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A study on the effects of using different ignition sources on explosion severity characteristics of coals in oxy-fuel atmospheres

Sepideh Hosseinzadeh [a], Frederik Norman [b], Filip Verplaetsen [b], Jan Berghmans [a,*], Eric Van den Bulck [a]

[a] KU Leuven, Department of Mechanical Engineering, Celestijnenlaan300A, B3001 Leuven, Belgium
[b] Adinex NV, Brouwerijstraat 5/3, B 2200 Herentals, Belgium

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ABSTRACT

In this study, the explosion characteristics of coal powder in O_2–CO_2 atmospheres are studied. All experiments are performed in a 20 L spherical vessel. The maximum explosion pressure and the maximum rate of pressure rise are derived from the pressure time evolutions. A three-zone theoretical model has been applied to calculate the flame speed. To overcome the drawbacks of the non-spherical flames generated by pyrotechnical igniters, a continuous ignition spark is used as an alternative ignition source. The experimental results show that maximum explosion pressures are similar when different ignition sources are used. The maximum rate of pressure rise and the flame velocity are very sensitive to the ignition source.

Contents

1. Introduction

It is well-documented and well-understood that fossil fuels have major roles in the increase of carbon dioxide emissions (Boden et al., 1995). One of the new trends in reducing such emissions is a technology which is known as carbon capture (Chen et al., 2012). Oxy-fuel combustion is one of the most promising technologies for reducing carbon dioxide emissions through carbon capture (Chen et al., 2012). Nitrogen is removed from the oxidizer in an air separation unit and the pure oxygen is mixed with the recycling, clean flue and fed to the boiler (Toftegaard et al., 2010). But attention should be paid when using pulverized coal in an atmosphere of CO_2 and O_2 when the O_2-concentration is greater than 21%. To better

* Corresponding author.
E-mail addresses: sepideh.hosseinzadeh@kuleuven.be (S. Hosseinzadeh), jan.berghmans@kuleuven.be (J. Berghmans).

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Nomenclature

V_{vessel}	Explosion vessel volume [m^3]
R	Explosion vessel radius [m]
P_{max}	Maximum explosion pressure [bar]
P	Explosion pressure [bar]
P_0	Initial pressure [bar]
r_f	Radius of front boundary of the flame zone [m]
r_r	Radius of rear boundary of the flame zone [m]
γ	Specific heat ratio [-]
δ	Flame thickness [m]
S_u	Burning velocity [m/s]
S_{u0}	Burning velocity at reference condition [m/s]
T	Temperature [K]
T_0	Temperature at reference condition [K]
T	Time [s]
C_{opt}	Optimal concentration [g/m^3]

understand the complex process of coal ignition, we should identify its combustion characteristics in an Oxy-fuel environment. To that end, the assessment of the explosion severity, i.e. the maximum explosion pressure and maximum rate of pressure rise, plays a crucial role. The maximum explosion pressure (P_{max}) is a parameter that gives a measure of the degree of damage that is caused by an explosion of a dust cloud in a closed vessel. The other characteristic is the maximum rate of pressure rise $(dP/dt)_{max}$ or K_{St} that can be used as an indicator of the velocity of flame propagation which represents the violence of the explosion. These parameters are determined using a closed standard equipment (20 L vessel) over a wide concentration range according to the European standard EN 14034-1 (2004) and EN 14034-2 (2006). The burning velocity can be derived from the data of the closed vessel experiments.

There are various studies that demonstrate the relationship between the pressure evolution and the burning velocity (Nagy and Verakis, 1983; Dahoe et al., 1996; Cashdollar, 2000; Van den Bulck, 2005). Bradley and Mitcheson (1987) presented an analytical model to measure the rate of pressure rise in a closed vessel, based on a two-zone model. Also Pu et al. (2007) introduced an alternative parameter called the effective burning velocity, which is derived from the pressure-time curve. Her results show that unlike the K_{St} value, the effective burning velocity is less dependent on the apparatus.

One of the most important parameters in the measurement of the explosion severity is the type of ignition source. Because of the high cost and high energies of standard chemical or pyrotechnical igniters, the use of alternative igniters is more and more common. Hot surface, electrostatic discharge and mechanical sparks are some of the most popular ignition sources for a dust explosion. Cashdollar and Chatrathi (1992) showed that using chemical igniters can cause overdriving which leads to lower explosion pressure. Scheid et al. (2013) used an exploding or a fuse wire as an alternative igniter and studied its effects on explosion characteristics. He observed that the influence of the ignition source on the maximum explosion pressure is negligible while measured values for maximum rate of pressure rise using the fuse wire were slightly higher than those in which chemical igniters with the same total energy are used. Porowski et al. (2014) used a HV-spark as an igniter. Their results show that the maximum explosion pressure could slightly differ from those with chemical igniters.

In this manuscript, we study the influence of the oxy-fuel atmosphere on the ignition severity characteristics of two types of coal. Moreover, the burning velocity is calculated by analyzing the pressure-time curve. We use the three-zone model of Dahoe et al. (1996) to do so. We also study the effect of using different igniter types on the explosion characteristics.

The layout of the paper is as follows. In Section 2 the experimental set-up and the experiment procedure are described. The analytical model is also explained in this section. In Section 3 the experimental results and analytical predictions are given. Section 4 contains the conclusions.

2. Experimental approach

2.1. Experimental apparatus

Fig. 1 shows the standardized test sphere used to measure the explosion characteristics, including the explosion pressure (P_{max}) and the maximum rate of pressure rise $(dP/dt)_{max}$. It has a volume of 20 L and complies with the EN 14034-1 (2004) and EN 14034-2 (2006). The dust to be investigated is dispersed into the explosion chamber using a special distribution system called rebound nozzle. The tests are carried out with two pyrotechnical igniters of 5 KJ which are located in the center of the explosion vessel. The ignition delay is set at 60 ms which is standard for the 20L-sphere tests. Prior to dispersing the dust, the sphere would be partially evacuated to a pressure of 0.4 bar, so after dust injection, the pressure in the sphere (initial pressure) is equal to 1 bar. The explosion pressure is recorded as a function of time using two piezoelectric pressure sensors whose rise time is 6 μs. The pressure measuring system has an accuracy of ±0.1 bar and a time resolution of 1 ms. The dust concentration is varied over a wide range in order to find the maximum value of the explosion pressure and of the rate of pressure rise.

The pyrotechnical igniters include two chemical igniters each having an energy of 5 KJ. The total mass of each igniter is 1.2 g and consists of 40% by weight zirconium metal, 30% by weight barium nitrate and 30% by weight barium peroxide. The igniters are fired by the electrical fuse. The power supply circuit for the chemical igniters will be capable of firing the fuse heads in less than 10 ms.

In order to investigate the influence of the ignition source, the two chemical igniters were replaced by a high voltage ignition source. This spark has an equivalent ignition energy of about 10 J according to VDI 2263, Blatt 1 (1990). This equivalent energy is defined as the amount of energy in a spark from the discrete discharge of a capacitor that has the same incendivity as the high voltage spark. We use an igniter which is a continuous induction

Fig. 1. 20 L sphere for the determination of the explosion indices P_{max}, K_{St}.