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On the influence of the char gasification reactions on NO formation in flameless coal combustion

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ABSTRACT

Flameless combustion is a well known measure to reduce NO_x emissions in gas combustion but has not yet been fully adapted to pulverised coal combustion. Numerical predictions can provide detailed information on the combustion process thus playing a significant role in understanding the basic mechanisms for pollutant formation. In simulations of conventional pulverised coal combustion the gasification by CO_2 or H_2O is usually omitted since its overall contribution to char oxidation is negligible compared to the oxidation with O_2. In flameless combustion, however, due to the strong recirculation of hot combustion products, primarily CO_2 and H_2O, and the thereby reduced concentration of O_2 in the reaction zone the local partial pressures of CO_2 and H_2O become significantly higher than that for O_2. Therefore, the char reaction with CO_2 and H_2O is being reconsidered. This paper presents a numerical study on the importance of these reactions on pollutant formation in flameless combustion. The numerical models used have been validated against experimental data. By varying the wall temperature and the burner excess air ratio, different cases have been investigated and the impact of considering gasification on the prediction of NO formation has been assessed. It was found that within the investigated ranges of these parameters the fraction of char being gasified increases up to 35%. This leads to changes in the local gas composition, primarily CO distribution, which in turn influences NO formation predictions. Considering gasification the prediction of NO emission is up to 40% lower than the predicted emissions without gasification reactions being taken into account.

1. Introduction

Flameless combustion is of ever growing interest as a measure to reduce NO_x emissions from combustion processes. It is state of the art for gas burners in the heat treatment industry. Here, NO_x emissions are near the detection limit. In flameless combustion the reaction zone is extended throughout a large volume of the furnace. Thus, flame formation with its inherent high temperature peaks is inhibited and the temperature field and species distribution are more homogeneous. This combustion mode is achieved by a strong recirculation of flue gases to the primary reaction zone causing the reactants to be significantly diluted. Recently, there is an increased interest in applying this technique to pulverised coal combustion. It has already been shown experimentally that NO_x emissions of coal combustion could be significantly reduced with such a burner design [1,2].

In conventional flames the oxygen concentration in the reaction zone is high enough for most of the char to be oxidised by oxygen. This reaction is several orders of magnitude faster than the reactions with carbon dioxide and water vapour. Therefore, the gasification reactions are often neglected in numerical investigations, [3–7].

In flameless combustion, however, the intense recirculation of hot combustion products causes fast dilution of the O_2 in the reaction zone. Thus, the partial pressure of CO_2 and H_2O become higher than that of O_2 and therefore the oxidation of char is likely to follow diverse paths in parallel. Considering this in numerical simulations should lead to more accurate predictions of gas species concentrations. The need for more detailed models for char burnout was recently reported by Schaffel et al. [8].

The importance of consideration of the gasification reactions was already observed for a standard low NO_x burner [9]. In order to identify the boundary conditions under which gasification reactions should be considered and to get a better understanding of the pollutant formation mechanisms in flameless coal combustion, a numeric parameter study was carried out to determine the relative importance of oxygen, carbon dioxide and water vapour as oxidiser for char and the influence of the changed temperature field and species concentration on NO formation.

2. Experimental setup

Experiments were conducted in a vertical, cylindrical, top fired furnace with a diameter of 400 mm and a total length of 4200 mm, Fig. 1. In this furnace the burner is axially traversable allowing for

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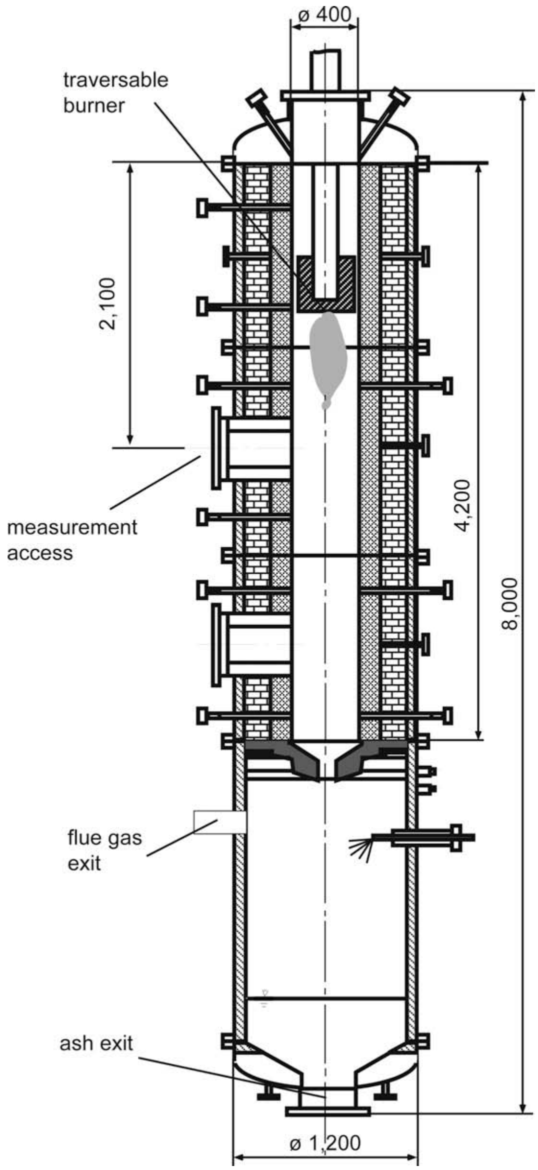

