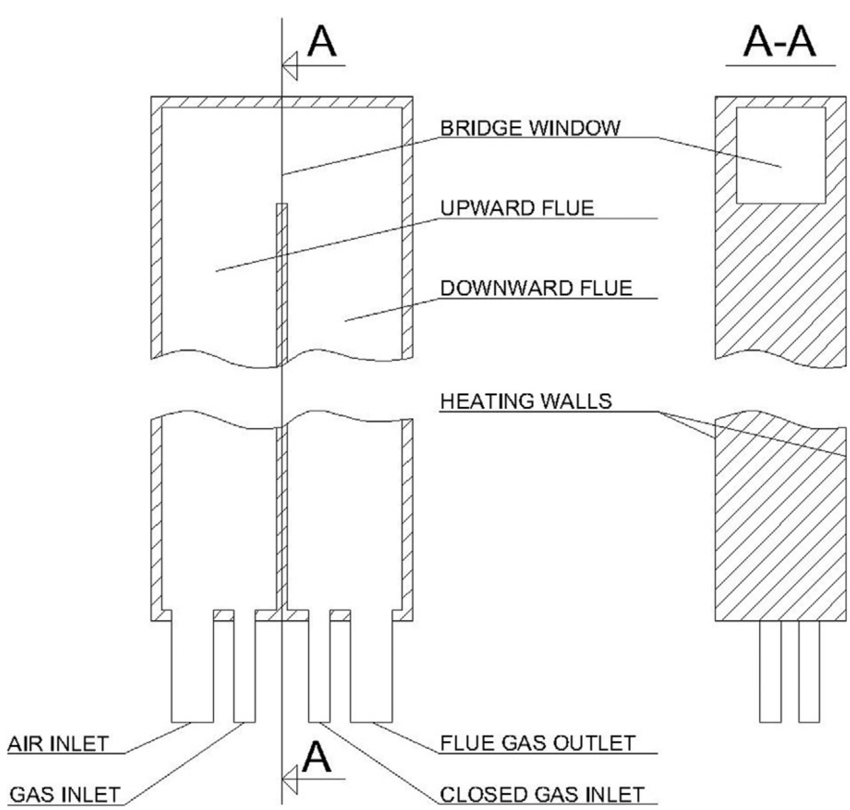

Fig. 1. Cross-sections through the heating flue.