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Coal dust/air explosions in a large-scale tube

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ABSTRACT

Coal dust/air mixture explosions under weak ignition conditions have been studied in a horizontal experimental tube of diameter 199 mm and length 29.6 m. The experimental tube is closed at one end and open at the downstream end. An array of 40 equally spaced dust dispersion units was used to disperse coal dust particles into the experimental tube. The coal dust/air mixture was ignited by an electric spark. A constant-temperature hot-wire anemometer was used to measure the gas velocity during the dispersion process. Kistler piezoelectric pressure sensors were used to measure the propagation of the pressure wave during the explosion process. The maximum overpressure of the coal dust explosion under the weak ignition conditions in the tube was 70 kPa and the propagation velocity of the pressure wave along the tube was approximately 370 m/s. The minimum concentration for obtaining a coal dust explosion that propagated along the tube was 120 g/m^3. The suppressing effects on the coal dust explosion of two different kinds of suppressing agents have been studied.

1. Introduction

The hazards that coal dust presents in underground coal mining were not fully accepted until the turn of the last century, when mine-scale experiments in England, France, and the USA established that coal dust explosion was possible in the absence of methane [1]. Despite the efforts of state bodies and private companies to find means of preventing these accidents, coal dust explosion continues to represent a constant threat in the coal mining industry. A lack of methods for predicting the structures of real dust clouds and flame propagation has been a major obstacle to predicting the courses and consequences of dust explosions in practice. Full-scale coal dust explosion tests have been performed in USA [2] and mine-scale grain dust explosions have been conducted in Poland [3] to investigate the characteristics of dust explosions in the mining and other process industries.

Full-scale mine tests are expensive and time-consuming. As a result, researchers have attempted to develop laboratory-scale tests that can reliably reproduce the results from full-scale tests, thereby saving labor and capital.

Knowledge of the propagation characteristics of flames in turbulent dust/air mixtures is essential when applying comprehensive numerical models for dust explosion propagation. Understanding flame acceleration due to flame distortion and turbulence produced by the explosion itself is central for understanding both dust and gas explosions in practice. Extensive experimental research programs have been conducted to resolve the basic flame acceleration mechanism in gas explosions in obstructed geometries [4–6]. In order to evaluate the explosion violence in ducts of different dust/air mixtures, Bartknecht [7] proposed use of the coefficient *K*st as a parameter representing the reactivity of the mixture. Nevertheless, experiments performed with two different dust samples having the same *K*st coefficient, under exactly the same experimental conditions, indicated that very different levels of explosion violence could be obtained [8]. From the viewpoint of flame propagation, an industrial installation may be represented by "vessels" ($L/D < 3.5$) and "pipes" ($L/D > 5$). Many experimental studies on dust and gas explosions have been performed in relation to uncontrolled explosion in mining by using a 1.2 L Hartman tube, a 20 L Siwek chamber [9,10], a 1.25 m^3 explosion chamber [11], ducts [12–15], ducts connected to a vessel in which the explosion was initiated [16–18], etc.

Coal dust/air explosion experiments by Bartknecht [12,13] were performed in two experimental tubes with different diameters and lengths. The dust cloud was generated along the whole experimental tube by injecting dust from a number of equally spaced external pressurized reservoirs. The coal dust/air mixture was ignited by a pocket of exploding methane/air mixture. The maximum flame speed of the explosion in the 2.5 m diameter and 130 m long tube at the dust concentrations of 250 g/m^3 and 500 g/m^3 were 500 and 700 m/s, respectively. Wolanski, Kauffman and coworkers [14,15] performed dust explosion research by using a vertical experimental tube. The dust cloud was formed by charging dust samples at the top of the vertical experimental tube at a mass rate giving

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the desired dust concentration during the gravity setting down the tube. The dust explosion was initiated by hydrogen/oxygen explosion. Grain dust/air explosions and coal dust/air explosions by Pineau and Ronchail [16,17] were conducted in a duct connected to a vessel in which the explosion was initiated. In their experiments, dust was layered initially at the bottom of the duct and it was dispersed and ignited by the powerful explosion. In the experiments by Gardner et al. [18], the dust/air mixtures were formed by blowing air and coal dust through the experimental tube connected to an ignition chamber from just the upstream of the ignition chamber. The dust explosion was initiated by a flame jet or chemical ignitor.

In the present work, experiments on coal dust explosion and its suppression have been conducted in a large-scale horizontal tube with an inner diameter of 199 mm and a length of 29.6 m. To form dust clouds in the experimental tube, samples of coal dust and suppressing agent particles were dispersed into the tube by means of in-house-constructed dispersion systems. Combustion of the coal dust/air mixtures was initiated by an electric spark. The objectives of the research were to investigate the propagation characteristics of coal dust explosion under weak ignition condition and the means to suppress the coal dust explosion using the 199-mm-diameter and 29.6-m-long tube. The study aimed at to investigate the propagation and suppression mechanism of coal dust explosion. The influences of coal dust and suppressing agent dust cloud parameters (particle diameter, dust concentration) on the propagation characteristics of the explosion waves have been investigated. The effective means to prevent coal dust explosion are appreciated in the study.

