Fuel 260 (2020) 116304

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Study on the explosion characteristics of methane–air with coal dust originating from low-temperature oxidation of coal

Dong Ma[a,b,c], Botao Qin[a,b,c,*], Yuan Gao[c], Jianan Jiang[c], Baochao Feng[c]

[a] Key Laboratory of Coal Methane and Fire Control, Ministry of Education, China University of Mining and Technology, Xuzhou 221116, China
[b] State Key Laboratory of Coal Resources and Mine Safety, China University of Mining and Technology, Xuzhou, Jiangsu 221008, China
[c] School of Safety Engineering, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China

ARTICLE INFO

Keywords:
Low-temperature oxidation
Methane explosion
Coal dust
Flame propagation

ABSTRACT

The aim of this research was to reveal the explosion characteristics of methane-air with the admixtures of low-temperature oxidized coal dust. For this purpose, the particles (48–75 μm) of raw and oxidized coal dust with oxidation temperature of 80 °C, 160 °C and 240 °C were sampled. The industrial analysis and surface morphology of coal dust after low-temperature oxidation were comparatively investigated. In addition, the explosion parameters and flame propagation behaviors of methane-air/coal dust mixtures were monitored and analyzed by a 20 L spherical vessel reactor and a high speed camera, respectively. The results indicated that coal dust after low-temperature oxidation showed a significant decrease in the content of moisture and volatiles, and more cracks and pores were formed on their surface. The explosion experiments revealed that the coal dust after low-temperature oxidation of 240 °C had prolonged the combustion time of methane-air/coal dust mixtures by 81.69%, and increased the maximum overpressure from 0.67 MPa to 0.73 MPa as compared to the raw coal dust. The flame propagation behaviors of methane-air/coal dust mixtures showed that the coal dust after low-temperature oxidation displayed a lower flame propagation speed in the stage of gas phase combustion reaction, mainly due to the loss of volatile matter. This paper concluded that the reduction of volatile matter in the coal dust caused by the low-temperature oxidation inhibited the flame propagation of the methane-air/coal dust mixtures, but the cracks and pores formed during the low-temperature oxidation process promoted the combustion of coke in the coal dust.

1. Introduction

Methane and coal dust explosions are the major disasters in the world's coal mine production [1,2]. Such explosions often occur in tunnels and working faces of coal mines, usually starting with a methane explosion and entraining coal dust as the flame spread forward [3]. The addition of coal dust not only increases the violence of the explosion, but also releases a large amount of poison gas due to incomplete reaction of coal dust, resulting in more casualties and property losses [4,5]. Especially in recent years, the re-mining of residual coal remained after the first mining have received more attention [6,7]. According to the statistics, the resources of residual coal in China amount to 80.2 billion tons [8].However, the potential explosion hazard is existing because of that the coal seam undergoes a long-term process of oxidation and methane desorption, further form the explosive mixtures of methane and coal dust originating from low-temperature oxidation of coal [9].

For a long time, researches on the explosion of methane-air/coal dust mixtures mainly focused on the flammability, source of ignition, explosion characteristics parameters and flame propagation behaviors [10,11]. Cashdolla [12] conducted the ignition experiments of the methane-air/coal dust mixtures through a 20-L explosibility test chamber. The results showed that the increase in m ethane concentration and the volatiles in coal dust can reduce the lower limit of flammable concentration of coal dust. Amyotte et al. [13] investigated the ignitability of methane-air/coal dust mixtures using a 26 L explosion chamber. They found that the lower flammability limit of coal dust decreased with the admixtures of methane concentration, and besides, the volatile matter and particle size also showed a significant influence on the lower flammability limit. The similar research work can be seen from literature [14–16]. The study of explosion parameters was also very important to the understandings of the methane-air/coal dust explosion characteristics. Li et al. [17] undertook an experimental study on the explosion overpressures and deflagration index of methane-air/

* Corresponding author.
E-mail address: qbt2003@163.com (B. Qin).

https://doi.org/10.1016/j.fuel.2019.116304
Received 26 April 2019; Received in revised form 11 August 2019; Accepted 26 September 2019

coal dust mixtures. The results indicated that with the addition of methane in the mixture, both the explosion overpressure and deflagration index increased significantly. Typically, Ajrash et al. [18] experimentally and theoretically studied the evolution of explosion overpressure for the hybrid methane and coal dust mixtures using a 20 L explosion chamber. They found that the presence of 10 g/m^3 coal dust resulted in a significantly increase of overpressure for the 5% methane. Subsequently, Ajrash et al. [19] investigate the effect of diluted coal dust on the explosion characteristics of methane-air by a large scale detonation tube. The result showed that the addition of coal dust to the methane mixture lead to a conspicuous influence on stagnation pressure and pressure distribution.

The flame propagation behaviors can reveal the combustion process and internal mechanism of the explosion [20]. By a self-designed experiment platform, Rockwell and Rangwala [3] investigated the flame velocity of coal dust particles (75–90 μm and 106–120 μm) in a premixed methane–air flame. It was found that due to the entrained of coal dust, the turbulent propagation velocity of methane–air flames increased obviously. Bai et al. [21] studied the flame structure of methane-air/coal dust mixtures in a large-scale system of 10 m^3 with the high speed camera. Their results showed that the flame structure of the methane/coal/air mixture can be divided into three concentric regions from the outside: a red region, a yellow region, and a bright white illumination region. Similarly, Chen et al. [22] analyzed the combustion characteristics and flame structure of the methane/coal mixed by a high speed camera and photodiode, which emphasized that as the flame propagated forward, the intensity of the yellow light and the illuminating zone increased.

