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Effect of ignition delay on explosion parameters of corn dust/air in confined chamber

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ABSTRACT

This paper presents the explosion parameters of corn dust/air mixtures in confined chamber. The measurements were conducted in a setup which comprises a 5 L explosion chamber, a dust dispersion sub-system, and a transient pressure measurement sub-system. The influences of the ignition delay on the pressure and the rate of pressure rise for the dust/air explosion have been discussed based on the experimental data. It is found that at the lower concentrations, the explosion pressure and the rate of pressure rise of corn dust/air mixtures decrease as the ignition delay increases from 60 ms; But at the higher concentrations, the explosion pressure and the rate of pressure rise increase slightly as the ignition delay increases from 60 ms to 80 ms, and decrease beyond 80 ms. The maximum explosion pressure of corn dust/air mixtures reaches its highest value equal to 0.79 MPa at the concentration of 1000 gm^{-3}.

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1. Introduction

The most common dust explosion occurs in underground coal mines. In coal mine tunnel, coal dust explosion is usually caused by gas explosion. Moving at the speed of sound, pressure wave resulting from gas explosion lifts the deposited coal dust in the air. Then gas flame reaches the coal dust causing a dust explosion which is more severe than the first one (Bidabadi et al., 2014a and Bidabadi et al., 2014b).

Corn powder is one of the sources that can result in explosion when it is mixed with an oxidant like O_2 and the mixture is ignited with an energy source. Explosion resulted from corn dust is a major reason responsible for the loss in the crop process industry. However, corn dust explosion, whose hazards have posed great challenges to the process industries today, is far from understood.

Callé et al. (2005) measured the explosion of wood dust with different sizes. Cashdollar and Zlochower (2007) studied the explosion characteristics of metal and nonmetal elemental dust. It was found that explosion characteristics depended on flow of dust in the experimental chamber. It is reported that the explosion characteristics were as a function of time (Serafin et al., 2012; Dahoe et al., 2001). However, it is difficult to observe flow in the experimental chamber. The ignition delay (the time interval between the onset of dust dispersion and the activation of ignition of dust/air mixture) has a significant effect on explosion characteristics. Among all the factors affecting the explosion behavior of fuel/air mixtures, turbulence is generally recognized to have the primary role. Especially, in dust explosion testing, dust clouds are usually formed by means of a pneumatic dispersion system (Benedetto et al., 2012). It has been reported that the maximum explosion pressure and the deflagration index significantly increase as the ignition delay decreases for both dust/air and dust/gas/air mixtures (Zhen and Leuckel, 1996; van der Wel et al., 1992).

In fact, variation of pressure and rate of pressure rise in a dust/air mixture explosion with ignition delay depend on dust concentration for a given experimental system. This can be observed the experimental data of this study. Although extensive efforts have been dedicated to determining explosion parameters of flammable dust (Dastidar and Amyotte, 2002; Ebadat and Prugh, 2007; Kwon et al., 2003; May and Berard, 1987; Yuan et al., 2012; Callé et al., 2005; Cashdollar, 2000; Sun et al., 2006; Amyotte et al., 1993; Zhang and Tan, 2013; Zhang et al., 2014), unfortunately, the effects of ignition delay on explosion behavior of corn dust/air mixtures at various concentrations is seldom concentrated on.

In the literature, there are significant differences between the reported experimental data about both ignition delay and pressure

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of dust dispersion used in dust explosion experiments. Pilao et al. (2006) used a 22.7 L chamber and the ignition delay of 0.4 s for dust explosion experiments. Cashdollar and Zlochower (2007) used a 20 L chamber and a 0.3 s blast of air at 8–9 bar pressure to disperse dust. An ignition delay of 0.06 s and a dust reservoir pressure of 20 bar were used for the Siwek 20 L chamber (Cashdollar, 2000). Cashdollar (2000) assumed that the 1 m^3 chamber might give more realistic measurements of minimum explosion concentrations, maximum explosion pressures, and the maximum rate of pressure rise. But it took much longer and needed quite larger dust samples in the 1 m^3 chamber than the 20 L chambers. Dufaud et al. (2009) carried out dust explosion tests using a 5 L apparatus. Various experimental results may be obtained at various initial experimental parameters and conditions. The physical mechanism needs to be researched.

Until now, only a limited number of experimental works have tried to study quantitatively the influence of initial conditions on the characteristics of a dust explosion in a closed vessel (Bozier and Veyssière, 2006). Few researchers have paid attention to the effects of ignition delay on explosion behavior of mixtures of corn dust and air.