2. Experimental

2.1. Experimental set-up

The experimental set-up is shown schematically in Fig. 1. It consists of an experimental tube, an electric ignition system, a control unit, a data acquisition system, a venting system, a vacuum pump, an air pump, and a 10 m^3 dumping tank, which is shared by three different experimental tubes. The experimental tube is composed of an experimental section, 40 sets of dust/liquid dispersion systems, and a connecting section. The dispersion systems are mounted horizontally on both sides of the experimental section, regularly spaced at intervals of 0.7 m in the axial direction of the tube. The electric ignition system consists of an electric ignition rod and an electric spark generator. The pressure measurement system comprises 16 Kistler pressure gauges mounted on the wall of the experimental tube. A plastic film is placed between the experimental tube and the dumping tank to facilitate the establishment of vacuum conditions in the experimental tube and to prevent the cloud of dispersed coal dust from escaping the experimental tube before passage of the explosion wave. The experimental section is a 199 mm diameter tube with a length of 28 m. It is closed at the ignition end and open at the downstream end. And it is divided equally into four parts so that each part is 7 m long. The ignition system consists of an electric ignition rod and a capacitor discharge apparatus. The electric ignition rod which is mounted at the closed end of the tube is made of two stainless steel electrodes, one of which is a cylinder while the other is a tube. The two electrodes are coaxially mounted with a clearance of 2 mm and a ceramic tube between them is used as an isolator. The electric energy produced by the spark generator is 40 J. Each dust dispersion unit consists of a pressure chamber, a solenoid valve, a directional valve, a sample can, and a spherical nozzle. The pressure chamber is linked to an air pump and the pressure used to disperse the coal or suppressing agent particles is 800 kPa. The dispersion of the dust in the sample cans is controlled by solenoid valves, which are commanded by the control unit. To produce a uniformly dispersed dust cloud in the tube, 164 holes of diameter from 1.2 to 1.8 mm are drilled through each spherical nozzle. The dispersion of the coal/suppressing agent dust, the ignition of coal dust/air mixture, and the triggering of the data acquisition system are all controlled by the control unit. To study the propagation of the coal dust/air mixture explosion, 16 pressure gauges are arranged on the tube wall along the axial direction. The connecting section is 1.6 m long and has the same inner diameter as the experimental section. It consists of an optical visualization part and a wave structure test part. Pressure data are recorded by a data acquisition system with a sampling frequency of 1 MHz.

2.2. Coal dust samples

The coal samples used for the study were Qitaihe soft mine, Shenhua soft mine, and Zhungeer soft mine, with volatile contents of 36%, 32%, and 26%, respectively. In the laboratory, the coal samples were ground and sieved to produce coal dusts with different size distributions. Coal dusts with two different size distributions were used in the experimental studies. One was a fine coal dust sample with particle diameters in the range 45–75 μm. The other was sieved through a 105 μm screen but then retained on a 75 μm screen in order to obtain a coarse sample. To eliminate moisture and prevent the loss of volatiles and surface oxidation, the coal dust was kept in airtight driers. 0.5–1% very fine (16 nm diameter) SiO_2 (Acrosil) fluidizing agent was added to the samples to increase the dispersibility of the coal dust by decreasing its surface binding energy. Thus, uniformly dispersed coal dust clouds could be formed in the experimental tube, which could be ignited by an electric spark with an ignition energy of 40 J.

2.3. Experimental procedure and conditions

Before each test, coal dust or suppressing agent samples were weighed by means of an electric balance according to the required

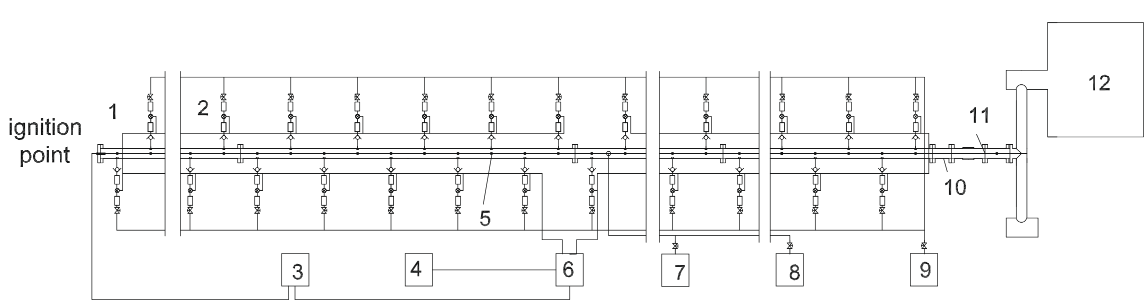

Fig. 1. Schematic diagram of the experimental set-up. (1) experimental tube, (2) dispersion system, (3) ignition system, (4) data acquisition system, (5) pressure sensor, (6) control unit, (7) vacuum pump, (8) venting system, (9) air pump, (10) connecting section, (11) plastic film, and (12) dumping tank.