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Flame propagation behaviors and temperature characteristics in polyethylene dust explosions

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ABSTRACT

To reveal the flame propagation mechanism in polyethylene (PE) dust explosions, the flame propagation behaviors and temperature characteristics of polyethylene dust clouds were experimentally studied in an open duct. Flame propagations in polyethylene dust clouds with different concentrations and particle size distributions were recorded using high-speed photography. The flame temperatures were measured using two fine thermocouples comprising Pt–Pt/Rh13% wires of diameter 25 μm. Because of severe agglomeration, the minimum explosible concentration of polyethylene particles with diameter < 75 μm was higher than that of the particles with diameter 75–100 μm. It was observed that the flame front gradually became continuous as the particle size increased with the same polyethylene dust concentration of 300 g/m^3. With higher polyethylene dust concentration, the flame front of the polyethylene particles of size <75 μm could quickly become discrete, and the floating flame appeared early, while the flame front of the 100–212 μm polyethylene particles transformed from a continuous flame into several independent diffusion flames. It was demonstrated that the flame propagation velocities were not constant, and that they fluctuated owing to the turbulence and expansion of the combustion products. The average flame propagation velocity increased initially, and then decreased with increasing dust concentration. The peak velocity of the polyethylene particles of size <75 μm was 4.79 m/s at a mass density of 300 g/m^3, while the peak velocity of the 75–100 μm particles was 4.55 m/s at a mass density of 400 g/m^3, and that of the 100–212 μm particles was 2.67 m/s at a mass density of 500 g/m^3. In addition, it was found that the maximum flame temperatures of the different polyethylene particles were approximately the same; the temperatures were 1585.4 °C, 1511.8 °C, and 1508.4 °C for the polyethylene particles of sizes of 100–200 μm, <75 μm, and 75–100 μm, respectively. This phenomenon may be caused by the combustion behavior of the molten polyethylene particles. When the dust concentration is increased within the optimum concentration, flame temperature increased with the increase in flame propagation velocity. The flame temperature of the polyethylene particles of size <75 μm decreased as the flame propagation velocity decreased, while the flame temperature of the 75–100 μm polyethylene particles did not change significantly.

1. Introduction

Polyethylene(PE)is a thermoplastic polymer with a variable crystalline structure; it has several applications ranging from plastic bags to medical devices. The annual global production of PE is around 80 million tons. The most important step of polyethylene synthetic process is the conversion of purified ethylene gas into polyethylene. There are a number of different processes that can be used to accomplish this conversion, but a common method used in the industry is to produce polyethylene in a fluidized bed reactor. During this conversion, polyethylene dust explosions might occur, which can result in catastrophic personal injuries and devastating damage. For example, in 2002, a polyethylene dust explosion occurred in China Petroleum and Natural Gas Company, causing 8 fatalities, 19 injured cases, and a direct economic loss of 4.5278 million yuan [1]. Another violent polyethylene dust explosion had occurred at the West Pharmaceutical Services in Kinston, North Carolina in 2003.

Considerable research has therefore been conducted with the aim of either preventing the occurrence of such incidents or mitigating the consequences. Cashdollar [2,3] measured the explosion

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characteristics of polyethylene dust in a 20 L chamber in the Pittsburgh Research Laboratory (PRL). It was found that the polyethylene dust had a maximum explosion pressure of approximately 6.4 bar (g), and that the minimum explosible concentration (MEC) for the polyethylene dust explosion was approximately 20 g/m^3. It was also observed that polyethylene and high-volatile bituminous coal have similar maximum pressures, but polyethylene has a faster rate of pressure rise owing to its higher volatility and H:C ratio. Eckhoff [4] studied the minimum ignition energy (MIE) of polyethylene dust explosion, and it was proved that a decrease in median particle size resulted in a lower MIE. Mittal et al. [5,6] developed a model for predicting the minimum ignition temperature of polyethylene dust cloud.

These parameters are very useful for evaluating the hazards of polyethylene dust. However, it is also important to understand the flame propagation characteristics. Only few studies have focused on the characteristics of flame propagation in polyethylene dust clouds. Butlin [7] observed that the polyethylene particles that were initially falling at a constant velocity reversed their direction immediately prior to the passage of the flame and moved upward ahead of the flames. Very shortly after the passage of the flame, the particles disappeared from the preheat zone. The most likely reason is the occurrence of pyrolysis of the polyethylene particles. The characteristics of flame propagation through polyethylene particle clouds have not yet been sufficiently explored. However, many studies on flame propagation characteristics of high polymer dust clouds serve as useful references to understand the flame propagation behaviors in a polyethylene dust cloud explosion. Sun et al. [8] observed that the flame structure of the PMMA particle cloud consisted of an unburnt zone, a reaction zone, and a yellow luminous zone. Zhang et al. [9,10] studied the flame propagation behaviors of nano- and micro-PMMA dust explosions. Proust et al. [11,12] observed that the flame front of starch dust clouds was very luminous with a shape corresponding to a fraction of a sphere. It was also found that a typical cellular flame appeared at a certain period after the ignition of the starch-air suspension.

