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Effect of dust explosion suppression by sodium bicarbonate with different granulometric distribution

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ABSTRACT

The inert powder of sodium bicarbonate with different particle size distribution in certain proportion was employed to study its suppressing effect on dust explosion and flame propagation. A certain proportion of combustible aluminum dust was mixed with different granular sodium bicarbonate powder with single-diameter particle or different granulometric distribution. The explosion experiment was performed in a vertical pipe experimental platform. The ionic current and flame propagation behavior and flame temperature were obtained to evaluate the inhibitory effects of inert powder on dust explosion flame. The experimental results showed that the sodium bicarbonate with different granulomertic distribution made suppression effect on the flame of aluminum dust explosion. The inert inhibition powder with different granulomertic distribution led to flame structure change and reduced the thickness of the preheat zone during flame propagation. Meanwhile, the flame propagation velocity and flame temperature were reduced. Furthermore, an optimum proportion of sodium bicarbonate was obtained for the best inhibition effect on the aluminum dust explosion. Results show that the suppression effect on the flame combustion reaction zone was the critical factor for dust explosion mitigation.

1. Introduction

As frequently industrial accidents, dust explosions happen usually accompanied with large amount of energy release and destruction. Therefore, it is very important to prevent and mitigate dust explosion process. A lot of conditions can trigger the dust explosions, and many studies on explosion prevention by removing the factors have been performed in past decades (Mintz and Bray, 1996; Siwek, 1996; Amyotte, 2014; Wang and Dong, 2015; Wang and Huang, 2016). Amyotte (1996) described the difference between inerting and inhibition techniques on suppressing and preventing the dust explosion accidents. An overview of metal dust deflagration suppression experiments were performed in a 4.4 m^3 vessel (Taveau and Vingerhoets, 2015). According to the experiments, the aluminum dust deflagrations can be effectively suppressed on a large scale, and metal dust explosion can be managed safely when the possible hazards have been well investigated. Huang and Risha. (2009) studied the influence of particle size on the combustion rate of aluminum dust cloud with numerical simulation method. With the particle size decreasing to nanoscale, the combustion mechanism of aluminum powder was transformed from diffusion combustion to kinetic combustion. Yuasa and Zhu. (1997) studied the combustion reaction of aluminum powder in air. The surface and gas-phase thermal reactions of aluminum generate aluminum vapor, AlO, Al_2O, AlO_2, O and condensed Al_2O_3. Gao and Mogi. (2013a,b) investigated the effects of particle size distributions on flame propagation mechanism during octadecanol dust explosions. The flame front structures and propagation mechanisms through octadecanol dust clouds with three different particle size distributions were obtained. However, the solid inertants as inhibitor was an effective method for preventing and mitigating the dust explosions (Amyotte, 2006). It is necessary to understand fundamental suppression characteristics of dust explosions, such as fire extinguishment mechanism, flame structure change and particle behaviors of the dust cloud. Aluminum powder is a kind of highly energetic explosive dust in industrial process.

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Thus it is very meaningful to study the suppression effect of solid inertants on the dust explosions.

In this study, sodium bicarbonate with different granulometric distribution was applied to carry out explosion experiments in a pipeline to examine the suppression effects on the aluminum dust explosion.

2. Experimental section

2.1. Experimental apparatus

The experimental apparatus is shown in Fig. 1. The experimental system includes dust combustion pipeline, high voltage ignition system, temperature monitoring system, distribution system, data acquisition system, high-speed photography, optical filtering system and synchronization control system. The dust combustion experimental pipeline is a rectangle vertical pipe with square cross section which is 500 mm long and the cross section of 80 mm × 80 mm. Two sides of the pipeline consist of 15 mm thick stainless steel plates with high mechanical strength, and the other two sides are removable quartz glass with excellent optical performance and high temperature endurance. Meanwhile, a decompression port is set above the pipeline. To capture the aluminum dust flame propagation process clearly, an intermediate AlO radiation wavelength (484 nm) of aluminum dust particles combustion is chosen as the object for observation (Yuasa and Zhu, 1997; Gao and Mogi. (2013a,b)).