The physicochemical properties of coal dust played an important role in the explosion characteristics and the flame propagation behaviors of methane-air/coal dust mixtures. Previous research mainly focused on the influence of the coal dust concentration, chemical composition and particles size on methane-air/coal dust mixtures explosion [23]. However, the low-temperature oxidation was another factor leading to the changes of physical structure and chemical composition of coal dust, which may affect the explosions it participated [24,25]. Chen et al. [26] investigated the change of surface properties of low rank coal in oxidation process. The results showed after low-temperature oxidation, there were more pores and cracks appeared on the coal surface and the contact angle of coals showed a significant decrease. Uchida et al. [27] studied the effect of low-temperature oxidation on structure of coke making coal by using a stainless steel closed container at 80°C for 24 h. It was found that the low-temperature oxidation of coal lead to a reduction of aliphatic side chains and an increase in hydroxyl groups. Those studies showed that the low-temperature oxidation process would change the properties of coal, but the influence of its involvement on the explosions was still unclear.

The literature review had shown an absence of research work in the influence of low-temperature oxidation on the explosion of methane-air/coal dust mixtures. In this paper, the coal dust with different degrees of low-temperature oxidation was obtained by a self-designed oxidation system. Then the changes of industrial parameters and surface morphology of coal dust after low-temperature oxidation were analyzed. Finally the explosion characteristics and flame propagation behaviors of methane-air/coal dust mixtures were investigated based on a standard 20L spherical vessel reactor and a high speed camera, respectively. This study was of great significance to provide guidance for the prevention and control of methane and dust explosions in underground coal mines.

2. Experiment

2.1. Experimental equipment

2.1.1. Self-designed system for low-temperature oxidation of coal

The self-designed system for low-temperature oxidation of coal was shown in Fig. 1, which consisted of a coal autoxidation vessel, preheating tubes, a temperature logger and a programed temperature enclosure. This system can increase the temperature within a range of 30–500 °C (minimum temperature rise rate of 0.1 °C/min). In addition, the system was also equipped with a LCD to display the temperature of the sample in real time.

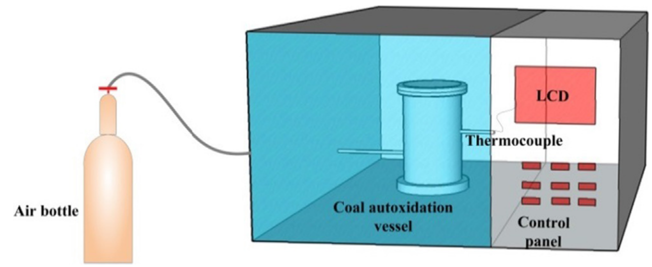

Fig. 1. Self-designed system for low-temperature oxidation of coal.

2.1.2. Industrial analysis

Proximate analysis of coals was performed by a 5E-MAG6600B industrial analyzer, which consisted multi-furnace double balance structures. The test accuracy was in line with the requirements of GB/T212-2008 standard (the Chinese standard) and ASTM D5142-2009 standard.

2.1.3. Surface morphology analysis

The surface morphology of coal dusts was analyzed by employing a Quanta 250 scanning electron microscope (SEM). First, about 3 mm of coal particles were selected and dried at about 70° C for 5 h. Then, all coal samples are coated with gold to increase the conductivity of the coal. Finally, the SEM test was performed in a high vacuum mode.

2.1.4. Explosion parameters analysis

The explosion characteristics of methane–air/coal dust mixtures were operated by a HY16426B explosion test device as illustrated in Fig. 2, consisted of a standard 20L spherical vessel reactor, a gas mixing system, an ignition system, and a data acquisition system. A 40 mm diameter observation window was placed in the center of the 20L spherical vessel reactor to observe the spread of the explosion flame. The ignition electrodes were located in the center of the spherical vessel reactor controlled automatically by the computer, and the ignition energy was ca. 1 J with a 60 ms time delay. During the explosion experiment, the evolution of the explosion pressure was measured by a pressure sensor mounted in the wall of the vessel and recorded by the data acquisition system, and the maximum explosion pressure (P_m) and maximum rate of pressure rise $(dP/dt)_m$ were obtained.

2.1.5. Explosion flame analysis

In order to study the propagation of the explosion flame of methane-air/coal dust mixtures, a Phantom V211High Speed Camera had been applied in front of the observe window of 20L spherical vessel reactor. The camera had a maximum shooting rate of 300,000 frames per second and a minimum exposure time of 2 us, enabling recording of the explosion flame propagation process accurately.

2.2. Preparation of coals

Lignite coal collected from Ermuwan Coal mine, Datong City of Shanxi Province in China was sealed as experimental coal samples. According to the ASTM D2013-72 standards, the coal sample was stored in an oxygen-free vacuum box after stripping the oxidation layer. Next, the sizes of coal particles in the range of 48 ~ 75 μm were milled and dried at 40 °C for 48 h to remove the moisture of coal sample.

In order to obtain the coal dusts with different low-temperature oxidation temperatures, 50 g (± 0.01 g) of dried coal sample was