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Detailed analyzes of pulverized coal swirl flames in oxy-fuel atmospheres

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ABSTRACT

This work presents experimental data from a downward fired cylindrical combustion chamber at 60 kW_{th} equipped with a swirl burner. The swirl flame was aerodynamically stabilized in two different oxy-fuel (O_2, CO_2) atmospheres with 21 vol% and 25 vol% oxygen content in the oxidizer. Flame details were studied by means of local gas concentration measurements for CO, CO_2, H_2O, total hydrocarbons, NO and SO_2. The concentrations were measured at different axial and radial distances from the burner using a tempered suction probe and a Fourier Transform Infrared Spectrometer (FTIR). Additionally wall temperatures were measured by two-color-pyrometry. Based on all these measurements the flames were described in terms of reaction zones, pyrolyses, volatile combustion as well as formation of pollutants.

1. Introduction

In terms of overall efficiency, oxy-fuel combustion is one of the favored CCS (Carbon Capture and Storage) technologies; thus, a significant scientific interest on this technology has been developed for approximately one decade. By now, a significant number of scientific publications on this topic has been released. Extensive reviews on the conducted investigations are given by Scheffknecht et al. [1], Chen et al. [2], Wall et al. [3] and Stanger et al. [4]. In contrast to air firing, oxy-fuel combustion takes place in a mixture of CO_2, H_2O and O_2 (commonly oxygen enriched recirculated flue gas) resulting in a flue gas highly concentrated in CO_2. After condensation of water vapor, CO_2-concentrations above 95% can be reached (depending on air leakages and excess air ratios) and thus CO_2 subsequently can be sequestrated or processed as raw material.

Most of the early research work conducted on oxy-fuel combustion of coal focused mainly on the demonstration of feasibility of this combustion technology using equipment for conventional combustion and adopting it to obtain a stable oxy-fuel combustion [4,5] and to design power plant processes incorporating an oxy-fuel combustion of coal [6,7]. The different thermo-physical properties of CO_2 compared to N_2 [2] cause significant changes in the oxidation process when switching from air to oxy-firing mode. The higher molar heat capacity of CO_2 compared to N_2 (factor of 1.66) contributes to reduced combustion temperatures while keeping the O_2 content similar to air [8–11]. Furthermore, the influence of changed reaction paths [12], reaction kinetics [13,14] and devolatilization [15] were investigated.

In the further course of research on oxy-fuel coal combustion, spatially resolved measurements of conditions within the flames were conducted in order to understand the interaction of the different sub-processes occurring during solid fuel combustion and to provide a development and validation data base for the computational treatment of oxy-fuel combustion in CFD codes. In-flame measurements have been conducted with respect to the velocity field of a coal swirl burner [11,16], gas temperature [8,11], radiative intensities [17], formation of noxious species [8,18] and gas composition [8].

Smart et al. [19] used a vision-based monitoring system to investigate impact of oxy-fuel combustion on flame characteristics. They found that a higher O_2 content increases the stability of an oxy-fuel flame. Hjärtstam et al. [8] increased the oxygen content in the oxidizer to 25 vol% in a combustion chamber of 100 kW_{th} and reported similar gas temperatures compared to the air reference case. They observed that an increased O_2-fraction in the feed gas intensifies combustion and leads to higher peak temperatures as well as faster burnout. From local O_2 and CO concentration measurements it was derived that oxy-fuel combustion can be designed to achieve similar flame structures and CO emission levels as in the air-fired case. A similar conclusion was drawn by da Silva et al. [11] employing a 400 kW_{th} pilot scale combustion facility to investigate flame patterns and stability limits of oxy-fuel pulverized coal flames. The evaluation of local gas temperatures led to

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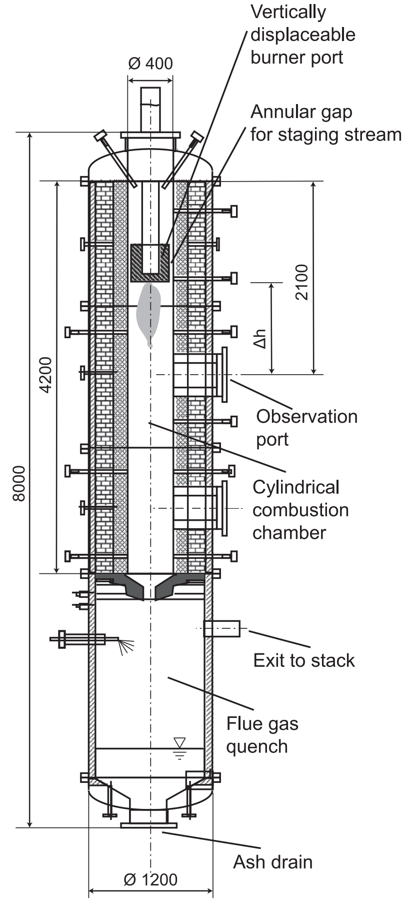

Fig. 1. Overview of the combustion chamber, all dimensions given in mm.

