Fuel 113 (2013) 448–453

Contents lists available at SciVerse ScienceDirect

Fuel

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

Influence of coal dust on the ignition of methane/air mixtures by friction sparks from rubbing of titanium against steel

Li Gang *, Shang Rong-xue, Yu Yun-jiang, Wang Jia-zheng, Yuan Chun-miao

Fire & Explosion Protection Laboratory, Northeastern University, Shenyang 110004, China

HIGHLIGHTS

- Tested the ignition process of methane/air by rotating friction.
- Investigated the influence of coal dust on the ignition process.
- Adding coal dust does not make the methane/air mixture more incentive by friction.

ARTICLE INFO

Article history:
Received 25 March 2013
Received in revised form 24 May 2013
Accepted 25 May 2013
Available online 12 June 2013

Keywords:
Methane
Coal dust
Rotating friction spark
Ignition delay

ABSTRACT

Based on the Chinese national standard GB13813, a rotating friction test device was set up for investigating the influence of coal dust on the ignition of methane/air mixtures by friction sparks from rubbing of titanium against steel. By using a high speed video camera and an infrared thermal imager, it was observed that it was the flying titanium particle sparks that ignited the methane/air mixtures during the process of rubbing a titanium rod against a rotating A3 steel disk, rather than the hot surface of the titanium rod. A set of experiments, using three different particle size fractions of lignite, bituminous coal and anthracite, were conducted to test the influence of coal dust on the process of ignition of methane/air mixture by titanium friction sparks. It was found that the ignition delay time generally increased when introducing coal dust. Furthermore, the smaller the coal particle size the longer the ignition delay time. A possible reason could be that smaller coal particles absorb a greater fraction of the energy of the titanium sparks, which reduces the ability of the sparks to ignite the methane/air mixture. The shortest ignition delay times were observed with bituminous coal and the longest with lignite, with the anthracite in between. This is in accordance with the increasing water content of the coals in the same order, but not with the variation of the contents of volatiles and sulfur. Presumably the emission of volatile and sulfur compounds is not as important as the heat loss by water evaporation.

1. Introduction

Mechanical friction and impacting sparks were usually regarded as one of the potential ignitions of fire and explosion accidents in coal mine as discussed in [1–4]. Many researchers have studied this kind of ignition process both experimentally and theoretically. Pairs of friction partners, such as metal against metal, metal against rock, and rock against rock, were widely studied in previous research. Blickensderfer [3] investigated friction of metal against rock and concluded that only 1% of the friction energy was consumed by shaving off small particles from the bulk surfaces. Practically all the energy was transformed to heat at the friction spot, and it was just the hot metal deposited on the grinding disk that ignited the combustible gas mixture. Qu et al. [4], investigating friction-heat-ignition with rock against rock, found that the quartz content in the rock affected the ignition ability of the sparks greatly. Mud rock against mud rock could not ignite firedamp at any rotating speed. In general, it was difficult to ignite firedamp by hot surfaces and/or sparks from friction between any rocks if they were wetted by water. Card et al. [5] conducted experimental studies of the ignition of methane/air using rock friction sparks. They pointed out that the most easily ignited concentration of methane was 7 vol.%, and that only friction between rocks having a significant content of quartz could ignite methane/air mixtures. Proust et al. [6], when analyzing the mechanical friction/impact process, concluded that heat conduction was the main way of heat transmission and that hot spots were the most likely ignition source.

For the ignition of firedamp by continuous friction between two solid bodies, the references mentioned above mostly focus on the methane/air mixture only, without considering the effect of coal dust, which can also be present in practical situations. Coal dust exists everywhere in a coal mine, either deposited on surfaces or

* Corresponding author. Tel.: +86 024 83681830; fax: +86 024 83688327.
E-mail address: ligang@mail.neu.edu.cn (G. Li).

0016-2361/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2013.05.082

suspended in the air. It is well-known that the glowing temperature (the smolder temperature, the minimum ignition temperature of a dust layer of thickness 5 mm on a hot surface) of coal is 200–500 °C, which is much lower than that of methane/air mixture 640 °C [7]. It means coal dusts are more ignition susceptive to hot surfaces than premixed methane/air. Possibly, the coal particles are first ignited by the friction sources (hot surfaces or hot particles) at a relatively low temperature, and then the ignited coal dust may ignite the combustible gas mixture. This implies that the results without considering coal dust may underestimate the ignition risk from mechanical friction. Very few references, such as Wu et al. [8] and Li et al. [9] have reported this possibility when introducing coal dust.

