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Research article

Quantitative and qualitative relationship between swirl burner operatingconditions and pulverized coal flame length

Christian Katzer[a,*], Konrad Babul[b], M. Klatt[a], H.-J. Krautz[a]

[a] *Chair of Power Plant Technology, BTU Cottbus–Senftenberg, Postbox 101344, Cottbus 03013, Germany*

[b] *The Chair of Energy Technology, Turbines and Modelling of Thermal and Fluid Flow Processes, Wrocław University of Technology, WybrzeŻe Wyspiańskiego 27, Postbox 50-370, Wrocław, Poland*

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ABSTRACT

Currently, there are used in power plants two types of burners to combustion the pulverized coal: jet burners and swirl burners. Most of the published works in the field of analysis of burners operating conditions are related to jet burners and are limited to initial region of the flame at the outlet of the burner. For jet burners an offset between the burner outlet and the flame beginning point could be analyzed. In the case of swirl burners with the pre-mixing diffuser chamber an offset between flame ignition point and burner outlet is usually not visible. Because already in the pre-mixing diffuser chamber of swirl burner occurs the ignition of coal-dust together with oxidant-gas cloud and thereby the formation of the flame. Therefore, the analysis of operating conditions for this types of burners requires a different approach. There is a lack of researches, in which will be analyzed changes of the flame length, that are caused by changes of design and operating parameters of swirl burner with the pre-mixing diffuser chamber. Therefore the aim of this study was to implement and verify the methodology for estimating the flame length, which will allow monitoring changes of operating conditions, that are caused by changes of design and operating parameters of swirl burner with the pre-mixing diffuser chamber. To carry out the analysis of the image of the coal flame, the two algorithms have been presented. This two algorithms, being based on the video images of the coal flame allows to specify and detect the end point of the flame and on that basis the length of the flame, as well as the fluctuation changes of flame length can be later determined. Both, the change thermal loads of coal burner, streams of secondary air, as well as the constructional change of the angle of swirler assemblies, resulted in distinct changes in the length of the pulverized coal flame.

1. Introduction

The international policy pursued in the field of electricity generation tends to minimize the anthropogenic impact on the environment. Coal power plants play an important role in the structure of the electric power generation in the world. The operation of such power unit depends on many process parameters, one of the most important is the constructional and operational characteristics of pulverized coal burner. Which helps ensure stable conditions for ignition and combustion of the fuel in the combustion chamber, with the lowest emission of harmful gases into the atmosphere at the same time. Ignition and combustion of a single coal particle in the pulverized flame depends on its local access to the oxidizer, its interaction with other particles, temperature profile occurring in the combustion chamber, the conditions of heat and mass transfer in its surroundings and the local characteristics of the turbulent flow of carrier gases. Also, taking into account the fact, that the combustion of a single particle is a complex, multistep process [1] (heating, drying, fragmentation [2], devolatilization, ignition, combustion of volatiles, combustion of coke, transformation of mineral matter), it will be obtain the multi-parameter reaction system of ‘single particle - reactive atmosphere’, and at a larger scale ‘group of particles - reactive atmosphere’, which when integrated at the time, gives a image of the pulverized flame. The introduction of this multi-parameter reaction system in the form of a continuous function and variable at the time would allow an accurate representation of pulverized coal flame and its instantaneous changes at the time. Due to the size and extent of entanglement of the reaction system describing the coal flame, the existing mathematical descriptions are limited to the simplified analysis of the reaction system based on the probability density functions [3]. High volatility of size and shape of the

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* Corresponding author.

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coal flame happening at short intervals and at high temperatures in the combustion chamber, contributed to the fact, that the description of the geometry of the coal flame and its instantaneous changes are very limited and there is a small number of works devoted to this subject [4–6].

The development of measurement techniques related to the recording and processing of video image [7–9], and the progress of the thermo-vision temperature measurement using 2-color pyrometry [10]. Which allows currently to conduct the analyzes connected with both - the shape of the pulverized coal flame, as well as the profile of the temperature distribution of the flame [11]. The progress reported in this field allowed to provide further information to the boiler operator in the form of coal flame image in the outlet zone of the burner [12–14], so that it is possible to monitor the situation and react to any problems associated with the formation of the pulverized coal flame or its extinction. In order to be able to predict the mutual influence between the shape of the coal flame in the outlet zone of the burner and work of boiler, currently steps are being taken to develop measurement methodology, which characteristic the coal flame laid down in the area of its formation after the outlet from the burner [15–18].

In the case of gas burners, a key role in assessing the stability and operational characteristics played the length and shape of the flame, which are also important design parameters [19]. In contrast to the relatively well-described physical chemistry of the combustion gas flame by its geometric structure, such a description in the case of pulverized coal burners does not occur. The main reason for this is the multi-parametric nature of the technological process of pulverized coal combustion and the multi-step combustion process of individual particles, which are forming the coal flame. The terminology of characterize the gas flame stability, is determined based on the length and shape of the flame [20], which directly depend on the burner geometry and parameters of his work (e.g. discharge of fuel and discharge of oxidizer). In the case of pulverized coal burners, the term "flame stability" in practical device it means the flame is anchored at a desired location and is resistant to flashback, standoff and blowoff [21–23]. To characteristic the flame stability of a coal burner mainly the flame root are under investigation and therefore an unstable flame is not attached to the burner outlet [18,24] or luminous parameters at the ignition zone are characterized [16,25].

