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Experimental study on the effects of co-firing coal mine waste residues with coal in PF swirl burners

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ABSTRACT

Co-firing coal mine discards with coal in pulverized fuel burners of the current power plants would be a promising way both to reduce the environmental impact of coal production and to energy valorize such residues, with an acceptable economic investment. Changes in fuel blends bring along alterations in flame dynamics and structure which must be considered for successful operation. The paper addresses the challenge of co-firing coal mine waste residues of low rank, high ash content and rich in sulfur with bituminous South African coal in a 500 kW_{th} pulverized fuel pilot plant. The effect of fuel blend composition on combustion performance is investigated by means of image processing and through some relevant operation parameters recordered during the tests. Lower brightness, fluctuations and flicker frequency are registered in the flame videos as coal mine waste residues are added. Nonetheless, the experimental tests confirmed the viability of the process with acceptable levels of carbon monoxide and nitrogen oxides, very stable chamber pressure and gases temperature. The present work also shows the usefulness of visualization systems for detecting and characterizing dynamical instabilities associated with changes in flame structure and certain flame features could be used as inputs in monitoring systems or predictive control.

1. Introduction

During the last decade, coal keeps the 40% of electricity generation in the world [1]. In spite of the recent economic crisis and the structural changes in many economies, such as China and OECD countries, the demand of coal remains very high and is forecast to increase in the coming years due to India and Southeast Asia [2].

One of the biggest environmental impacts from extraction and processing of coal is the stockpiled of millions tons of sterile mine waste per year, representing between 10 and 15% of the total coal production [3]. The high content in sulfur and metals, such as manganese or aluminum, can cause pollution of soil and ground and surface water. Furthermore, the spontaneous combustion produces atmospheric pollution due to the dispersion of particles, trace metals (As, Be, Cd, Co, Mn, Pb, Zn, …) and species such as NO_x or SO_2, harmful to the environment and human health [4].

To date, the energy use of these wastes of very low heating value has been carried out only in circulating fluidized bed facilities in dedicated plants [3] or co-fired with coal and biomass [5]. However, since about a 90% of thermal power generation facilities are based on pulverized fuel (PF) burners, it would be desirable to introduce these residues in conventional power plants [6]. Nevertheless, the introduction of new fuels, especially those with high ash content, might produce important changes in flame dynamics which could involve operational instabilities and inefficiencies.

The lack of investigation to this respect has prevented any commercially exploitation of this co-firing option, remaining an important research field to be explored. The present work tackles for the first time the characterization of co-firing flames of coal mine waste residues (CMWR) and coal in a pulverized fuel burner through image processing based analysis. Visualization systems provide on-line and direct information about combustion process which could be used for diagnosis purposes and to develop monitoring and control systems, allowing the improving of stability and efficiency.

Advanced image monitoring systems, as two-color pirometry, have been employed in pulverized coal flames to measure soot particle concentration [7], temperature distribution in two [7,8] and

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three dimensions [9] and flame emissivity [10]. However, the necessity of specific dedicated algorithms with accurate calibration makes difficult the practical integration on the control systems of industrial units.

Charged coupled devices (CCDs) are a simple and cost-effective option for flame characterization [11]. Geometrical and luminous flame parameters were correlated with furnace load, mass flow rate of primary air and particle size in a coal-fired test facility [12]. Image parameters of coal-biomass flames were also used to analyze and compare the ignition points and brightness to investigate the relationship between flame characteristics and the primary combustion process [13]. Some other combustion indicators, as stability, volatile content or pollutant emissions, were related to flame features in co-firing experiments with various biomass-coal blends [14]. Spatial and temporal flame parameters have been related to operating conditions as swirl number [15] and were used for coal identification through the development of a predictive model [16].

The present paper addresses to analyze the effects of CMWR addition on the combustion process in a 500 kW_{th} PF pilot plant using the flame characterization by imaging. The methodology followed in previous works [17] based in statistical and spectral parameters is here applied to characterize CMWR/coal co-firing flames, and to investigate its relationship with stability and pollutant emissions.

According to that, the main objectives of this work are to show the viability of the co-firing of CMWR with coal in a PF burner and present the usefulness of flame imaging as combustion diagnosis tool. The test facility, the experimental program and the image processing methodology are detailed in Section 2. Several substitution ratios have been evaluated and a comprehensive statistical analysis has been carried out. In Section 3 the results about the stability of co-firing are shown and the time evolution of global flame features, effects of temperature and CMWR percentage on flame parameters and the identification of unstable flame states are presented and discussed. Finally, Section 4 gathers the main conclusions of the paper.

