Journal of Loss Prevention in the Process Industries 55 (2018) 107–112

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Effect of metal mesh on the flame propagation characteristics of wheat starch dust

Xianfeng Chen[a,b], Zhao Qi[a,b], Huaming Dai[a,b,*], Shuhui Yin[a,b], Song He[a,b,**], Ying Zhang[a,b], Xiaotong Wang[a,b], Bihe Yuan[a,b]

[a] *School of Resources and Environmental Engineering, Wuhan University of Technology, Luoshi Road 122, Wuhan, 430070, China*
[b] *Hubei Key Laboratory of Mineral Resources Processing and Environment, Wuhan University of Technology, Luoshi Road 122, Wuhan, 430070, China*

ARTICLE INFO

Keywords:
Metal mesh
Wheat starch dust
Flame propagation
Flame temperature

ABSTRACT

A self-designed vertical dust combustion pipeline platform was used to study the explosion of wheat starch dust along with the different characteristic parameters of metal meshes and to highlight the influence of the metal mesh on the flame propagation of wheat starch dust. The temperature and pressure of flames were measured using a micro-thermocouple and pressure sensors, and spontaneous images of flames under different working conditions were captured by a high-speed photography system. It was observed that the metal meshes damaged the structural characteristics of flame propagation and the flame front surfaces, which led to the distortion and prevention of flame spread. This blocking effect increased with an increase in the number of metal meshes and layers. When the metal mesh had a smaller aperture, there was an increased suppression of the flame propagation. The presence of metal meshes in flame propagation also quenched a large portion of the flame, with the decrease in flame temperature being large and inversely proportional to the number of meshes and layers. The metal mesh also moderately inhibited the propagation of the combustion pressure wave. The inhibitory effect on pressure wave propagation was more evident and the combustion pressure decreased with an increase in the number of metal meshes and layers.

1. Introduction

Rapid industrial development has led to an increase in the annual number of dust explosion accidents, resulting in a large number of casualties and loss of property (Skjold and Eckhoff, 2016). The occurrence of dust explosions, specifically those involving high-temperatures and high-pressure, is usually accompanied by a severe energy release. Dust explosions have become a problem that cannot be ignored, and thus its prevention and control are of great importance for safe industrial production.

Given the frequent occurrence of dust accidents and the serious losses incurred, scholars have performed extensive experiments and theoretical research to characterise dust explosions. Proust (2006) studied the basic mechanism of dust combustion flame and determined the propagation modes of two types of flames, namely, turbulent flow and laminar flow. Dust experiments involving the three different particle sizes of corn starch in semi-closed vertical pipes showed that the structure of maize starch dust flame varied with the increase in particle size, which showed a positive correlation with the thicknesses of the reaction area and the preheating zone (Zhang et al., 2017). Gao et al. (2013a,b, 2017, 2012) tested the flame propagation of organic dust explosions in open space and semi-closed pipelines using a combination of high-speed photography and bandpass filters and found that the structure of flame propagation was largely influenced by thermal characteristics, volatility and concentrations of dust. It was also observed that the flame temperature and propagation speed initially increased and then decreased with an increase in dust concentration. Additionally, the propagation behaviour and combustion mechanism of the dust explosion flame caused by three different 40 nm metal powders (titanium, aluminium and iron) were studied using high-speed photography. This demonstrated that the three metal powders burned at different states of liquid, gas and solid, and their flames were spherical in shape discrete showing single luminous combustion. Zhang et al. (2016) discovered that the flame propagation characteristics and combustion structure of polymethyl methacrylate nanoparticles in a space dust explosive device were more regular and continuous, whereas the flame structure of microparticles was more irregular. Numerical simulation performed in a 20 L spherical container verified the relevant

* Corresponding author. School of Resources and Environmental Engineering, Wuhan University of Technology, Luoshi Road 122, Wuhan, 430070, China.
** Corresponding author. School of Resources and Environmental Engineering, Wuhan University of Technology, Luoshi Road 122, Wuhan, 430070, China.
E-mail addresses: daihm@whut.edu.cn (H. Dai), hsong@whut.edu.cn (S. He).

https://doi.org/10.1016/j.jlp.2018.06.005
Received 4 January 2018; Received in revised form 11 June 2018; Accepted 11 June 2018
Available online 12 June 2018

data pertaining to the explosion characteristics of coal, and demonstrated that the explosion characteristics of different concentrations of coal showed a positive correlation with the maximum experimental explosive pressure (Salamonowicz et al., 2015). Han et al. (2000) studied the flame propagation of lycopodium dust using a vertical pipe and found that the individual combustion particles and spherical flame created a double flame structure. Further microscopic observation showed that the lycopodium flame front was discontinuous and non-smooth.

