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Effects of particle size distributions on flame propagation behavior through dust clouds of PMMA

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A B S T R A C T

A dust explosion occurs when an ignition source such as static electricity gives energy to a cloud of combustible particles. The flame propagates at high speed and the pressure rises up drastically. To take appropriate measures preventing dust explosions accidents, it is necessary to understand the phenomenon scientifically, in particular, to elucidate the effects of particle size distributions on flame propagating behavior. The purpose of this study is to investigate the effects of particle size distributions systematically. On this account, experiments were performed, in which PMMA particles with a very narrow particle size distribution (monodispersed) and blended samples of these monodispersed particles in various ratios were used. Flame propagation behavior of blended samples was compared with that of monodispersed samples of 3, 10, 20, and 30 μm diameters. As a result, it was found that flame propagation behavior varied according to the particle size distributions even if Sauter mean diameter was same. In particular, flame propagated very fast in small and monodispersed particles which didn't contain large particles.

1. Introduction

As a high risk industrial disaster, dust explosion is a complex phenomenon that flame propagates in the heterogeneous medium, where particles undergo heating, vaporization/pyrolysis, mixing with oxidizer, ignition, burning, and flame extinction. In this phenomenon, the flame propagates at high speed and the pressure rises up drastically. It is predicted that the potential risk of the dust explosion will increase as industrial powder has recently become smaller (Dobashi, 2008). To take appropriate measures preventing dust explosions accidents, it is necessary to understand the phenomenon scientifically, in particular, to elucidate the effects of particle size distributions on flame propagation behavior.

Mechanisms of flame propagation through octadecanol particle clouds were revealed by Chen et al. (1996). It was concluded that in the schlieren front smaller particles rapidly gasified, while the gasification of particles with a diameter larger than 80 μm was delayed, and vapour lumps were formed behind the schlieren front. These lumps then burned to form circular dispersed blue flames. Jun et al. (1998) observed that when the mass density of smaller particles was high, the flame propagation mechanism was similar to that of a usual hydrocarbon–air premixed flame; when the mass density of smaller particles was low, the flame propagation was supported by the heat release due to combustion at the blue spots. Huang et al. (2009). found that as the particle diameter decreased from the micron to the nano range, the flame speed increased and the combustion transited from a diffusion-controlled to a kinetically controlled mode. A. Di Benedetto et al. (Benedetto et al., 2010) developed a novel model to quantify the effect of particle size on dust reactivity in an explosion. It was found that varying the dust size could establish different regimes depending on the values of the characteristic time of each step and of several dimensionless numbers. Wei Gao et al. (Gao et al., 2013) revealed that flame propagated in the dust cloud with a smaller particle size was characterized by a regular shape and spatially continuous combustion zone structure, which was similar to the premixed gas explosions. On the contrary, when flame propagated through the dust cloud with a larger particle size, discrete blue luminous spots appeared surrounding the yellow luminous zone. Castellanos et al.

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(2014). indicated that the explosion hazard characterization was effected by surface median diameter and particle size dispersity. Taking surface area into consideration, Harris et al. (2015). proved that dust particle size had the greatest influence on the propagation and inhibition of dust explosions. Unfortunately, to date the effects of particle size distributions on flame propagation behavior have not been sufficiently studied.

The purpose of this study is to investigate the effects of particle size distributions systematically. On this account, the experiments were performed, in which PMMA particles with a very narrow particle size distribution (monodispersed) and blended particles of small, middle, and large ones in various ratios were used. Flame propagation behavior of blended samples was compared with that of monodispersed samples with 3, 10, 20, and 30 μm diameters.

2. Experiments

2.1. Experimental apparatus

The dust explosion experiment apparatus, Air-Blowing-Type is schematically shown in Fig. 1. PMMA particles were set in the bottom of the rectangular duct (7 × 7 × 30 cm) and dispersed by compressed air of 0.07 MPa to form dust cloud. To observe the flame structures in detail, the rectangular duct was constructed with quartz glasses. The photograph of the rectangular duct is shown in Fig. 2. A mesh was attached to the top of the duct, which prevented the particles out of the duct. The equivalent ratio of dust cloud was 2 (concentration: 290 g/m^3) in all conditions, at which the particles were successfully fully dispersed and burnt completely. Direct observation of the propagating flames could be made clearly. 0.2s later, the 15 kV neon transformer was discharged and the suspended particles were ignited. The ignition duration was controlled by the pulse generator (Quantum Composer Sapphire 9200 Series). The pressure of the compressed air and the ignition duration conformed to Japanese Industrial Standards Z 8818: 2002. The flame propagation behavior was recorded directly by a high-speed camera (Photron FASTCAM SA2).

