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Ignition behaviour and flame stability of different ranks coals in oxy fuel atmosphere

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HIGHLIGHTS

- We present research studies on ignition and flame stability in the oxy-fuel atmosphere.
- We use five coals – three black coals and two brown coals.
- We use three atmospheres i.e. air, dry RFG and wet RFG.
- A type of gas with which O_2 was mixed had a fundamental impact onto the characteristics of ignition.
- The specific thermal capacity and density of main gases making up a mixture with oxygen are of fundamental importance.

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ABSTRACT

The aim of the research has been to investigate the impact of a type of atmosphere onto the ignition of fuel and the stability of dust–gas flames. Three black coals and two brown coals were applied in the research. It covered performing their physicochemical analyses and determining the induction time of ignition of single particles and dust–air cloud as well as parameters of dust flames and their stability. The research program referred to various aspects of the ignition of fuel, including: effects of its temperature, size of grains, type of atmosphere (air, O_2/CO_2), O_2 share (5–30%) in the O_2/CO_2 atmosphere. The conducted research highlighted that the ignition of fuel is connected with a degree of its carbonisation, temperature and the type of atmosphere at which it takes place. The ignition of black coals is more difficult (hindered) than the one of brown coals. For its enhancement it is required to apply (among others): higher oxygen concentrations, higher dust concentrations, fined dust milling or higher ambient temperatures. A type of gas (N_2, CO_2) with which oxygen was mixed had a fundamental impact onto the characteristics of ignition. For all the examined coals, the induction times of ignition of dust cloud measured in the air atmosphere were shorter than the ones measured in the oxy atmosphere. The presented research demonstrated that – for the stability of flames and the parameters of fuel – the specific thermal capacity and density of main gases making up a mixture with oxygen are of fundamental importance.

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1. Introduction

The general motivation of this research is to develop practical oxy-coal combustion techniques in order to facilitate the conversion of coal-fired utility power plants so as to recover a CO_2 rich flue gas flow for use and/or sequestration. The ignition of dust coal in O_2/CO_2 conditions is important for optimising the oxy-fuel combustion technology, mainly the furnace design. For example, when retrofitting the existing dust furnace with oxy-firing technology, the ignition of coal and the stability of flames at good levels should be obtained. The leading technologies for power generation in the current market are pulverised fuel (PF) combustion, steam cycles or natural gas combined cycles (NGCC). CO_2 can be captured from flue gas of both of these types of plants by scrubbing. Alternatively, oxygen can be used for combustion instead of air which results in flue gas consisting mainly of CO_2 and H_2O. This is known as oxy-fuel combustion. The oxy-fuel combustion has been recognised as one of the most promising technologies for pulverised coal-fired power plants, particularly for retrofitting the existing ones, to control CO_2 emissions, which has motivated extensive research efforts around the world. In order to reduce a high level of temperature related to the combustion of dust coal in pure oxygen, several possibilities are considered which – in case of their application – will have a significant impact onto its ignition as well as the propagation and stability of flames. These methods include:

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internal recirculation with exhaust gases in the burner (rather low potential for practical use), external recirculation of exhaust gases to the furnace chamber and the burners with non-stoichiometric operational conditions (CSNB). On the basis of the conducted experiments [1–3] it is concluded that the presence of CO_2 in a mixture with oxygen, in comparison to the ignition in the air atmosphere, slowed down the ignition of coal and carbon char. Then, the presence of CO_2 in the combustion process has a negligible effect on the duration of degassing. The impact of CO_2 onto the ignition of coal particles as compared to N_2 is justified by other values of the specific heat of these gases. A rise of oxygen concentration accelerates the ignition of particles in the O_2/N_2 and O_2/CO_2 atmospheres [4–7]. The impact of oxygen concentration onto the ignition of particles is also justified by O_2 having an impact onto the local reactivity of a given mixture. Degassing of particles runs faster for higher O_2 concentrations and gets reduced together with an increased share of CO_2. Both of these factors affect a rate of diffusion of oxygen and volatile matter. CO_2 has an impact onto a dropped rate of degassing due to a lower speed of the diffusion of volatile matter in a mixture with CO_2, while higher CO_2 concentrations decreases a flow of oxygen mass fed to flames of volatile matter surrounding coal particles. Thus, there is an rise of gas temperature around a particle and at the same time leads to an decreased rate of degassing. A rise in oxygen concentration in recycled exhaust gases, if it is appropriately chosen, allows to obtain the times of ignition being similar to the ones obtained in the combustion of coal in the air [8,9]. The flame theory and the examination of combustion of dust coal in laboratory installations show that a temperature of flames in the $21\%O_2/79\%CO_2$ atmosphere is considerably lower than the ones at the combustion in the air [1,10,11]. It is found that, in some cases, it is not possible to keep the stability of flames and – in order to ensure their stability – it is necessary to increase a level of oxygen concentration in the fed gas for raising their temperature. Under combustion conditions in the oxy atmosphere [12–15], the most stable flames were recorded for a share of oxygen within 27–30%. The research on the stability of flames demonstrated that for their stability and shape, the thermal capacity and densities of main gases (N_2 and CO_2) forming a mixture with oxygen are of fundamental importance [16,17]. Variances in a composition of gasses in the air and OXY atmospheres have an impact on an increased ignition time of particles and decreased rates of propagation of flames. Shifting the burners from the air atmosphere to the oxy atmosphere will require to make changes of rates and volumes of mass flows (both the first flow as well as the second oxidant flow). Changes in the aerodynamics of flows will have an influence onto shapes and types of achieved flames.

