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ScienceDirect
Journal of Loss Prevention in the Process Industries 20 (2007) 691–697
Journal of Loss Prevention in the process industries
www.elsevier.com/locate/jlp

Flame propagation in hybrid mixture of coal dust and methane

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Received 30 November 2006; received in revised form 30 April 2007; accepted 30 April 2007

Abstract

To investigate the flame propagation through hybrid mixture of coal dust and methane in a combustion chamber, a high-speed video camera with a microscopic lens and a Schlieren optical system were used to record the flame propagation process and to obtain the direct light emission photographs. Flame temperature was detected by a fine thermocouple. The suspended coal dust in the mixture of methane and air was ignited by an electric spark. The flame propagation speeds and maximum flame temperatures of the mixture were analyzed. The results show that the co-presence of coal dust and methane improves the flame propagation speed and maximum flame temperature notably, which become much higher than that of the single-coal dust flame. The flame front temperature varies with the coal dust concentration.

Keywords: Coal dust; Methane; Flame propagation; Dust explosions

1. Introduction

The hazards of coal dust or gas have been well recognized in the past decades. Many experimental and theoretical studies on a single-coal dust or gas explosion phenomenon have been performed against uncontrolled explosions in mining (Amyotte, Basu, & Khan, 2005; Amyotte et al., 2006; Cashdollar, 1996; Chawla, Amyotte, & Pegg, 1996; Dahoe, Zevenbergen, Lemkowitz, & Scarlett, 1996; Going, Chatrathi, & Cashdollar, 2000; Lunn, Holbrow, Andrews, & Gummer, 1996). Unfortunately, accidental coal mine accidents still cause a great loss of lives and damage to property every year in China. According to the data released by the state administration of work safety (SAWS, 2006), coal mine accidents resulted in 5938 fatalities in 2005. The accidents reveal that there are still some technical problems unsolved.

Most of previous studies focus on the characteristics of coal dust explosions or gas explosions, such as the maximum explosion pressure, maximum rate of pressure rise, explosion concentration limits and minimum ignition energy. Others concentrate on the design of new explosion protection equipments or methods (Chuyanov & Topilski, 2006; Dastidar, Amyotte, & Pegg, 1997; Dastidar, Amyotte, Going, & Chatrathi, 2001; Reddy, Amyotte, & Pegg, 1998). Amyotte, Mintz, Pegg, and Sun (1993) and Amyotte, Mintz, Pegg, Sun, and Wilkie (1991) also stated that the explosion parameters (maximum explosion pressure, P_{max}, and the maximum rate of pressure rise, $(dP/dt)_{max}$) of the hybrid mixture of coal dust and methane are found to increase, the effect of which is most significant at lower dust concentrations. However, their studies on the hybrid mixture of coal dust and methane are restricted in the stage of ignition and deflagration. The initial flame propagation in the mixture is rarely studied. Recently, some studies were conducted to investigate the fundamental aspect of flame propagation through suspended combustible particles, such as iron, aluminum and 1-octadecanol (Han et al., 2001; Ju, Dobashi, & Hirano, 1998; Proust & Veyssiere, 1988; Sun, Dobashi, & Hirano, 2001; Sun, Dobashi, & Hirano, 2003). Nevertheless, more detailed information about the mechanisms of flame propagation through the hybrid mixture of coal dust and methane, which is most important in understanding the

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0950-4230/$ - see front matter
doi:10.1016/j.jlp.2007.04.029

explosions of the combustible mixture in coal mine, assisting the modeling task and taking appropriate measures for preventing accidents, has not been sufficiently explored (Eckhoff, 2005).

In this study, flame propagation through the hybrid mixture of coal dust and methane in a small-scale chamber has been conducted. Some features related to the flame behaviors of the mixture are elucidated.