2.2. PMMA particles

3, 10, 20, 30 μm PMMA particles provided by Soken Chemical Co.,Ltd. of Japan Ministry were used as samples. The product name was MX Series, which exhibited a very narrow particle size distribution (monodispersed) with regular spherical shape. The SEM image of the smallest monodispersed particles (3 μm PMMA particles) is shown in Fig. 3, from which it could be proved that there must be no cohesion in other larger diameter particles due to the weaker interparticle forces for them. The quantiles of the volumetric distributions of a production lot were as follows. d_{32}(Sauter mean diameter) = 2.781 μm, d(0.5) (the diameter under which the percentage in volume is 50%) = 2.709 μm, d(0.9) = 3.496 μm.

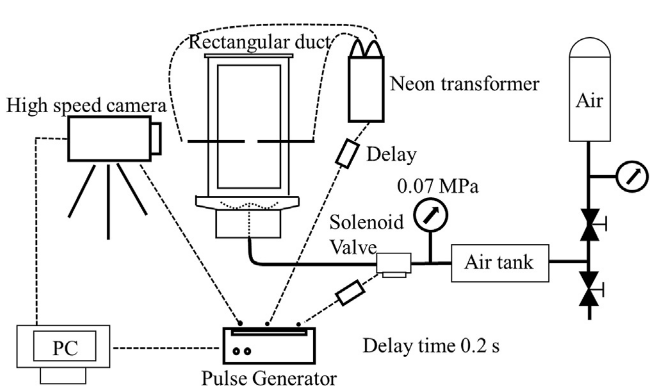

Fig. 1. Experimental apparatus.

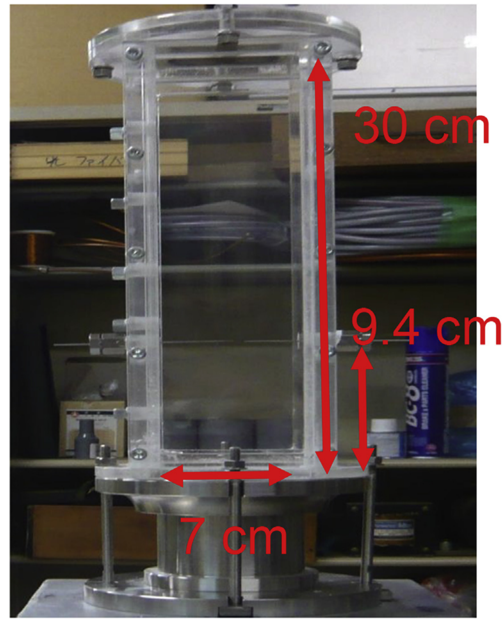

Fig. 2. Rectangular duct.

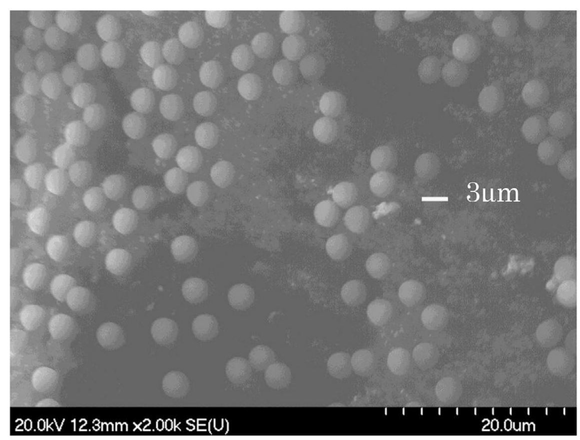

Fig. 3. SEM image of 3 μm PMMA particles.

2.3. Blend conditions

Blended samples A ~ D were prepared by blending two or three monodispersed particles. The blend conditions of PMMA particles are shown in Table 1.

Sauter mean diameter *d32* was calculated by particle diameter

Table 1
Blend conditions.

Sample	3 μm[%]	10 μm[%]	30 μm[%]	Sauter mean diameter[μm]
Blend A	75.0	–	25.0	3.9
Blend B	50.0	–	50.0	5.5
Blend C	22.2	–	77.8	10.0
Blend D	–	25.0	75.0	20.0

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