In this study, to reveal the flame propagation mechanism in polyethylene dust explosions and establish an appropriate theoretical prediction model, the flame propagation behaviors and temperature characteristics in polyethylene dust clouds were experimentally studied in an open duct. The flame propagation processes were recorded by a high-speed camera, and the temperature of the combustion zone was measured using two fine thermocouples.

2. Experimental

2.1. Experimental apparatus

The experimental apparatus consisted of a small-scale combustion duct, an ignition system, two thermocouples, a high-speed camera, a data recorder, a time controller, and a gas supplying unit. The apparatus is schematically shown in Fig. 1. The small-scale combustion duct is 500 mm high with a cross section of 72 mm × 72 mm. Two sides of the duct were made of Plexiglas to observe the flame propagation, and the other sides were made of stainless steel. The combustion duct had an open upper end and a closed bottom end composed of a gas nozzle and a sample dish.

The ignition system was composed of a pair of tungsten wire electrodes with a diameter of 0.4 mm and a high-voltage transformer of 15 kV capacity to produce the ignition spark. The electrodes were located 50 mm above the bottom of the combustion duct. The distance between the tips of the two electrodes was approximately 5 mm and the ignition duration was 0.01 s. Two fine thermocouples, composed of Pt–Pt/Rh13% wires of 25 μm diameter, were located 100 mm and 250 mm above the ignition electrodes. To eliminate the influence of the electromagnetic field induced by the high voltage, the thermocouple wires were passed through a ceramic tube with an inner diameter of 1 mm. Further, the effect of thermal inertia on the thermocouple had to be considered. The convective heat transfer was much larger than the radiative and conductive heat transfers at the junction of the thermocouples. The temperature value was compensated as given by the following equation [13].

$$T = T_m + 8.75\frac{dT_m}{dt} \tag{1}$$

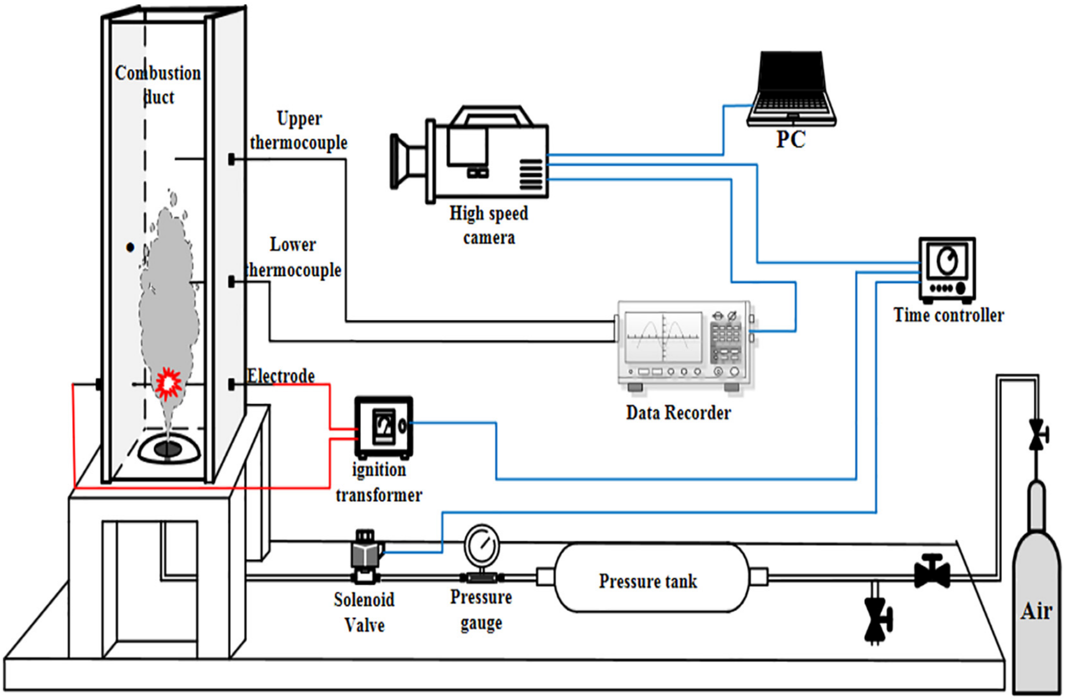

Fig. 1. Experimental apparatus.