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Research Paper

Analysis of explosion characteristics of combustible wood dust in confined system using the thermal decomposition rate and mass loss rate

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HIGHLIGHTS

- Practical dataset of wood dust explosion is provided according to the standard code.
- Max explosion pressure and max pressure rise rate appeared at around $\varphi = 4$.
- Explosion pressure and dust concentration are logarithmically related for $\varphi < 4$.
- Thermal decomposition rate and mass loss rate are keys to analyze results properly.
- Bubble and contour maps help to visualize risk level and to find safer condition.

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ABSTRACT

In this study, dust explosion experiments were conducted to investigate the explosion characteristics of three samples of dust from wood particleboard that had exploded in the manufacturing process. Explosion tests were conducted by utilizing a standardized Siwek 20L apparatus according to the standardized test procedures in the European Standard CEN EN 14034 series and CEN EN 13821. To understand the physiochemical properties of the tested dust samples, the element composition, particle size distribution, and heat release rate were obtained by utilizing an element analyzer, particle-size analyzer, and cone calorimeter, respectively. Explosion pressure and rising explosion pressure featured log-linearly increasing trends in dust concentration and equivalence ratios until the maximum. They then decreased linearly as the dust concentration and equivalence ratios increased. Dust particles of smaller sizes and non-spherical shapes achieved higher maximum explosion pressure and maximum explosion pressure rising rates. The dust concentration at maximum explosion pressure decreased as the dust particle size decreased. Thermal decomposition rates and mass loss rates of dusts, which were calculated from the results of the cone calorimeter test, were mainly affected by the content of noncombustible materials such as nitrogen and inorganic residuals. To suggest a proper method to analyze dust explosion characteristics, the correlations among the tested dust samples were calculated with four variables: dust concentration, equivalence ratio, equivalence ratio based on thermal decomposition rate, and mass loss rate. The results showed that the latter two variables were considered to be more proper methods than the dust concentration and showed slightly better correlation than the equivalence ratio. A bubble graph and a contour diagram of the explosion pressure were also utilized to visualize the degree of explosion risk and to determine a safe region of operation. The test results and analytical methods proposed in this study could be utilized to design methods for the prediction, prevention, and protection of dust explosions.

1. Introduction

As the technology in production industries has become more sophisticated, raw materials, products, and even waste have been handled in a fine particle state. This has various advantages, such

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Nomenclature

P	explosion pressure	ρ_b	bulk density
P′	rate of explosion pressure rise	ε	porosity
P_{max}	maximum explosion pressure	φ	equivalence ratio
P'_{max}	maximum rate of explosion pressure rise	R^2_p	Pearson correlation coefficients
THR	total heat release rate	Dust-(1)	silo dust
TDR	thermal decomposition rate	Dust-(2)	hammer mill dust
MLR	mass loss rate	Dust-(3)	radiata pine dust
ρ_t	true density		

as facilitating product processing, enhancing yield rates, and simplifying handling. However, the hazard of dust explosions should be recognized in processes where fine particles are handled. One of the most significant hazards in the fine particle-treating industry is dust explosions in combustible metal or combustible wood. These explosions are caused by known or unknown ignition sources when the dust is dispersed in the form of clouds in fully or partially confined spaces. Dust explosions involve high explosion pressure and rapid pressure rise and they threaten not only the facilities in factories or plants including pulverized coal power plants but also the health and lives of humans [1,2]. Thus, to prevent dust explosions and mitigate the damage caused by them, over three decades previous studies have investigated their physicochemical properties, such as maximum explosion pressure, maximum rate of pressure rise, minimum ignition energy, minimum ignition temperature, and the amount energy generated during the explosion [3–16]. Torrenta et al. studied maximum explosion pressure and rates of rising explosion pressure rise under conditions of high pressure and turbulence using airtight containers of biomass dust [15]. Amyotte et al. studied the explosion characteristics of wood fiber samples and polyethylene samples, focusing on particle sizes and shapes [16]. Cashdollar et al. found that dust particle sizes and shapes were related to explosion characteristics and the increase in specific surface areas. The latter physical characteristic of particles causes the increase in oxidation response areas, which influences the explosion characteristics [17]. In an experiment using 20-L dust explosion, Calle et al. found that smaller particle diameters were associated with higher explosion strength in a study of explosion pressure characteristics related to the particle diameters of wood dust [18].