2. Experimental methodology

2.1. Combustion pilot plant

Experiments have been performed in a 500 kW_{th} swirl burner for pulverized fuel, placed downward on top of a cylindrical chamber 3 m long and 1 m of internal diameter (Fig. 1). The combustion chamber consists of six water-cooled rings, being the upper three rings coated with refractory concrete to promote flame stability. The swirl burner includes an ignitor of natural gas of 35 kW_{th} and two concentric entries of primary air-fuel and secondary air streams.

Swirl is imposed by a tangential scroll to the primary air while the secondary air crosses radial vanes whose angle can be remotely varied. The multi-fuel feeding system allows the on-line regulation of the mass flow with high accuracy [18].

The facility is equipped with standard instruments for temperature, pressure and flow measurements at key points. Specifically, gases temperature indicated as T_g in Fig. 1 is measured inside the combustion chamber by means of a thermocouple (uncertainty of ±0.75% of the measure in the range 800–1200 °C). The measurement is corrected from convection and radiation effects, according to the method of Cox and Chitty reported in Ref. [19].

Concentrations of main species present in flue gases are continuously measured with a complete set of standard analyzers composed by NDIR (Non-disperse Infrared) absorption photometers and electrochemical sensor for O_2 (maximum uncertainty of 0.5% span). An advanced SCADA system (Supervisory Control and

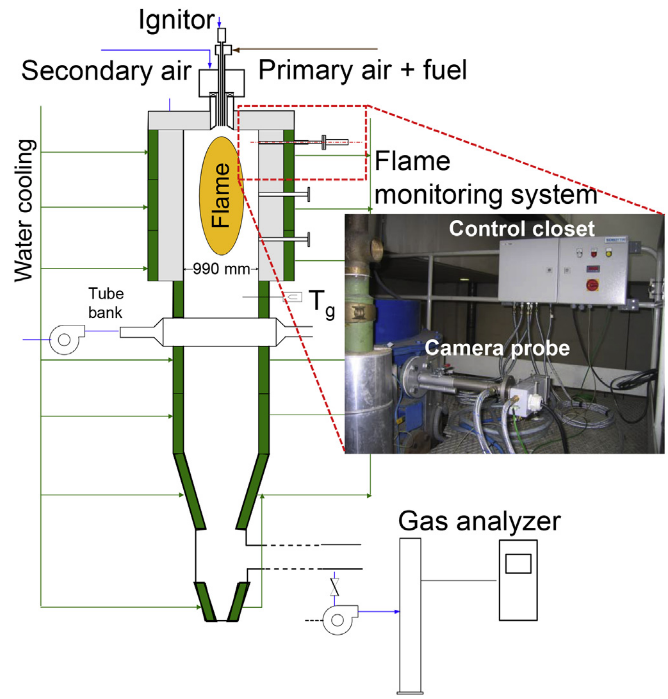

Fig. 1. Experimental facility layout including the location of the visualization system.

data Acquisition) provides the on-line control, visualization and recording of operation parameters and emissions.

The flame visualization system is constituted by a monochrome CCD camera with a remote head of 17 mm diameter, a protective probe with purging air and cooling water, an electronic control unit and a frame grabber installed in a PC. As it can be seen in Fig. 1, the probe is located in a spy-hole at the first refractory ring of the combustion chamber in order to register the root of the flame. The main characteristics of the camera and its optical system are gathered in Table 1.

Further details of the experimental facility and the visualization system can be found in Refs. [17,18,20].

2.2. Experimental tests

The experimental tests were carried out with different blends of bituminous South African coal (SAC) and coal mine waste residues (CMWR). Table 2 summarizes the main characteristics of granulometry, heating value, proximate and ultimate analyses. Preprocessing of samples and characterization analyses were performed according to ASTM and UNE standards [21]: ASTM 2016-65 and ASTM 871–872 for moisture; ASTM D-1102-84 and SS 187171 for ash (550 °C); ASTM E872-82 for volatiles; and chlorine according to ASTM D-2361-66 and UNE 32024. High heating value was measured according to the standard UNE 164001EX. Regarding

Table 1
Camera specifications.

Characteristic (unit)	Value
Active area (mm)	6.4 (h) x 4.8 (v)
Active pixels	659 (h) x 494 (v)
Signal/Noise ratio (dB)	> 50
Electronic shutter (s)	1/10000
Spectral range (nm)	400–1000
Max. Spectral response (nm)	500
Focal length (mm)	7