



Research article

Explosion of different ranks coal dust in oxy-fuel atmosphere



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ABSTRACT

Significant impact of the coal power generation onto the environment causes that new technological solutions aimed to reduce the impact of coal combustion onto the environment have currently been sought. Oxy-fuel is one of the technologies which reduces conventional pollutants such as NO_x , SO_2 and contribute to the elimination of CO_2 . The strategy for the implementation of this technology has currently been connected with two directions: (1) retrofitting of existing power plants to fit new combustion conditions or (2) design of new units. When air is replaced with CO_2/O_2 , it leads to lots of doubts and concerns on boiler construction solutions. The article presents the results of research studies on four coals, on four coals, two bituminous coals and two lignite. The laboratory studies analysed the impact of CO_2/O_2 atmosphere onto explosion risks in fuel handling/preparation installations. These research studies were performed with the application of 20-litre sphere and TGA/DTG. It was found that the impact of the oxy-fuel atmosphere onto increased explosion risks is lower than it could be concluded from an increase in oxygen concentration in the system. The TGA/DTG studies showed, however, that devolatilisation and fuel ignition in the oxy-fuel atmosphere occur at lower temperatures compared to the air atmosphere.

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1. Introduction

The technology of coal oxygen combustion is a promising technological solution which gives an opportunity to significantly reduce the impact of combustion products onto the environment. Its practical implementation in conjunction with the capture and storage of CO_2 (CCS – carbon capture storage) will reduce NO_x emissions as well as virtually completely eliminates CO_2 emissions [1,2]. The so-far research studies have focused mainly on the three main elements of the oxy-fuel combustion, namely: (1) how to obtain oxygen needed for the combustion process, (2) how to organise the combustion process and (3) how to capture and store CO_2 . On the grounds of the conducted research studies it can be concluded that the combustion process in the oxygen-enriched atmosphere can be conducted both in new units as well as in units subjected to modernisation to fit new combustion conditions [2–5]. The retrofitting of units entails constructing a new exhaust recirculation system, re-organising the combustion process and eliminating any air heaters etc. [6–8]. The possibility of reconstruction of old units fulfilling ox-fuel conditions also significantly reduces installation costs, and older units have lower capacities, thereby their demand for oxygen required for combustion is lower, which means that it is possible to reduce the size of ASU (Air Separation Unit).

When we consider the concept of combustion in the oxygen-enriched atmosphere, we should ask a question how to run the start-up process of a boiler under the regimen of oxygen combustion? At the start-up of the boiler there are no exhaust gases for recirculation

in order to ensure the proper concentration of oxygen in the combustion chamber. Hence the natural solution seems to start it up in the air regime, and then – after achieving its stable operation – shift to combustion conditions under the oxygen regime [9,10]. This solution facilitates to run the boiler in a variety of configurations and to implement the Flexi-Burn™ strategy [11] which is suggested for fluidised bed boilers.

The elimination of air from the combustion process causes that it will also be required to use a mixture of CO_2/O_2 at the preparation and transport of dust to burners. Burners of dust boilers without any major construction changes can be supplied with air or a mixture of oxygen and FGR (Flue Gas Recycle) [7]. The result is that mills will be also required to work in the CO_2/O_2 atmosphere. An increase in the concentration of oxidant in the mill chamber over 21% may contribute to an increased risk of coal dust explosion [12–17]. Therefore, one of the methods to avoid explosion is to keep oxygen concentration at a level of 21% (just like in the air), however, it requires the application of additional regulation and control systems. The recirculation of moist exhaust gases to the milling system may cause a reduction of explosion risks while increased moisture content gradually leads to the agglomeration of fine particles by reducing distances between/among them and creating water bridges between molecules [18,16]. These phenomena limit the parameters of fuel explosion, however, it should be remembered that such increased moisture content (compactness) may make it difficult to obtain the appropriate quality of milling and transportation of milled fuel to the burners. The qualification to assess explosion risks posed by coal dust under combustion conditions in the oxygen-enriched atmosphere and projected conduct of different types of coal is relevant for the development of the oxy-fuel technology, projection of boiler installations as well as safety of the power plant. Smooth

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operation of the milling plant both in the air and CO₂/O₂ atmosphere significantly facilitates the operation of the whole boiler system, allows to perform a smooth start-up of the boiler as well as to adequately react in emergency situations (for example in case of a failure of AUS and necessity to return to air-based combustion). Therefore, this paper focused on the assessment of explosion risks occurring at mill installations operating under the CO₂/O₂ atmosphere. The research studies included in the paper covered both marking (determination) of explosion parameters as well as attempts to assess factors which increase or decrease such risks.

In fact, there are just few research studies on the phenomenon of explosion in the OXY atmosphere [13–15,19,20]. The paper [15] included research studies on the conduct of 13 coals at different degree of their coalification in the air and CO₂/O₂ atmospheres with their oxygen concentration ranging from 20 up to 40% and for dust concentrations within 100–600 g/m³. Similar levels of the lower explosiveness limit were set for the tested fuels in the air and at their concentration of 30–35% under the OXY conditions. The explosiveness limit decreased with an increase of oxygen concentration but it was negligible in case of the oxygen concentration at 40%. The paper [13] covered the assessment of effects of the type of atmosphere onto Minimum Ignition Energy for two coals. The values of minimum ignition energy were found comparable for the air and 30% O₂/70% CO₂ atmosphere. In case of the oxygen-enriched atmosphere (up to 50%), its minimum ignition energy got significantly decreased. The papers [13,14] found a linear increase of the maximum explosion pressure and maximum rate of pressure rise with a return of oxygen concentration within 20–50% with CO₂. For 30% oxygen the maximum explosion pressure is higher in the OXY atmosphere; by contrast the maximum rate of pressure rise is lower than the one for the air atmosphere. These research studies were performed for dust concentration within 250–2500 g/m³. In addition, the extensive literature on explosions includes a couple of references [21,22] on the effects of oxygen onto the process and methods of explosion inertisation by entering inert gas into an explosion area. These works suggest a stronger impact of CO₂ than N₂ onto the limiting oxygen concentration (LOC) by increasing this value. This effect occurs even for magnesium dust [23] in spite of ongoing combustion of Mg with CO₂. It was found that at low dust concentrations CO₂ is a better inerting gas than N₂ or Ar.