Although much research has been conducted to find the individual explosion characteristics and common physical laws of various dust types, no study on the characteristics of wood dust explosions has focused on the energy quantification of dust explosions. Thus, this experimental study was conducted to identify the explosion characteristics of wood dust that is utilized during wood-based panel production with the objective of presenting a new methodology for the analysis of explosion characteristics by quantifying and dividing the thermal decomposition energy and loss of dust mass into participating and non-participating explosions.

2. Materials and properties of tested dust samples

In this study, three types of dust samples were tested. Two samples were of regenerated wood dust from the raw materials used in the production of particleboard in factories where dust explosions have occurred. The third sample was Radiata Pine (*Pinus radiata* D. Don), which was selected as a representative reference material. Fig. 1 shows the process flow in the production of particleboard. During the production, dangerous processes capable of dust explosion include drying, in which chips are dried to a moisture content of less than 2%. Other processes include the crushing process in the mill, the chip screening processes, dust collection by environmental facilities, and integrated dust storage in the silo. We selected two dust samples obtained from silos that stored dryer fuel dust for drying processes (Dust-(1)) and hammer mills in dried chip-crushing processes (Dust-(2)). These dust samples, which were mainly from the breaking of pinewood, were collected from processes in which explosions had occurred. The coniferous Radiata Pine is distributed in at least 70% of the world's planted forests. It was selected as a representative reference dust sample (Dust-(3)). Before the experiment, three dust samples were pretreated by drying and then passing through a 230 mesh (mesh size = 63 μm) sieve.

Table 1 shows the chemical composition and physical properties of the dust samples. The weights (%) of carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O) were measured using an elemental analyzer (Model: EA 1110, CE Instruments). The particle size distribution in the dust samples was measured using the light scattering method with a particle size analyzer (Model: CiLAS 1090 Liquid, CiLAS). A video microscope system (Model: SV-55, Sometech) was used to photograph the dust shapes. Figs. 2–4 show the distribution of the shapes and sizes of the particles in the three dust samples. The mean particle sizes of Dust-(1), Dust-(2), and Dust-(3) were 56.02 μm, 15.96 μm, and 92.08 μm, respectively. It is notable that the mean particle size of Dust-(3) was 92.08 μm even after sieving through a 230 mesh (mesh size = 63 μm) sieve. This result is attributed to the long needle shape of the particles in Dust-(3), as shown in Fig. 4a. Because of their with high slenderness ratios (length to diameter ratio), the long needle shapes were able to pass lengthwise though the sieve. The particle size of Dust-(2) was much smaller than that of Dust-(1). Dust-(2) was collected from the hammer mill vessel after the dust was crushed into smaller particles through the chip-crushing process. Figs. 2a and 3a show the microscopic particle shapes of Dust-(1) and Dust-(2). Dust-(1) has spherical shapes whereas Dust-(2) has flocculent forms of spherically shaped fine particles.

3. Experimental methods

In the present study, all experiments were carried out in accordance with the standardized test procedures in European Standard CEN EN 14034 series [19–21] and CEN EN 13821 [22].

Two types of international standard apparatuses are generally used for the dust explosion test: the 1-m^3 apparatus and the 20-L apparatus. In this study, the Siwek 20L apparatus (Kuhner) was utilized. As shown in Fig. 5, this apparatus is composed of a water-cooled spherical vessel that is ignited by chemical igniters installed at the center, a rebound nozzle that was designed to disperse dust injected from the bottom of the vessel, and a dust container that supplies the 20-L volume of dust with compressed air. Using the EN 14034 standard, the ignition delay time was set to at 60 ms and the ignition energy of 10 kJ was applied.

The total heat release (THR) for the three dust samples before and after the explosion test were measured using a cone