Journal of Loss Prevention in the Process Industries 54 (2018) 146–152

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Effects of reduced oxygen levels on flame propagation behaviors of starch dust deflagration

Hongming Zhang[a], Xianfeng Chen[a,*], Tian Xie[a], Bihe Yuan[a], Huaming Dai[a], Song He[a], Xuanya Liu[b]

[a] *School of Resources and Environmental Engineering, Wuhan University of Technology, Wuhan 430070, China*
[b] *Key Laboratory of Building Fire Protection Engineering and Technology of MPS, Tianjin 300381, China*

ARTICLE INFO

Keywords:
Dust explosion
Deflagration flame
Flame propagation behavior
Oxygen concentration

ABSTRACT

An experimental investigation of reduced oxygen levels on flame behaviors of starch dust deflagration is studied in a half-closed dust explosion tube. Six kinds of nitrogen/air ratio mixtures are prepared as the experimental atmosphere for flame propagation. A high-speed photography is used to record flame propagation behaviors and luminous features. The characteristics of flame temperature and deflagration pressure are measured by fine thermocouple and pressure sensor, respectively. The influence of reduced oxygen concentration on flame propagation characteristics are discussed in different conditions. The results show that reducing the oxygen content can effectively retard the flame propagation process and weaken the dust combustion reaction. Compared with air atmosphere, flame acceleration process under reduced oxygen atmosphere is suppressed and the luminous intensity of flame post-combustion zone is greatly diminished. The characteristic parameters of flame velocity, flame temperature and deflagration pressure are all influenced by the reduction in oxygen concentration. Furthermore, effective partial inerting suppression can be achieved for starch deflagration flame, when the oxygen concentration is lower than 18.90%. This study is helpful for dust explosion prevention and mitigation. Additionally, the dust cloud concentration changes the flame velocity characteristic at low oxygen levels and higher dust concentration is more limited the flame acceleration.

1. Introduction

Starch has a very wide range of applications in lots of processing industries, such as food processing, chemical synthesis and pharmaceutical manufacturing. However, starch dust diffusion in the processing industries cannot be effectively controlled, usually leading to increase the possibility of starch dust explosions. Starch production and processing require a high degree of environmental cleanliness, and the inerting method to reduce the ambient oxygen concentration is a very suitable application for the prevention of starch dust explosions. Studies on inerting technology have been extensively conducted, and most of the studies have focused on determination of limiting oxygen concentration (LOC) for the dust explosion (Nomura et al., 1984; Dastidar et al., 1999; Dastidar and Amyotte, 2002; Cashdollar, 2000; Going et al., 2000; Eckhoff, 2003). The LOC is the maximum oxygen concentration of a dust/air/inert gas mixture by which dust explosions cannot occur. Both EN 14034-4 (2005) and ASTM E2931 (2013) describe the standard test method for LOC of combustible dust clouds in the 1 m^3 vessel or 20 L sphere apparatus and point out that the measurement of LOC is the basis for inerting and explosion prevention. Mittal (2013) experimentally measured the LOC data for two types of coals with varying volatile matter and evaluated the effect of particle size and moisture on LOC. Particle size has a comparatively small influence on the LOC of coal dust while the effect of moisture on LOC is opposite. Furthermore, the LOC measurement cannot be directly used to represent the inerting level and the processing conditions need consideration. Wilen et al. (1998) found that the LOC values of biomass dust clouds increase with increasing initial pressure in the range 0.5–1.8 MPa. This result was different from coal dust and others. Hassan et al. (2014) proposed a predictive model to assess the probability of a dust explosion occurrence under a given environment. LOC was considered as a key parameter in the model and the probabilistic model of dust explosion with respect to the change of oxygen concentration was determined. Meanwhile, reducing the oxygen content above the LOC in the atmosphere by adding nitrogen is another core mean of preventing and mitigating dust explosions (Eckhoff, 2005) and partial inerting is called for more extensive use in industrial dust explosion protection (Eckhoff, 2004). The European standard CEN/TR

---

[*] Corresponding author.
E-mail address: cxf618@whut.edu.cn (X. Chen).

https://doi.org/10.1016/j.jlp.2018.03.011
Received 16 November 2017; Received in revised form 16 March 2018; Accepted 16 March 2018

15281:2006 (CEN, 2006) has systematically introduced the influence of oxygen concentration on explosion atmospheres and the methods of inerting. The supply of inert gas is confirmed and the empirical equations is provided for inerting design. Li et al. (2009) investigated the inerting effect of N_2, CO_2 and Ar on the magnesium dust explosion. Comparing the parameters of explosion characteristics, the inerting effect of N_2 is better than Ar, and N_2 has a better economic efficiency for dust explosion prevention as an inert gas. Chaudhari and Mashuga (2017) utilized a modified standard minimum ignition energy (MIE) device to measure the MIE value of partial inerting dust clouds. The partial inerting MIE was influenced by purge-induced turbulence and a higher MIE value was obtained due to the turbulence in the ignition zone. As mentioned above, studies on the dust explosion sensitivity under inerting conditions have been very extensive. However, the flame propagation process is also an essential stage for the transformation from deflagration to explosion, which is always unsteady and controlled by numerous factors (Gao et al., 2013; Chen et al., 2017; Li et al., 2017; Yang et al., 2017; Zhang et al., 2017). While, few studies are available on flame propagation characteristics of dust deflagration with the reduction of oxygen concentrations.

