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A high-speed camera based approach for the on-line analysis of particles in multi-fuel burner flames

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ABSTRACT

A high-speed camera based approach for the analysis of the trajectories, the velocities and the burning behavior of alternative fuel macroscopic particles during co-firing in a coal dust flame is presented. The new approach can be used as on-line measurement for the burner control. It consists of an image processing and a particle tracking step. The image processing algorithm allows for the detection of particles within as well as outside of the coal dust flame. The tracking algorithm connects particle detections in single images to particle trajectories in image sequences. It is tolerant to temporarily missing particle detections. Based on the particle trajectories various characteristic parameters describing the distribution of light duration and of the particle velocity can be calculated on-line. The new approach is demonstrated on the basis of measurements from an experimental combustion chamber with a 1 MW multi-fuel burner.

1. Introduction

An increasing number of power and process plants apply multi-fuel burner systems for heat production [1,2]. The thermal power of these burners ranges up to several 100 MW. In addition to standard fuels like coal, gas and oil, alternative fuels like solid recovered fuels and biogenic fuels are used. To increase the share of alternative low grade fuels, especially from wastes, is an attractive option to save costs. Many firing processes aim at using alternative fuels only.

On the one hand in contrast to standard fuels the alternative fuels possess larger variations in their properties like particle size distribution and humidity, which leads to larger variations in the burning behavior. Additionally, different wear and soiling are induced by alternative fuels. On the other hand in modern processes and decentralized power plant concepts there is a strong demand for a high flexibility of the burner system to changing load conditions [3].

In order to meet the needs for “variable fuel properties” and “high load flexibility” new improved burner technologies have been investigated in recent years. On the side of the burner hardware new sophisticated adaptable air and fuel management features are developed. In addition to the flow and velocity of primary and secondary air modern burners can adapt air swirl or carrier air as actuating variables [4]. On the side of the burner control it is attempted to compensate the variations of load and fuel properties by utilizing the new actuating variables. However, this can only succeed if the effect of fuel variations on the flame can be detected on-line. For this reason camera-based measurement systems are developed [5].

In addition to the analysis of ignited dust and gaseous flame shares stated in [6,7], which constitute the primary flame body, camera-based methods offer the possibility to study the behavior of single ignited macroscopic fuel particles [8–10]. Such fuel particles result from the co-firing of alternative fuels from biomass or waste.

An on-line analysis of trajectories of burning fuel particles and their velocities for industrial burner systems, as well as the time spent in certain regions of the combustion chamber, e.g. inside and outside of the flame body is of special interest. These parameters are a direct indicator of the quality of the combustion and can be used for the burner control. For the image acquisition cameras in the near infrared (NIR) and in the visual spectral range (VIS) are suitable because in these ranges the bright glowing flame body surrounding each burning particle can be well captured. Due to the high particle velocities, the use of a high-speed camera system is necessary for the analysis of the trajectories of single fuel particles.

In this paper, a high-speed camera based approach for the analysis of the trajectories, the velocities, and the combustion behavior of macroscopic particles of alternative fuel is proposed. In the given examples the particles result from co-firing of rice husks in a coal

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dust flame, but the approach is applicable to a wide range of alternative fuels. In contrast to the works in [8,9] here the fuel particles appear not separately, but in connection with a pulverized coal flame, which significantly complicates the task. The new approach is demonstrated using images of a multi-fuel burner in an experimental combustion chamber.

The particle densities considered in the experiments are representative for many industrial applications with co-firing of alternative fuels [11]. Nevertheless, if the particle density exceeds a certain value the tracking of each individual particle presented here is not feasible. Then, particle image velocimetry (PIV) can be applied to obtain a flow field.

In Section 2the experimental combustion chamber Brenda, the measurement setup and the experimental procedure are described briefly. In Section 2, a new multi-level particle detection method is presented. Using these particle detections a Kalman-filter based tracking of fuel particles is described in Section 4. Section 5 gives some results of the application with the proposed approach.

2. Experimental setup

The combustion chamber Brenda (Fig. 1) installed at the Karlsruhe Institute of Technology (KIT) is used to develop and investigate multi-fuel burner systems in conjunction with the development of new camera based burner analysis and control methods. The main focus is on the co-firing of alternative fuels with pulverized coal.

To simulate a combustor with a base-load and fast-loaded process, a rotary kiln is used as a horizontal primary combustion chamber (PCC) with a thermal throughput of 1.2 MW. Connected to the PCC the vertical combustion chamber with the multi-fuel dust burner was installed. The PCC generates the base load with a constant flue gas flow generated from a combination of an oil/gas burner and solid fuels (see Fig. 1).

