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Study on suppression of the coal dust/methane/air mixture explosion in experimental tube by water mist

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Abstract

In order to develop highly effective and reliable measures to suppress the coal dust/methane/air mixture explosion frequently occurred in coal mine, the effect of the presence of methane on the coal dust explosion was investigated in this study. The flame propagation velocity and the explosion temperature were measured for explosion tests with the different methane concentration in the mixture. The flame evolution histories were also captured by high speed camera. The inhibiting efficiency of water mist was qualitatively studied and analyzed by explaining mechanism of gas and goal dust explosion. The results showed that water mist can efficiently decline the flame propagation velocity, reduce flame temperature, and change flame characteristics of gas and coal dust explosion. It can be concluded that water mist can effectively inhibit gas and coal dust explosion.

Keywords: water mist; gas; coal dust; explosion

1. Introduction

Coal seam methane by gas drainage was generally transported through pipeline. The coal dust carried by the mine gas may be accumulated and deposited in the gas transportation pipeline. Once the coal seam methane in the tube is ignited, the gas and coal dust explosion (or the coal dust/methane/air mixture explosion) may be occurred and formed a serious disaster. The experimental study on the methane and

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coal dust explosion in the spherical vessel by Amyotte [1-2] showed that the upper explosion limit of the coal dust was decreased in the presence of the vol. 2% methane. Hence, the coal dust deposited beneath the gas pipeline will increase its explosibility. Moreover, the blast wave generated by the mine gas explosion in the transportation pipeline will roll up the deposited coal dust, thus leading to a coal dust cloud. The high temperature of the blast wave will heat up the cloud and result in a larger scale explosion. Therefore, the gas and coal dust explosion presents a serious threat to the gas transportation pipeline. The safe transportation system is needed for the exploitation and utilization of the mine gas.

The water mist as a novel fire extinguishing technology has attracted more and more interests. Recently, the water mist was also employed to suppress the gas explosion [4]. Yao carried out experiments on diffusion flame by water mist [5]. Lu et al investigated the suppression mechanism of water mist on gas explosion [6]. However, the study on the gas and coal dust suppression by water mist, especially occurred in the gas drainage transportation pipeline, was rare. The aim of this work is to check the effectiveness of water mist to suppress the gas and coal dust explosion in the gas transportation pipeline.

2. Experimental set up and procedure

2.1. Experimental set up

The gas and coal dust explosion suppression was carried out on the lab-scale experimental facility, as shown in Figure 1. The facility consisted of the simulated gas transportation pipeline (i.e. an experimental tube), the water mist generation system, the ignition device, a venting system, the gas supply and the data acquisition system. The gas pipeline is 2000 mm long, 168mm i.d., and 221.5 cm² of cross-sectional area. The total volume of the gas pipeline is about 0.0443m³. It is closed at the ignition end and open at the downstream end. A pressure relief film is placed between the explosion zone and the water mist application zone to prevent the cloud of dispersed coal dust from escaping the experimental tube before passage of the explosion wave. Certain mass of coal dust was dispersed into the gas pipeline through the dust dispersion unit. The water mist nozzle was mounted along the axis line of the gas pipeline. The ignitor was placed at the closed end of the gas pipeline. Three K type thermocouples with the response time of 1 millisecond were arranged along the axis line of the gas pipeline. The gas explosion temperature was measured by K-type TC. The first TC was placed at 1400 mm away from the ignitor. The distance between TCs is about 205mm. An optical window was employed to visualize the gas and coal dust explosion process.

Fig.1 Schematic of the experimental system
2.2. Experimental procedure

Before each test, coal dust samples were weighed by means of an electric balance according to the required average concentrations in the tube (the dust concentration was evaluated from the volume of the tube and the mass of the dust sample dispersed into it). In this study, 0.4 gram of coal dust was deposited in the gas pipeline. Then, an air blower was employed to roll up the coal dust, thus leading to the suspended coal dust cloud. Methane was injected into the gas pipeline from the closed end. The methane concentration was measured by the gas detector. The gas and coal dust was formed in the gas pipeline by regulating the volume of the methane.