Fig. 1. Test facility, all dimensions in (mm).

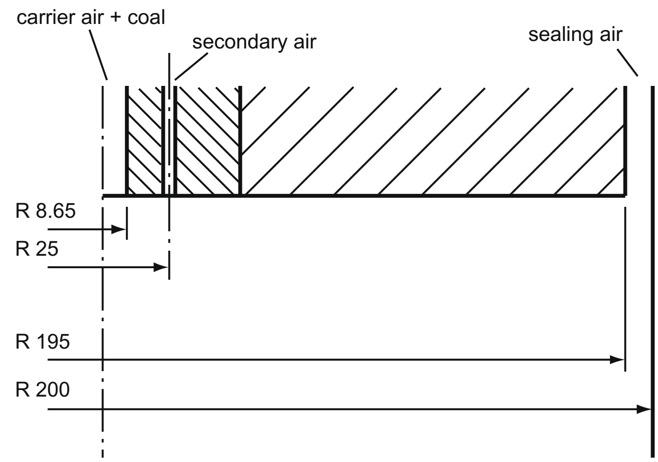

Fig. 2. Sketch of burner design, all dimensions in (mm).

measurements at different distances from the burner through a single measurement plane. Thus, for measurements of the velocity the furnace is only 2100 mm plus the actual distance of the measurement plane from the burner whereas global measurements were carried out with a total furnace length of 3900 mm. During in flame measurements burnout air was introduced 700 mm from the bottom of the furnace, whereas during global measurements it was introduced at the measurement plane with the burner 1800 mm above the measurement plane. Electrical heating was used for regulation of the wall temperature.

The pulverised coal burner employed in this study, Fig. 2, was developed according to the design of flameless gas burners. The predominant design criterion for a flameless combustion burner is the avoidance of high temperature zones in order to reduce the formation of thermal NO. In coal flames thermal NO makes up only a small fraction of the total NO emission as fuel NO accounts for a major portion of NO emissions. However, experiments [2] have shown the high NO reduction potential of flameless coal combustion which cannot be attributed to the prevention of thermal NO alone. In accordance with gas burners for flameless combustion a homogeneous temperature distribution is achieved by good mixing of the incoming fresh mixture and the flue gas. A high inlet momentum of the secondary air is used to induce the required recirculation of the flue gas which is then entrained into the inlet streams.

The dimensions of the investigated burner are given in Fig. 2. The coal is transported by a carrier air flow and enters the chamber through a central inlet. The secondary air is injected through three nozzles (diameter 4.2 mm) which are arranged annularly around the central coal jet. A sealing air stream was used in the gap between the traversable burner and the furnace wall in order to prevent particles from entering the volume above the burner. For the calculation of the burner excess air ratio this air stream is also considered.

This burner design was subject to an experimental study investigating its performance with different coals and different stoichiometric boundary conditions [2]. The arrangement of the nozzles allows recirculated hot flue gases to penetrate between the air jets directly to the coal jet. Thus, the secondary air as well as the coal are diluted with flue gas before they mix. The oxygen concentration in the reacting mixture is reduced and thus the peak flame temperature is lowered.

Furthermore, it can be expected that NO that is produced in the reaction zone is partially recirculated together with the flue gases thus allowing for NO reduction in the burner vicinity.

For the current numerical investigation reference data from three different experiments were considered. The boundary conditions are listed in Table 1. The first case at a burner excess air ratio of 0.7 was used to verify the flow field as data from velocity measurements were available for comparison. The other two cases (burner excess air ratios 0.8 and 0.9) were used for validation of NO predictions.

The investigated coal is a blend from different Polish bituminous coals. Proximate and ultimate analysis are given in Table 2.

2.1. Measurement technique

Velocity measurements were carried out using Laser Doppler Anemometry (LDA). The Laser Doppler Anemometry permits non-intrusive measurements of axial and tangential velocities with high spatial and temporal resolution.

For measurements within the coal flame no additional seeding of the flow was necessary since the particle density of coal and ash particles is sufficient within the whole measurement volume. Due to the small particle size (90% of the coal mass is contained in particles smaller than 75 μm; D_{p90} < 75 μm) it can be assumed