The factors influencing the suppression of the dust explosion have also been a point of concern for many scholars. Yu et al. (2016) and Gao et al. (2015) used high-speed photography to study the flame propagation mechanism and microstructure of titanium dust explosion with different particle characteristics, and found that the thermal characteristics, particle sizes, and flame propagation mechanisms were different in each case because the particle size has a large influence on flame propagation in s dust explosion. Sun et al. (2006) observed the flame propagation and combustion of an aluminium particle dust cloud using a high-speed image camera, and discovered asymmetrical flame combustion around each aluminium particle. Eckhoff (2005) reviewed the developments and trends in dust explosion research, and analysed the development and application of prevention methods. Amyotte (2006) explained the functional difference between prevention of dust explosions and control measures. Wang et al. (2017) discussed basic information pertaining to gas/dust explosions and the deflagration to detonation transition. They also briefly reviewed the prevention, mitigation and isolation methods for industrial explosions, and comparatively summarised the various passive and active suppression techniques. Chen et al. (2017) tested the dust explosion and flame propagation of aluminium using sodium bicarbonate powder of different particle sizes in a vertical tube, and found that flame structures of sodium bicarbonate powder changed at a slower flame speed and lower flame temperature, and the ideal proportion of aluminium powder explosion could counteract the effect of sodium bicarbonate to the maximum extent. Liu et al. (2013) discussed how three kinds of solid particle inhibitors (ABC powder, SiO_2 powder, $CaCO_3$ powder) influenced the methane/coal dust/air explosion. They observed that solid particles can quickly reduce the overpressure of the blast wave and the propagation speed, and effectively inhibit the dust/air explosion of methane/coal mixture.

Present studies on dust explosions are mainly focused on the factors influencing them, and the microstructure and propagation mechanism of dust flame. Since there is little research on the inhibition and flame suppression of grain dust, we have designed a vertical dust combustion tube that was used along with high-speed photography technology to study the characteristics and inhibition of flame propagation of wheat starch due to a mesh made using a porous metal with different characteristic parameters. The purpose of this study was to explain the mechanism of the porous mesh inhibiting the propagation of wheat starch flame and subsequently underlying the prevention and control of explosion of grain dust.

2. Experiment

2.1. Experimental setup

The self-designed vertical dust combustion tube used in this study mainly consists of combustion pipes, a gas distribution system, a high-voltage ignition system, a synchronous control system, a data acquisition system (for values of temperature and pressure) and a high-speed photography system (Fig. 1). The experimental vertical pipe was divided into two sections by the flange connection, with the size of each section being $50 \times 8 \times 8\ cm^3$ corresponding to the height, width and length, respectively. A stainless steel plate with high temperature resistance and a thickness of 20 mm was selected as the pipe material. Meanwhile, quartz glass was installed on the opposite sides of the pipe to observe the dust flame. The bottom of the pipe was equipped with a spray powder, consisting a bowl and mushroom shaped reflectors. A pressure outlet was set at the top of the pipe. A pressure sensor was installed at a length of 80 cm from the lower end of the pipe, vertical to its inner wall. The porous metal mesh was placed parallel to the horizontal section of the pipe and 65 cm away from the lower end of the pipeline.

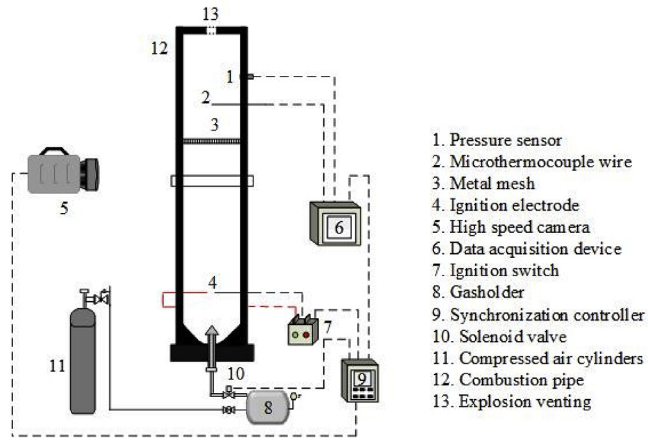

Fig. 1. Experimental setup.

2.2. Experimental process

The wheat starch samples were sieved through a standard 200-mesh screen, and the mean particle size of wheat starch dust was found to be 75 μm. Before the experiment, the samples were dried in a vacuum oven at 50 °C for more than 8 h. Five types of porous stainless steel wire meshes with square apertures were used (Fig. 2), whose specific parameters can be seen in Table 1. In this paper, the mesh number refers to the number of apertures in a length of 2.54 cm (Zalosh, 2007). Thus, a larger mesh number is associated with a smaller aperture. Meanwhile, the layer number refers to the number of the meshes superimposed over the same aperture size.

The porous metal mesh was placed in a fixed position (Fig. 1) prior to the connection and debugging of the experimental equipment connection and debugging. Then a fixed quantity of wheat starch was evenly spread across the bowl shaped groove. After the quartz glass was installed, the air tank ventilator was filled with dry air with a pressure of 0.13 MPa in order to disperse the dust. Once the air distribution system began to create the wheat starch form dust cloud, the high-voltage igniter was activated immediately at a discharge voltage of 14 kV. A high-speed camera and a data acquisition instrument were used to record and measure the flame propagation and its characteristic parameters. A programmable logic controller was used to simultaneously control the starting time of the camera, data acquisition instrument and igniter. Meanwhile, the high-speed photography recording rate was set to 1000 FPS/s to obtain continuous images. The pipeline was also cleaned after each experiment to ensure data accuracy.

3. Results and discussion

3.1. Analysis of the flame structure of wheat starch dust

The particle size of wheat starch dust in the experiments was 75 μm, and the flame image was recorded via high-speed photography after the ignition of wheat starch dust without metal meshes (Fig. 3). When the dust was lit after 2 ms, the arc-shaped flames were formed near the point of ignition. Then the initial flame area began to spread around slowly and the yellow light gradually became brighter. At a propagation