The literature review indicated that there was a need to broader the knowledge concerning the impact of O_2/CO_2 atmosphere on the ignition, combustion and emissions. The experiments were focused on the process of combustion in air-dust cloud. Authors believe that performed, basic experiments of single particle combustion in different atmospheres, may be useful for modification and validation of existing air conditions models into oxy-fuel conditions. Obtained results are complementary to research presented in the literature, expanding knowledge about the impact of different coal rank fuels on the combustion process in O_2/CO_2. Moreover, the paper presented results of ignition of air-dust clouds and flame stability in oxy-fuel, which are not so common in the literature.

2. Fuel samples

Five Polish' coals – three black coals (Janina – WK1, Sobieski – WK2, Ziemowit – WK3) and two brown coals (Turów – WB1, Bełchatów – WB2) – were used in the research. For these fuels their chemical and physical properties were measured on the grounds of their technical and elemental analyses. These measurements were performed in accordance with the Polish Standards, and their results presented in Table 1.

Table 1
Proximate and ultimate analyses of fuels (on air dried basis).

Fuels		WK1	WK2	WK3	WB1	WB2
Proximate analyses						
Moisture, *W*	%	3.1	3.7	2.4	2.0	4.4
Ash, *A*		8.6	10.4	7.7	17.5	16.1
Volatile Matter, *VM*		32.7	33.0	34.9	46.6	44.4
Fixed Carbon, *FC*		55.6	52.9	54.9	33.8	35.0
Fuel Ratio, *FR*	–	1.7	1.6	1.6	0.7	0.8
Calorific values, *CV*	MJ/kg	24.7	25.8	27.0	21.7	18.9
Ultimate analyses						
Carbon, *C*	%	75.7	76.0	77.1	59.0	55.2
Hydrogen, *H*		4.3	4.1	4.6	4.8	4.5
Nitrogen, *N*		1.2	1.2	1.2	0.5	0.6
Sulphur, *S*		1.2	1.6	1.1	1.3	1.8
Oxigen (by diff.), *O*		5.9	2.9	5.7	14.8	17.4

3. Ignition of single particle

The induction time of ignition was measured at a station equipped with a horizontal, heated electrically, tube furnace at temperatures from 300 °C to 1100 °C. Fuel grains were fed to the combustion zone through a water-cooled probe in order to prevent premature degassing and ignition. Simultaneously with the moment of placing a grain in the combustion zone, a detection set (high-speed camera) was switched on to record the combustion process of single fuel particle. A fuel grain was cement-attached to an quartz needle fixed to the piston (its axis) which could move in the cylindrical guide. The applied optical system allows to get an enlarged tape-image of a fuel grain. The coal particle was introduced to the stable temperature field at estimated time about 30 ms. Their digital processing was based on placing a digital threshold filter which allowed to mask uniform colours and thus made it easier to observe changes of particles/ their shapes. The change of boundary flame zone and grain size was recorded using the digital filter threshold (calibrated based on wall temperature). As a criterion for assessing the various stages of devolatilization, ignition and char combustion, the change of geometry of fuel grain was taken. Moreover, in order to facilitate the assessment i.e. to eliminate the influence of the furnace background on the measurement and to optically separate combusted volatiles from the coal grain, the digital filter threshold was adopted. In order to record measurements in the range of visible light, the high-speed camera was used. For each size of fuel grains, measurements of 10 samples were made and further processed. Carrying out of 10 measurements for each size of grain enables to minimise the possibility of errors in geometry and time of devolatilization/ignition/char combustion assessment. The time of char combustion was determined at point when the grain was not longer visible on the background of the furnace wall. It was assumed, that at this time the combustion process stopped and unburned residue was at temperature of furnace atmosphere. In order to keep stable temperature field gases were preheated. Moreover the flow rates (about 0.5 l/min) and the way of their introducing were adjusted to ensure minimal impact on the flame zone. The temperature of gases were measured in the vicinity of grain, at the zone of stable conditions, about 0.5 cm far from combusted grain.

As a result of the conducted measurements, the following characteristics of ignition and combustion of the examined coals were obtained: induction time of ignition, combustion time of volatile matter and combustion time of coal char for a temperature of

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