The combustion chamber has a diameter of 1.9 m and is 15 m high. The pulverized-multi-fuel burner is located in the middle of the combustion chamber. The dust burner has a thermal power of 1.0 MW at a maximum fuel flow of about 100 kg/h. The dust burner is equipped with an integrated swirl generator. The swirl of the combustion air can be adjusted manually. The air can be preheated up to 300 °C. The alternative fuels to be combusted may either be added to the coal flow or fed into the burner separately via a central lance. The hot flue gases leaving the combustion chamber enter the boiler where they are cooled down to approximately 300 °C and generate saturated steam of 40 bar and 250 °C. The boiler has a maximum capacity of 2.5 MW.

Flue gas cleaning meets the requirements outlined in the 17th Federal Emission Control Ordinance, which sets emissions limits for waste incineration and co-incineration plants in Germany. Flue gas cleaning mainly consists of a spray dryer, a fabric filter, two scrubbers, and an SCR catalyst [6].

An opening in the ceiling of the combustion chamber allows for the insertion of a water-cooled camera probe. For the analysis of the fuel particles a high-speed camera system Optronis CL600x2 is used for capturing grayscale images at 2000 fps. The image resolution is 560×460 pixels. This corresponds to the size of a pixel of approximately 5×5 mm in the examined burner level. Fig. 2 shows a single image of a flame during the combustion of 72 kg/h coal dust and 10 kg/h rice husks at a swirl number of 1. The bright diffuse areas in the image indicate the radiation of burning coal dust. In addition, the burning rice husks can be seen as bright points over the entire cross section of the combustion chamber. The rice husks have a size of 7–8 mm. In the images, however, they appear more than twice as large due to their luminous flame body.

Here, the camera was not calibrated for measuring absolute temperatures of the particles and flame. Temperature measurement based on calibrated cameras in the visual spectral range (VIS) assumes pure Planck radiation. This assumption is not fulfilled in the case of additional chemiluminescence, which is typical in flames and would lead to measurement errors. Additionally, the dynamic range of typical high-speed cameras is too small, causing overexposed regions for flames and particles and hence preventing temperature calibration and measurement.

The camera uses no automatic adaptation of the image to the luminosity (e.g. automatic exposure). Thus, the gray values can directly be compared image by image. Changes of the luminosity of the background are compensated by an on-line background estimation (see Section 3.1).

In the experiments for co-firing alternatively to rice husks cereal residues, switch grass, wood dust and solid recovered fuel (SRF) were used. Here, motivated by manual observations of the

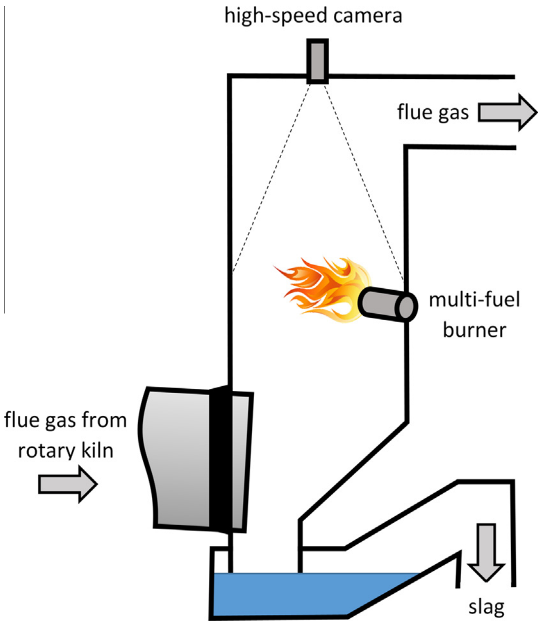

Fig. 1. Setup of experimental combustion chamber Brenda.

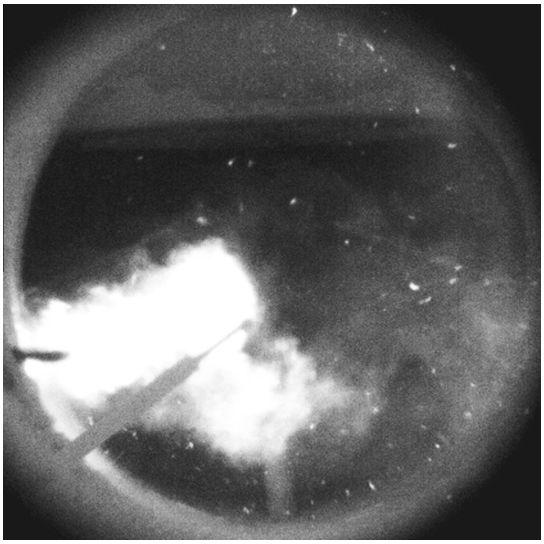

Fig. 2. Co-firing of rice husks with coal dust.