2.2. Experimental materials

Analytically pure aluminum dust and sodium bicarbonate powder were chosen in the experiments. Before the testing, aluminum dust and sodium bicarbonate powder were dried in a 50 °C vacuum oven for more than 8 h. The sodium bicarbonate powder was sifted by four standard analysis screens (200, 300, 400 and 500 mesh). The average particle sizes of reagents sifted out are shown in Table 1.

2.3. Experimental process

The experiments were conducted in the apparatus in Fig. 1. A certain amount of samples, as shown in Table 2, were placed in the pipe; then the air was released by the gas ejecting system; finally, the experiment started when dust cloud was ignited by an electric spark. Sodium bicarbonate particles (200–500 mesh) were selected to carry out the inerting experiments and the mass percent of the inerting agent added was 30%. The aluminum powder was mixed evenly in proportion with sodium bicarbonate. The variation of flame propagation process was recorded and measured by high-speed camera, ion probe analyzer and thermocouple. The operation of high-speed camera, data acquisition instrument and the high-voltage ignition was controlled by programmable synchronous control device. The pressure and duration of compressed air were set to be 0.1 MPa and 0.1 s, respectively. The ignition voltage was set to be 14 kV, meanwhile the delay time for ignition (the time from gas blow-out to ignition) was 0.1 s, and the record speed of the high-speed camera was set to be 2000 frames/s.

The plate insertion method (Gao and Mogi. (2013a,b)) was used to measure the mass concentration of dust cloud in the pipeline. Two hardboards were parallelly inserted into the middle part of the pipeline as soon as the dust cloud spraying. After a while, the dust particles deposited on the lower hardboard was weighed to determine the mass concentration of the particles in the pipeline. The mass concentration of dust cloud was calculated by the result of multiple measurements. The mass concentration obtained was about 0.346 kg/m^3.

Table 1
Characteristics of particle size screened out.

Serial number	Screening specifications	Average particle size (μm)
1	200~300 mesh	60
2	300~400 mesh	45
3	400~500 mesh	30
4	Above 500 mesh	15

Table 2
Granulometric distribution of sodium bicarbonate.

Type	Granular composition	Mass percent of each component
A	200 mesh + 300 mesh	200 mesh: 300 mesh = 50%:50%
B	200 mesh + 400 mesh	200 mesh: 400 mesh = 50%:50%
C	200 mesh + 500 mesh	200 mesh: 500 mesh = 50%:50%
D	300 mesh + 400 mesh	300 mesh: 400 mesh = 50%:50%
E	300 mesh + 500 mesh	300 mesh: 500 mesh = 50%:50%
F	400 mesh + 500 mesh	400 mesh: 500 mesh = 50%:50%

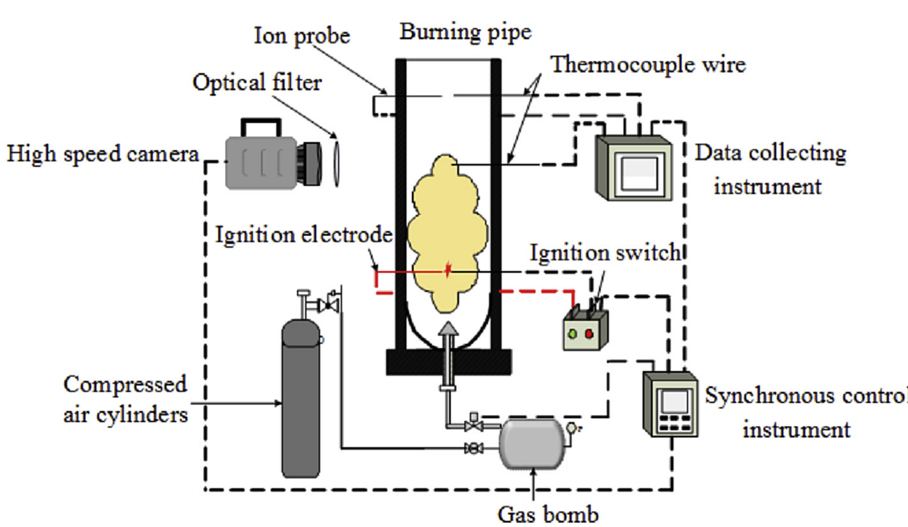

Fig. 1. The scheme of experimental system.