Consequently, a measurement system, which consisted of a 5 L explosion chamber, a dust dispersion sub-system and a transient pressure measurement sub-system, was used as experimental apparatus. The influences of ignition delay on the explosion pressure and on the rate of pressure rise were analyzed and discussed on the basis of a serial experimental data obtained in this study. Moreover, the maximum pressure and the maximum rate of explosion pressure rise for corn dust/air mixtures at various concentrations were studied.

The initial flow of the tested dust in the vessel is induced by the pressure used to disperse dust. Therefore, investigating the pressure used to disperse dust is equivalent to investigating the initial flow velocity. The ignition delay time determines the degree of turbulence in the dust cloud at the moment of ignition (Mercer et al., 2001). The turbulence intensity at time of ignition can replace the ignition delay time (Pu et al., 2007). Surely the latter can replace the former also. The effects of the ignition delay and the pressure for dust dispersion cover that of the turbulent intensity (Tamanini, 1990; Eckhoff, 2009), and the effects of the ignition delay and the pressure for dust dispersion were emphasized in this study.

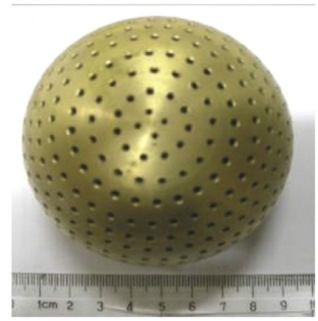

Fig. 2. Photograph of injection nozzle.

2. Experimental setup and procedures

The measurements were performed in a 5 L explosion chamber coupled with an electric ignition system and a data acquisition system, as shown in Fig. 1. The height *h* of the chamber was 160 mm and the inner diameter 2*R* was 199 mm. In the experimental chamber, ignition was achieved by means of an inductive-capacitive spark produced between stainless steel electrodes with rounded tips, separated by a spark gap of 4 mm. The ignition system consisted of an electric ignition rod and an electric spark generator. The electric energy produced by the spark generator was 28 J. The discharge capacitance and voltage for ignition were 14 μF and 2000 V respectively. A set of dust dispersion systems was mounted on the side of the experimental set-up. The dust dispersion system , which is presented in Fig. 2, was composed of a pressure chamber, a solenoid valve, a directional valve, a sample can, and a half spherical nozzle. The pressure chamber was linked to an air pump and the pressure used to disperse dust was 0.6 MPa. The duration for dust injection was 10 ms. The room temperature was 24 °C and the environmental humidity was 75%.

The molecular formula of the corn powder used in this study was $(C_6H_{10}O_5)_n$ and its molecular weight was162 g. The mean size of the corn powder particle used was about 10 μm. Scanning electron microscope (SEM) was performed for the corn powder samples , as shown in Fig. 3.

To form a dust/air mixture in the experimental chamber, the dust was dispersed into the chamber from a pressurized storage

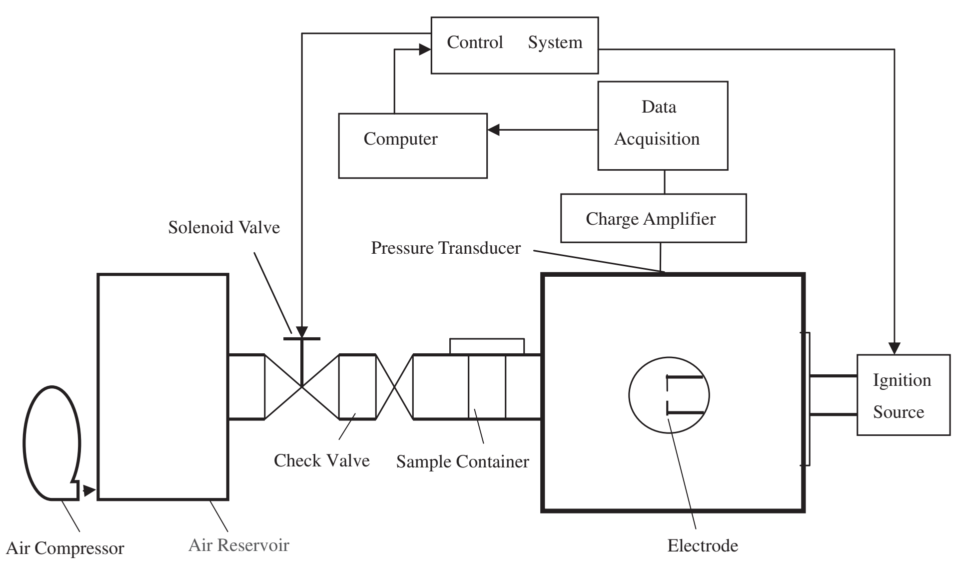

Fig. 1. Explosive experimental device.

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