The behaviour of gaseous mixtures in oxygen enriched atmospheres and/or atmospheres containing carbon dioxide/nitrogen was investigated in papers [24,25]. Based on experiments and modelling calculations [24], it was stated that for mixtures of CH₄/O₂/N₂/CO₂ and H₂/O₂/N₂/CO₂, the presence of CO₂ decreases the maximum rate of pressure rise and the adiabatic temperature of combustion. It was shown that the main effect of CO₂ was not on kinetics and diffusive transport rates, but rather on the specific heat of the mixture. In the work [25], experiments performed in atmospheres of CH₄/O₂/N₂ indicate that the maximum (peak) pressure of explosion obtained in oxygen-enriched air atmosphere, was higher than the adiabatic one. The observed anomalous behaviour was attributed to the occurrence of cycles of condensation and vaporization of the water produced during the combustion.

The ignition temperatures of coals in the air atmosphere and 30% O₂/70% CO₂ atmosphere are similar. For the tested coals the paper [26] found there is a lower ignition temperature in the air for bituminous coal and higher - for bitumen coal. These differences did not exceed a few degrees (with the difference of almost 20 °C for the same concentration of oxygen in both atmospheres). Then, self-ignition temperatures [27] for the OXY conditions decrease with an increase of oxygen concentration, but it is higher when the air atmosphere is replaced by 21% O₂/79% CO₂ mix.

All of the above works suggest minor differences for ignition and explosions in the air and OXY (with 30% O₂) atmospheres. However, all the conducted research studies do not allow to determine to what extent these changes are relevant. The research studies on explosions

made so far refer to individual coals [13,14] or are conducted for their concentration below 600 g/m³.

2. Fuel samples

Four Polish coals of deferent i.e. two bituminous coals (Janina – WK1 and Sobieski – WK2) and two lignite coals (Turów – WB1 and Bełchatów – WB2) were used in this work. Coal samples were air dried, pulverized (Retsch mill ZM 200) and sieved to size below 200 μg (the R90 was approximately 55–65%, depending on the fuel type). For these fuels their chemical properties denotations were made on the grounds of proximate and ultimate analyses. Their contained moisture, volatile components, ash and elemental composition were denoted. The research results are presented in Table 1. By analysing the obtained results it can be observed that the selected fuels represented all currently used types of fuels in the energy sector. Bituminous coals have got significantly higher contents of their fixed carbon FC > 50% compared to lignite coals FC < 35%. It is worth to mention that in case of lignite coals, on as received basis (not shown in Table 1), ash and moisture are the dominant part of fuel.

The proximate analysis was performed following the Polish Standard [28–31], according to which all crucibles were dried at temperatur 105–110 °C for 45 min, cooled to ambient temperature and afterwards kept in an exsiccator. The weight measurement was carried out with an accuracy ± 0.0002 g for two samples. The difference between results of moisture (W) and ash (A) content for two measured samples was not higher than 0.7%, while for volatile matter (VM) about 1%.

The ultimate analysis was performed according to the Polish Standard [32,33], using the LECO Truspec CHNS analyser. The measurement was carried out with an accuracy ± 0.0002 g. The LECO 502–682 was applied as a calibration standard for solid fuels (coal), allowing to determine the content of elements with an accuracy: ± 0.9% (for C), ± 0.14% (H), ± 0.08% (N), ± 0.07 (S). The difference between two results obtained for the same sample was not higher than 0.1%.

3. Facility and investigated cases

The ongoing research studies applied the following two measuring systems: (1) 20-litre sphere to determine explosion risks, demonstrated at Fig. 1 and (2) TGA/DTG to examine a rate of devolatilisation and combustion of volatile components, demonstrated at Fig. 2. The following explosion risks were marked in the measurements: (1) maximum explosion pressure p_{max} , (2) maximum rate of pressure rise $(dp/dt)_{max}$, (3) maximum rate of pressure rise in 1 m³ sphere when a dust is ignited K_{st} . The measuring position was equipped with a shell cooling system,

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

Proximate analyses					
Fuels		WK1	WK2	WB1	WB2
Moisture, W	%	3.1	3.7	2.0	4.4
Ash, A		8.6	10.4	17.5	16.1
Volatile matter, VM		32.7	33.0	46.6	44.4
Fixed carbon, FC		55.6	52.9	33.8	35.0
Fuel ratio, FR	–	1.7	1.6	0.7	0.8
Calorific values, CV	MJ/kg	25.7	26.8	22.8	19.9
Ultimate analyses					
Fuels		WK1	WK2	WB1	WB2
Carbon, C	%	73.4	73.2	57.8	52.8
Hydrogen, H		4.19	3.97	4.69	4.29
Nitrogen, N		1.16	1.20	0.52	0.62
Sulphur, S		1.20	1.54	1.27	1.69
Oxygen (by diff.), O		8.4	6.0	16.2	20.1

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