In order to understand the ignition features of methane with coal dust involved, a set of experiment have been carried out and the results are analyzed accordingly.

2. Materials, apparatus and experimental procedures

2.1. Test materials

2.1.1. The coal dusts used

Dusts of three different coal qualities, viz. lignite, bituminous coal and anthracite, were used in the experiments. For each of the coal qualities three different particle size fractions were prepared, viz. a coarse size fraction, a medium size fraction and a fine size fraction. The three size fractions were prepared by dry sieving of the material obtained from the mill. The diameter distributions of sample are shown in Table 1.

Table 1
Diameter distributions of samples (*D*).

Samples	Coarse	Medium	Fine
Diameter (μm)	$140 < D < 270$	$74 < D < 140$	$D < 74$

Table 2
Industrial and elemental analysis of samples.

Samples (after drying at 40 °C)	Water (%)	Ash (%)	Volatile (%)	Sulfur content (%)
Lignite	17.63	6.99	47.56	0.44
Bituminous coal	2.4	10.11	39.97	1.31
Anthracite	5.84	10.53	8.63	0.053

All the coal dust samples were dried in an oven at 40 °C for 2 h. Then the dry samples were packaged as the experimental sample after cooling to the environmental temperature. The results from the analysis of the dried samples are indicated in Table 2.

2.1.2. The friction pair materials used

A titanium rod forced against a rotating disk made of construction A3 steel was used for generating the ignition source in all the experiments. The purity of the titanium was >96%. The diameter of the rod was 10 mm. The diameter of the rotating steel disc was 75 mm.

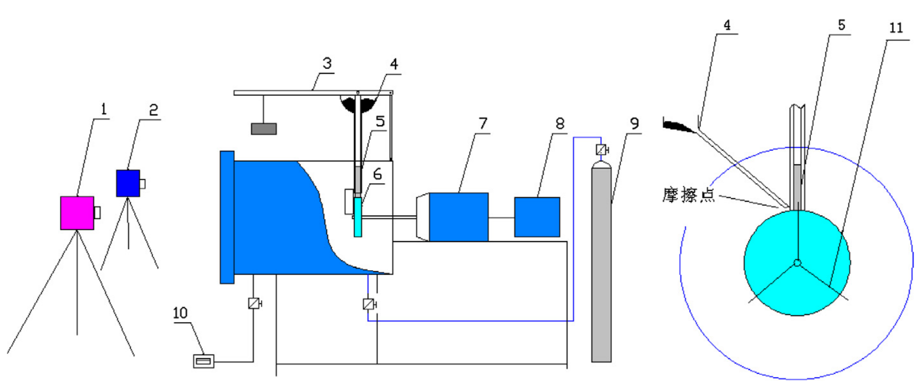
2.2. Apparatus and experimental procedures

2.2.1. Design and construction of the experimental apparatus

The design and construction of the experimental apparatus is based on China's National Standard GB 13813 [10]. The apparatus is shown in Fig. 1. It is composed of an explosion vessel, a rotating-disk system for producing the ignition source, and monitoring system. The friction disk (6) is driven by a motor (7), which is controlled by a frequency controller (DR1D5G-3) (8). The friction sparks/hot surfaces are produced by forcing the titanium rod (5) against the friction disk by means of the lever-and-counterweight system (3). The power of the ignition source (strength and frequency of friction sparks/temperatures of hot surfaces can be varied by regulating the force between the rod and the disk by varying the counterweight.

2.2.2. Experimental procedures

Pure methane is injected into the explosion vessel (a cylinder of diameter 325 mm and length 350 mm) continuously from the gas cylinder (9) and its concentration at the exit is monitored online by a methane tester (10) till the methane concentration there attains the desired value. Coal dust is poured onto the contact point between the rotating disk and the titanium rod by dust pouring system (4). The vane (11) is set in front of the friction disk in order to get the dust suspended into a cloud by the rotating friction disk. The number and intensity of the friction sparks prior to ignition and also whether ignition occurs or not, are recorded by an infrared thermal imager (1) (type IIR8800) and a high-speed video camera (2) (type MotionProY3). The outer side of the explosion vessel is sealed by transparent plastic film for facilitating visual observation during the experiments.



1-infrared thermal imager 2-high-speed video camera 3-lever 4-dust filler 5-titanium rod
6-friction disk 7-motor 8-frequency governor 9-gas cylinder 10-methane tester 11-vane

Fig. 1. Experimental apparatus.