Prior to each explosion test, the temperature acquisition device and the high speed camera were started, followed by the application of the water mist. After a given delay time, the gas and coal dust was ignited by the ignitor with more than 375mJ ignition energy. After ignition, a combustion wave of coal dust/methane/air mixture accelerated and propagated from the ignition end to the open end of the tube. The temperature histories of the coal dust/methane/air mixture explosions were recorded by temperature sensors linked to the data acquisition system. After each explosion experiment, the water mist system was shut down and the exhaust fan in the venting system was started, then the experimental tube was filled with fresh air in preparation for the next experiment.

By calculation, the coal dust concentration is about 12 g/m³. The lower explosion limit of the coal dust at the presence of the gas can be written as following [7],

\[
D = D_0 e^{(V_a-1)G}
\]

Where \( D \) is the lower explosion limit of the coal dust at the presence of the gas (g/m³); \( D_0 \) is the lower explosion limit of the coal dust at the absence of the gas (g/m³); \( V_a \) is the volatile content of the coal (%); \( G \) is the volumetric concentration of the gas (%). In this work, \( D_0 = 12 \) g/m³, \( V_a = 39.59\% \). The test parameters were shown in Table 1. Three gas contents were employed in the present study. The corresponding lower explosion limits of the coal dust were 11.88 g/m³, 11.82 g/m³, 11.71 g/m³. In our explosion tests, the coal dust concentration of 12 g/m³ was always used.

| Case | Gas content | Coal Type | Coal dust concentration (g/m³) |
|------|-------------|-----------|-------------------------------|
| A    | 3%          | Youyu     | 12                            |
| B    | 4%          | Youyu     | 12                            |
| C    | 5%          | Youyu     | 12                            |

3.3 Result and discussion

3.1. Propagation characteristics of the gas and coal dust explosion

The propagation characteristics of the coal dust/methane/air mixture explosions were studied by using coal dust samples with different gas concentration. In the tests, 3%, 4%, 5% volumetric concentrations of methane were used. The temperature and the propagation velocity of coal dust/methane/air explosion were measured respectively by thermocouples and high speed camera. The flame characteristics were also visualized by the high speed camera.

Propagation velocity of the gas and coal dust explosion for different gas concentrations was shown in Figure 2. In the early stage (less than 60ms), the rise rate of propagation velocity of coal dust/methane/air mixture is relatively slow. The propagation velocity increased rapidly at the time of more than 60ms. The
effect of gas concentration (3%, 4% and 5%) on the temperature was studied, as shown in Figure 3. Temperature of all TCs reached their maximum value by the time of 80ms, followed by a gradual decrease. In addition, the gas concentration has a positive influence on the coal dust explosion, as illustrated by Figure 3. For example, the maximum temperatures for gas concentration of 3%, 4% and 5% were respectively 700°C, 875°C and 1000°C.

![Fig.2 Propagation velocity of gas and coal dust explosion for different gas concentration](image1)

![Fig.3 Temperature of coal dust explosion for different gas concentration](image2)

3.2. The effect of water mist on explosion characteristics of coal dust/methane/air mixture

The effect of water mist on the coal dust/methane/air explosion was investigated in this section. The results showed that the propagation velocity of coal dust/methane/air mixture explosion was significantly suppressed by water mist, as shown in Figure 4. By the time of 180ms, the propagation velocities for all tests were decreased to zero. The temperature histories for different gas concentration were shown in Figure 5. Compared to explosion tests without water mist application (see Figure 3), temperature shown in Figure 5 were considerably decreased. The explosions for the gas concentration of 3%, 4% and 5% were respectively suppressed at the time of 100ms, 40ms and 100ms.