Currently, there are used in power plants two types of burners to combustion the pulverized coal: jet burners and swirl burners. Most of the published works in the field of analysis for burners operating conditions are related to jet burners and are limited to initial region of the flame at outlet of the burner, there is an offset between the flame beginning point and the burner outlet. In the case of swirl burners with the pre-mixing diffuser chamber for mixing the streams of fuel and oxidant are not possible to monitor the changes in the distance between the flame beginning point and the burner outlet, because already in the pre-mixing diffuser chamber of swirl burner occurs the ignition of coal-dust and oxidant-gas cloud and to the formation of the flame. Therefore, the analysis of operating conditions for this types of burners requires a different approach, than that, which it is commonly used for jet burners. There is a lack of researches, in which will be analyzed changes of the flame length, that are caused by changes of design and operating parameters of swirl burner with the pre-mixing diffuser chamber.

For the present investigated coal swirl burner with a pre-mixing diffuser chamber there exists the property that the flame is almost always attached to the burner outlet, also for operating conditions under lower burner load. However, if the flame will be unstable it results in an instant extinction of the flame without any early visible standoff. Therefore the aim of this study was to implement an analysis method that will allow to characterize the endpoint of the flame. In order to investigate the length of the coal flame and its fluctuation changes – the factors which would be able to provide two parameters characterizing the swirl burner stable operation.

2. Experiment setup

2.1. Description of the combustion test facility

The experimental furnace used for this work was the 0.4 MW_{th} oxy-fuel test facility available at the Chair of Power Plant Technology at BTU Cottbus–Senftenberg. The facility was designed for investigations of pulverized coal combustion in oxy-fuel atmospheres and experimental results about combustion stability limits and emission performance under oxy-fired conditions were carried out [26,27]. Fig. 1 provides a schematic of the actual plant configuration, which perform for the present work under air-firing conditions.

Crushed coal is transported to a storage silo which feeds a pulsation-free metering and pneumatic conveyance system capable of maintaining a steady flow of fuel up to the burner. The combustion air is split into three streams and volume flow rate continuously monitored to ensure the desired amount of feed gas at each burner register. A preheater is used to increase the temperature of secondary and tertiary air flow, except the transported air flow of the coal is not preheated. The combustion takes place in a horizontal up-fired furnace with a rated capacity of 0.4 MW_{th} designed to reproduce the time-temperature history of a fuel particle entering in a full-scale furnace. The burner geometry is typical of that used in power stations for wall-fired boilers and provides stable flames over a wide range of operating conditions capable of firing coal or combustible gases. After the furnace and economizer, the flue gas is passed through a preheater to reduce its temperature before being directed to the sulfur and fly ash wet scrubber. The furnace consists of a vertical water-cooled boiler and a cylindrical refractory section where the burner is attached. The cylindrical section of the furnace has an internal diameter 0.95 m and is 1.068 m long. The boiler consists of membrane walls where parallel tubes are connected by fins welded in between. The boiler has an internal square cross-section of 1.012 × 1.012 m and a height of 4.40 m. The floor section and the lower 2.20 m of the boiler are lined with a 0.05 m layer of refractory, to reduce thermal loss and decreases the time required to reach steady state. A major advantage of this laboratory furnace is that it is large enough to ensure that the physical phenomena of full-scale furnaces are reproduced (i.e. fully turbulent flow combined with significant heat transfer by radiation).

A dual-fuel burner for the laboratory facility can operate either with natural gas or pulverized coal (shown in Fig. 2). For the present investigations of flame pattern and limits of stable coal burner load, the natural gas is used to preheat the furnace. A supporting gas torch is used to stabilize the coal burner and after reach the starting investigative operating conditions the gas torch is turned off. As shown in Fig. 2 the primary stream, used for the introduction of pulverized coal, is positioned in the center of the burner and enclosed secondary feed gas and tertiary stream for staging purpose. In order to provide the flame stabilization and modify the flame pattern the secondary air stream is equipped with swirl blades. Three degrees of swirling blades are available, 15°, 30° and 60°, the calculated swirl numbers (S) are 0.24, 0.52 and 1.57. To increase the flexibility of combustion staging and flame shaping, part of the feed gas stream is also injected through an annulus orifice enclosing the burner quarl (named as tertiary stream). The velocity of primary air is one of the important parameters of stability for a pulverized coal burner [28,29]. For a better burner performance at low-load operation and to decrease the axial momentum of the center stream, a diffuser outlet is used to decrease the designed velocity of primary air from 25 m/s to 15 m/s. However, for the particle transport and avoid any flash back of flame, the velocity rear the pipe are constant over 25 m/s.