2. Experimental

2.1. Experimental apparatus

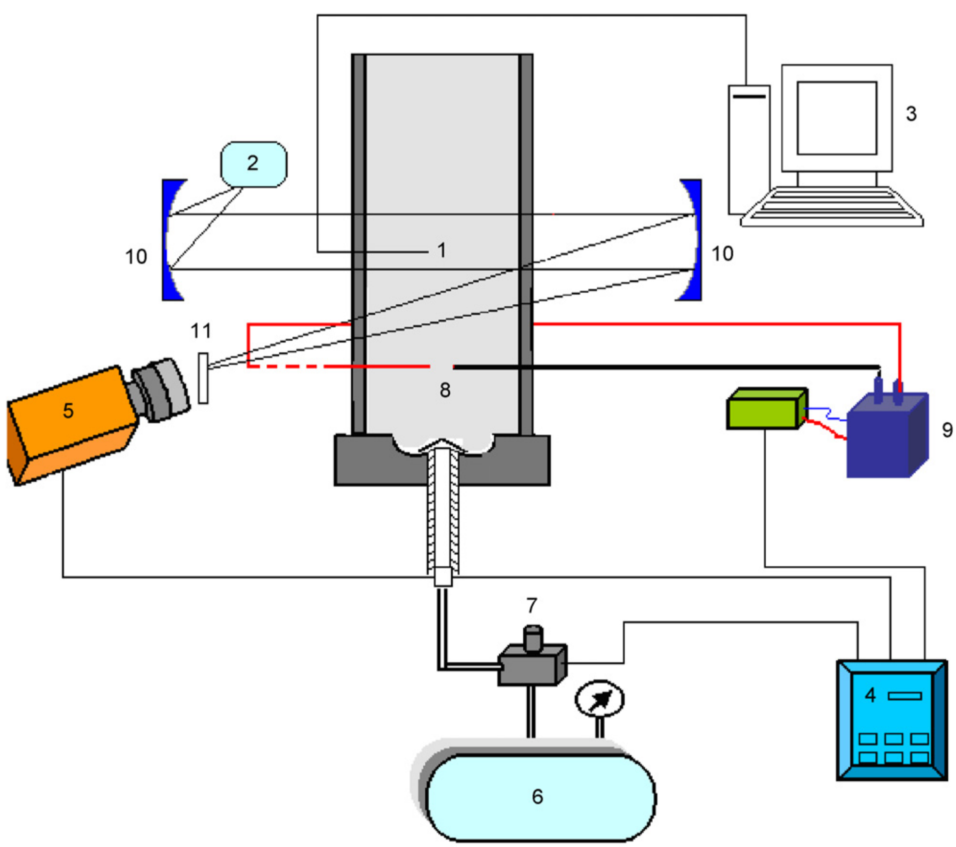
The experimental system is schematically shown in Fig. 1, which is composed of a gas supplying unit, a small-scale combustion chamber, a thermocouple, an ignition system, a data recorder, a high-speed video camera, a Schlieren optical part and a time controller. The vertical chamber is 500 mm high with square cross-section of 80 mm × 80 mm. To observe flame propagation process conveniently, two sides of it were made of Plexiglas and the others were made of stainless steel. The combustion chamber was also provided with a gas nozzle and a sample dish at the bottom.

The ignition system consists of a pair of tungsten wire electrodes with 0.4 mm diameter. The electrodes were positioned in the middle of the chamber, which locates 5 cm above the bottom of the chamber. The distance between the tips is approximately 5 mm. A high voltage transformer of 30 kV was used to produce an ignition spark.

The startup time of the high-speed video camera and the data recorder, the ignition time and on–off time of the electromagnetic valve were set and controlled by the time controller.

2.2. Experimental procedure and conditions

The experiments were carried out at atmospheric pressure with the upper end open and the lower end equipped with a gas and dust supplying part. Certain mass of coal dust weighed by a balance was put on the sample dish evenly. Then the coal dust was dispersed into the chamber with pressurized and premixed methane–air of a certain equivalence ratio. The coal dust concentration was



1. Thermocouple 2. Halogen lamp 3. Data recorder 4. Time controller

5. High speed video camera 6. Gas tank 7. Electromagnetic valve 8. Spark electrodes

9. High voltage transformer 10. Concave mirror 11. Knife edge

Fig. 1. Experimental system.