Application of water mist to coal dust/methane/air explosion will effectively reduce the occurrence of the mine disaster. The suppression mechanism of water mist on gas explosion is the termination of radical-chaining reaction and coal particle wetting. Water mist will attenuate the interaction between the explosion flame and the unburned coal dust/methane/air mixture, leading to weakening of heat conduction and heat radiation. The displacement of oxygen and methane with the evaporated water vapor will suppress the production of O radical and H radical, which are the predominant intermediates of
combustion reaction, leading to the reduction of combustion rate through the following elementary reactions,

\[ \text{H} + \text{H}_2\text{O} = \text{H}_2 + \text{OH} \quad (2) \]
\[ \text{O} + \text{H}_2\text{O} = \text{OH} + \text{OH} \quad (3) \]
\[ \text{HO}_2 + \text{H}_2\text{O} = \text{H}_2\text{O} + \text{OH} \quad (4) \]

Flame stretch in the early stage (0~30ms) showed that there is a preheat zone in the coal dust and gas compound flame. The length of the preheat zone was dependent on the particle size, concentration of coal dust and gas concentration. The flame propagation velocity of coal dust/methane/air mixture explosion in the presence of 5% methane was decreased from 8m/s for the test with no application of water mist to 4 m/s for the test with application of water mist.

The fact that flame propagation velocity increased rapidly 30ms after the ignition showed that the volatilization rate of coal dust was accelerated by high temperature in the preheat zone, thus promoting the coal dust explosion. At the case of application of water mist, the preheat zone was lengthened, volatilization rate of coal dust was decreased and the radical pool concentration was reduced. Therefore, the power of coal dust/methane/air mixture explosion is declined.

![Fig.4 Propagation velocity of gas and coal dust explosion suppressed by water mist for different gas concentration](image)

![Fig.5 Temperature of coal dust explosion suppressed by water mist for different gas concentration](image)

The temperature of the coal dust/methane/air mixture explosion showed a close relation with the gas concentration due to the variation of the physical and chemical property of mixture. It showed from Figure 4 and Figure 5 that the flame propagation velocity and distance and the flame temperature was
decreased at the case of application of water mist, which is attributed to physical and chemical interaction of water mist.

3.3. The flame evolution of the coal dust explosion

The flame evolution of the coal dust explosion captured by the high speed camera in the presence of 5% methane concentration was respectively shown in Figure 5 for no application of water mist and in Figure 6 for application of water mist. The duration time of the flame evolution is in the range from 0 to 90ms. The comparative study showed that the flame images with no application of water mist were consecutive but that with application of water mist is discontinuous. The flame area and flame brightness with no application of water mist were both higher than those with application of water mist. That means the coal dust/methane/air mixture explosion was significantly suppressed by the application of water mist.

It can be concluded from the experimental results that the coal dust/methane/air mixture explosion was suppressed by water mist through the following mechanisms such as cooling effect, oxygen displacement, adsorption of coal dust and volatilization inhibition of coal dust. Flame was covered by water mist and flame temperature was decreased. The flame can not be sustained and eventually will be extinguished due to disappearance of high temperature and oxygen resulted from the water mist. Moreover, water mist can adsorb and wet the coal dust, leading to the decreasing of the coal dust explosibility.

Fig. 6 The flame images of the mixture explosion in the presence of 5% methane
Fig. 7 The flame images of the mixture explosion in the presence of 5% methane suppressed by water mist

4. Conclusions

- The gas concentration is the predominant factors affecting the coal dust/methane/air mixture explosion. The gas concentration is higher, the flame propagation velocity is higher, the flame propagation distance is longer, as well as the explosion temperature is more higher.
- Water mist with the enough water flux can effectively suppress the coal dust/methane/air mixture explosion.
- It concluded from the flame evolution captured by the high speed camera that the flame image of the coal dust explosion in the presence of 5% methane concentration was partitioned into discontinuous parts, which is attributed to combinational mechanisms of cooling effect, oxygen displacement and adsorption of coal dust of water mist.

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