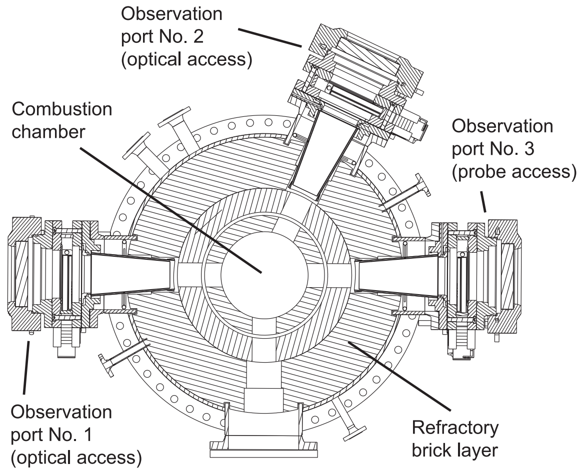

Fig. 2. Cross-sectional view of the measuring plane.

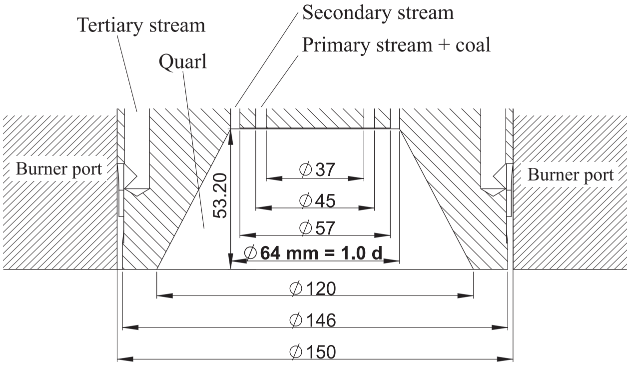

Fig. 3. Cross-sectional view of swirl burner, all dimensions given in mm.

the conclusion that stability of an oxy-fuel flame highly depends on the aerodynamic configuration of the burner.

From all these studies it can be concluded that oxy-fuel combustion can be designed to meet flame characteristics in terms of gas temperature and radiation intensities similar to the air-fired case mainly by adjusting the O_2 content of the oxidizer and aerodynamic configuration. However, local gas concentrations of some species will differ significantly for combustion in an oxy-fuel atmosphere and should be subject of further investigations.

The present study therefore connects to the series of in-flame investigations by presenting insights into the concentrations of gaseous species in the combustion zone, namely CO_2, CO, H_2O, SO_2, NO as well as different hydrocarbons for oxy-fuel flames with 21 vol% and 25 vol% oxygen in the oxidizer streams, since data regarding on the distribution of these species in coal flames are rarely provided in literature. The experimental configuration used for this investigation has been subject for several former investigations regarding flames under oxy-fuel conditions [7,16,20–23]. Additionally wall temperatures are measured in order to provide as many boundary conditions as possible for numerical validation.

2. Experimental setup

2.1. Test facility and burner design

The experimental facility consists of a downward fired cylindrical combustion chamber with an inner diameter of 400 mm and a total length of 4200 mm (cf. Fig. 1).

Burner and burner port are vertically displaceable. With a measuring plane fixed at an axial distance of 2100 mm from the top of the combustion chamber, different parts of the flame can be investigated by placing the burner at different heights above the measuring plane. The temperature of the refractory bricks of the combustion chamber is controlled by electrical heating elements within the bricks to reduce heat losses. The oxidizer gas is a mixture of CO_2 and O_2 provided by storage vessels. The purity of CO_2 specified by the supplier is >99.9 vol% with < 120 ppm of H_2O. The here used O_2 has a purity >99.95 vol% with < 500 ppm of nitrogen and argon. The flue gas exits the combustion chamber into a water-spray quench zone and is discharged through a chimney.

A cross-sectional view of the measuring plane is shown in Fig. 2. It includes three observation ports with two of them equipped for optical access whereas one port holds a traversing system for probe access.

A detail of the burner cross section is shown in Fig. 3: An inner annular orifice provides the primary stream which carries coal into the combustion chamber. The main oxidizer stream enters the combustion chamber through a secondary orifice. The secondary gas stream is swirled. This is achieved in a burner internal swirl chamber fed by tilted bores. Based on the burner geometry, the calculated swirl number (ratio of angular momentum flux to axial momentum flux over the secondary flow according to Chigier and Beer [24]) is $S_n = 0.95$ for all experiments presented here.

This fourth gas stream is referred to as staging stream, since this stream participates in the combustion process further