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Experimental and simulation studies on the influence of carbon monoxide on explosion characteristics of methane

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ABSTRACT

In underground coal mining, methane explosions often can cause tremendous disasters. In the meantime, carbon monoxide (CO), generated during the process of coal oxidation, may appear in the air. Therefore, the explosion characteristics of the mixture of CH_4 and CO must be investigated to prevent gas explosion accidents in coal mines. We conducted experiments by using a 20-L nearly spherical gas explosion testing device. The software FLACS was used to simulate the explosion of the mixture of CH_4 and CO at various mixing concentrations, and the simulation results corresponded to experimental results. With the increase of CO concentration, both upper and lower explosive limits of CH_4 decreased. On the whole, the explosion characteristic parameters of CH_4 and the mixture are similar. When CH_4 concentration was below the stoichiometric concentration, the addition of CO could promote the intensity of gas explosion; oppositely, excessive CO would inhibit the gas explosion reaction. The inhibitory effects become more significant as the concentration of CH_4 increases.

1. Introduction

In China, gas explosions are always the greatest threat in underground coal mines because of complicated geological conditions and other objective factors. In recent years, gas explosions have occurred frequently and brought great casualties and economic losses. In underground coal mines, methane is the primary explosive gas. Other gases, such as carbon monoxide (CO), ethane, or hydrogen, produced from the spontaneous combustion of coal, can also affect the explosion characteristics of methane (Li and Si, 2010; Peng et al., 2011; Wang et al., 2011; Huang et al., 2012). Previous studies mainly focused more on the explosion characteristics of methane-air than the multiple combustible gases existing in coal mines. Hu et al. (2002) studied the explosive limits of a mixture of H_2, CH_4 and CO as well as the influence of the container. Experimental results showed that their explosive limits were affected by various factors. Chen and Zhang (2009) experimentally studied the explosive limits and the critical oxygen concentration of multiple combustible gases. Li et al. (2008, 2012) conducted experiments on explosion characteristics of the mixture of CH_4, H_2, coal dust, and air. Yetter et al. (1991), Bougrine et al. (2011), Di Sarli et al. (2012), Di Sarli and Di Benedetto (2013) and Salzano et al. (2012) studied the explosion characteristics of CH_4–H_2 in air under different conditions. Di Sarli et al. (2014) studied the explosion behavior of mixtures with composition representative of wood chip-derived syngas ($CO/H_2/CH_4/CO_2/N_2$ mixtures). The above researches show that the behavior of a fuel blend is strongly non-linear and, as such, it cannot be extrapolated from the behavior of the pure components.

CO in coal mines is generated from the oxidation of coal. The content of CO increases exponentially as the temperature of coal rises. The existence of CO may increase the risk and consequence of gas explosion, which necessitates understanding the effect of CO on the methane-air explosion (Jia et al., 2013). In this paper, experiments and simulation were utilized to study the interaction of CO and CH_4 in terms of explosion characteristics.

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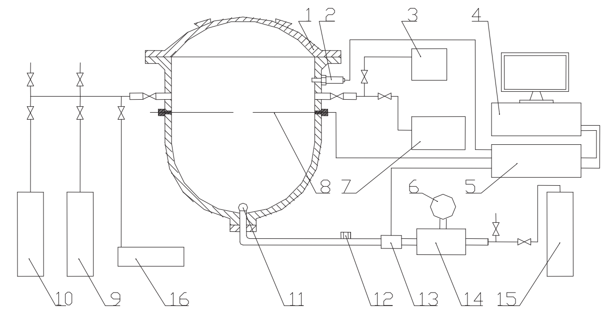

1-explosion reactor; 2- pressure sensor; 3-digital pressure gauge; 4-computer; 5-controller; 6-pressure gauge; 7-vacuum pump; 8-ignition source; 9-methane cylinder; l0-carbon monoxide compressor; 11- powder injector; 12-powder cylinder; 13-solenoid valve; 14-high pressure air tank; 15-compressed air cylinder; 16-digital pressure gauge

Fig. 1. Schematic of the experimental system.