In the present study, nitrogen was chosen as an inert gas, and the effect of reduced oxygen levels with different nitrogen/air ratios on flame propagation behaviors of starch dust deflagration was studied in a semi-closed tube. The flame propagation processes with different oxygen concentrations was recorded by high speed photography system. Flame temperature and deflagration pressure were detected by fine thermocouple and pressure sensor, respectively. Furthermore, the variation of flame propagation dynamics was explored in depth.

2. Experimental

2.1. Experimental apparatus

A schematic diagram of experimental apparatus was illustrated in Fig. 1, composed of nine parts: a small-scale square combustion tube, a dust dispersing device, a gas mixing system, a high voltage ignition unit, a high speed photography system, a data recorder, a thermocouple, a pressure sensor and a programmable logic controller. The size of square dust combustion tube was 1000 mm × 80 mm × 80 mm, which was connected by two half-meter long tubes. The front and rear sides of tube were set as optical windows, which were convenient to observe the flame propagation process. A dust dispersing device was installed at the bottom of the tube. A square vent with the size of 20 mm × 20 mm was placed at the top of the tube. The vent was opened to connect the external space for the nitrogen/air mixed gas flow through the tube to form an inert atmosphere. A pair of ignition electrodes were positioned at 50 mm above the bottom of the tube and linked with a high voltage ignition unit, which could generate ignition spark. The gas mixing system was used to form air/nitrogen mixtures with different concentrations. Furthermore, the mixed gas was filled into the tube to create an inerting atmosphere and to act as a driving gas for dust dispersion.

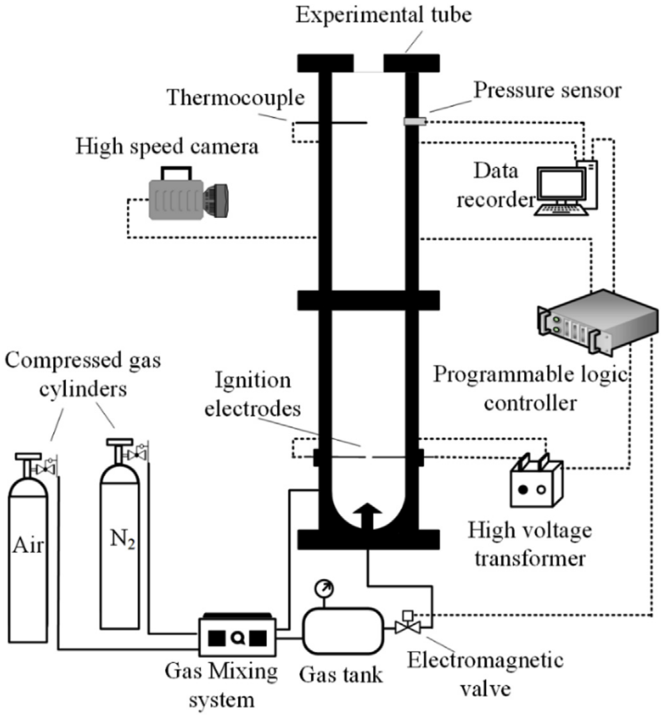

Fig. 1. Sketch of experimental apparatus.

In this study, the flame propagation behaviors were captured by a high speed photography camera (Photron FASTCAM SA1.1) with a normal lens of Nikon AF Nikkor 50 mm f/1.4. A fine thermocouple and a pressure sensor were mounted at 120 mm below the top of the tube. The thermocouple was comprised of 25 μm diameter Pt-Pt/Rh 13% wires. The flame deflagration pressure was measured by a pressure transducer (PCB Piezotronics, 113B21), which has a measuring range of 0–1379 kPa and a sensitivity of 3.703 mV/kPa. Data recorder was used to record the temperature and pressure data. Synchronous trigger switches of each system were controlled by the programmable logic controller.

2.2. Experimental materials

Wheat starch was utilized for experiments. Before experiments, dust samples were sifted in a vibration sieve with 300 mesh to ensure the particle size distribution in the same range. Then, the samples were dried and dewatered in a vacuum drying oven at 50 °C for 12 h. The median particle size (D_{50}) of the samples was 45 μm. High purity nitrogen (purity ≥ 99.9996 vol.%) and compressed air (oxygen concentration is 21.00 vol.%) were used for preparing different gas mixtures. The dust clouds was ignited by the high-voltage transformer with an output of 15 kV. The ignition duration was 100 ms and the nominal ignition energy was approximately 10 J.

2.3. Experimental conditions

Experiments were carried out in the different oxygen concentration atmosphere of 6 nitrogen/air ratios. The oxygen volume concentration for the mixed gases were 12.60%, 14.70%, 16.80%, 18.90%, 19.95% and 21.00%. The detailed conditions of the gas mixture were shown in Table 1.

In order to ensure the accuracy of the oxygen concentration in the experimental atmosphere, the flow through technique relying on the purge mixed gas was used to remove the original gas in tube. The gas flow in the experiments was 5 L/min and the purge time of the mixed gas flow through the tube was calculated from the following equation (CEN, 2006):

Table 1
Experimental gas atmospheres for starch dust explosions.

No.	Nitrogen (%)	Air (%)	Oxygen concentration (%)	Gas composition
1	0	100	21.00	Air
2	5	95	19.95	Air-Nitrogen
3	10	90	18.90	Air-Nitrogen
4	20	80	16.80	Air-Nitrogen
5	30	70	14.70	Air-Nitrogen
6	40	60	12.60	Air-Nitrogen