2. Experimental and methods

2.1. Experimental system

The experimental system, illustrated in Fig. 1, consists of explosion reactor, gas mixing system, ignition system, and measurement system.

(1) Explosion reactor: It is a 20-L nearly spherical tank with internal diameter and height 30 and 35 cm, respectively; there are inlet and outlet pipes, sensors, ignition electrode, powder nozzle, and some mounting interfaces in this instrument. The maximum pressure capacity is 2 MPa.
(2) Gas mixing system: The structure includes vacuum pump, air compressor, precise digital pressure gauge (range: 0–101.3 kPa; precision: 0.01 kPa), methane cylinder, and carbon monoxide cylinder. The compound gas is mixed based on partial pressure law.
(3) Ignition system: The ignition source is a chemical propellant located in the center of the explosion reactor. The ignition is controlled automatically by the computer, and the ignition energy is ca. 1 J.
(4) Measurement system: It mainly consists of pressure sensor, controller, and computer. The data can be collected simultaneously when the system is ignited. The response time and the maximum collecting time are 1 and 500 ms, respectively.

2.2. Testing conditions and operating process

The ambient temperature and humidity were 17–27 °C and 50–90%, respectively. The pressure before explosion was standard atmospheric. The test was carried out in the airtight and volume-constant tank. The occurrence of explosion can be considered when the pressure increases beyond 7% following the definition of ASTM (American Society for Testing and Materials).

3. Experimental results and analysis

3.1. Influence of CO on CH_4 explosive limits

According to the experimental results, the explosive limit of CH_4 was 5.35 and 17.35% by nearly spherical tank test. According to the number of oxygen atoms required for complete CH_4 combustion, the explosive limit was estimated to be from 6.52 to 17.42%. The limit should range from 5.20 to 14.70% according to the stoichiometric concentration method (Wang and Bi, 2000; Parra et al., 2004; Xu and Xu, 2005; Zhang et al., 2011; Liu et al., 2013). To be on the safe side, an explosive limit of 5.2–17.42% was used as the theoretical range of CH_4 explosive limit.

The explosive limits of the mixtures of CO/CH_4 with various concentrations were tested, and the results are shown in Fig. 2. We observed that when the CO concentration increased, the lower explosive limit of mixture decreased, and the lower explosive limit decreased 0.5% with increase of 1% CO concentration. Similarly, when CO concentration increased 0.5%, the upper explosive limit of the mixture went down 0.5–1%.

In summary, with increasing CO concentration, both the upper and the lower explosive limits decreased. When the CO concentration was increased from 0 to 3.0%, the upper limit was decreased by nearly 2.5%, while the lower limit dropped by about 1.5%. Therefore, the addition of CO increased the explosibility of low-concentration methane.

3.2. Explosion characteristics of the CH_4/CO mixture

Five groups of gas mixtures with CO concentrations of 0.0, 0.5, 1, 2, and 3%, respectively, were used for the explosion tests. Explosion

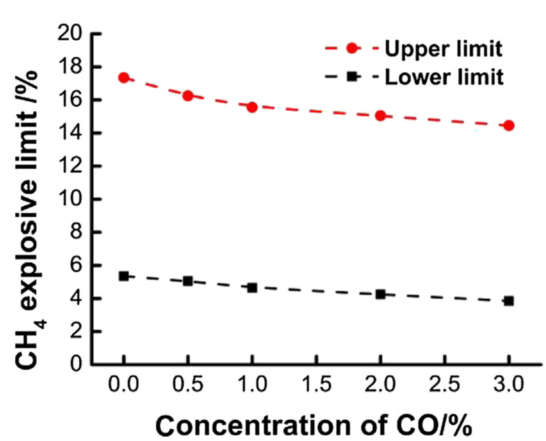

Fig. 2. The influence of CO on the CH_4 explosive limit.