Powder Technology 325 (2018) 42–48

Contents lists available at ScienceDirect

Powder Technology

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

Comparative analysis of the explosibility of several different hybrid mixtures

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A R T I C L E I N F O

Article history:
Received 31 May 2017
Received in revised form 24 August 2017
Accepted 7 November 2017
Available online 10 November 2017

Keywords:
Dust explosion
Hybrid mixtures
Explosion severity
Lycopodium
Polyethylene

A B S T R A C T

A standard 20 L spherical chamber was used to study the explosibility of hybrid mixtures systematically. Four different hybrid mixtures, which were composed of two different flammable gases (methane and ethylene) and two different flammable organic dusts (lycopodium and polyethylene), were selected. The maximum explosion pressure P_{ex} and the maximum explosion rate of pressure rise $(dP/dt)_{ex}$ of the four different hybrid mixtures were measured under initial high turbulence conditions over a wide range of composition concentrations (volume concentration y for gas and mass concentration c for dust). Explosion behaviours of the four different hybrid mixtures were analysed and compared with each other. Experimental results have shown that adding different flammable gases to the same dust cloud can all increase the explosion severity of the dust. However, the increase is almost equivalent when different flammable gases with the same equivalent ratio at low values are added. Only if the equivalent ratio is sufficiently higher can a higher increase in the explosion severity be induced by the more explosible gas. Adding the same flammable gas to different dust clouds clearly increases the explosion severity of all these dusts, but the increased ratios of P_{max} and $(dP/dt)_{max}$ are higher for the less explosible dusts, indicating that the influence of flammable gas on the explosion severity is more pronounced for less explosible dusts.

1. Introduction

Hybrid mixtures, which present a significant risk of explosion if subjected to an ignition source, are often encountered in process industries [1]. Typical examples include mixtures of pigments and diluents in paint factories, coal dust and methane in the mining sector, excipients and solvents in pharmaceutical industries, and wheat dust and fermentation gases in the food industries [2–3]. Knowledge of the explosibility of hybrid mixtures is thus vitally important when conducting a process hazard safety review.

Over the past decades, many investigations have been performed focusing on the peculiar explosion behaviours of hybrid mixtures. For example, Dahn et al. [4] studied the effects of small percentages of flammable vapours (gasoline) on the explosion severity of RDF (Refuse Derived Fuel) dust. Chatrathi [5] investigated the effects of low propane concentrations on the explosibility of optimum cornstarch concentrations. Pilão et al. [6] examined the explosibility of hybrid methane/cork dust mixtures. Denkevits [7] investigated the explosibility of hybrid hydrogen/graphite dust mixtures. Dufaud et al. [8–9] presented the results of hybrid explosions involving pharmaceutical dust and their associated solvents. Garcia-Agreda et al. [10] characterised the explosibility of nicotinic acid dust as a function of methane concentration. Sanchirico et al. [11] compared the explosion severity of hybrid mixtures with pure dust and vapour explosions. Kosinski et al. [12] studied the explosion of carbon black and propane hybrid mixtures. Landman [13], Britton [14], Khalili et al. [15] and Addai et al. [16–19] investigated the effects of combustible gas introduction on the minimum ignition energy (MIE), minimum explosion concentration (MEC) and minimum ignition temperature (MIT) of dust clouds.

According to these previous investigations, some of the common explosion characteristics of hybrid mixtures can be summarised as follows:

1. Adding a flammable gas to a dust/air mixture or a flammable dust to a gas/air mixture increases the explosion severity of the mixture significantly, even for concentrations of the flammable gas or dust below their respective lower flammability limit (LFL) or MEC;
2. The MIE, MEC and MIT of dust and the LFL of flammable gas all decrease in the presence of the other fuel.

Apart from these common explosion characteristics, hybrid mixtures composed of different gases and dusts also present different explosion behaviours. It is widely believed that for most hybrid mixtures, the gas below its LFL and the dust below its MEC can form an explosible mixture. But this is not the case in the research by Kosinski et al. [12] on the explosibility of carbon black and propane hybrid

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https://doi.org/10.1016/j.powtec.2017.11.022
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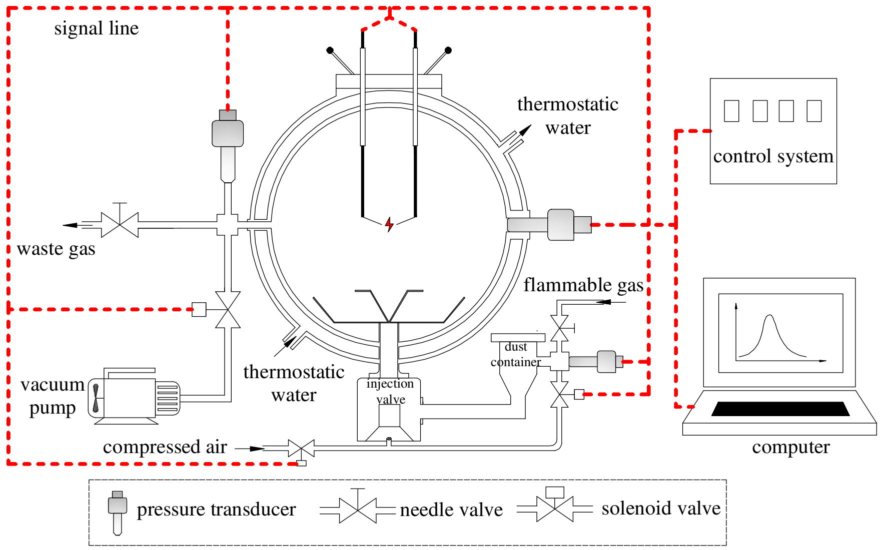

Fig. 1. Schematic diagram of experimental set-up.

mixtures. They confirmed that the propane concentration had to be above the LFL to start the hybrid flame propagation. They attributed the reason to the very low content of volatiles of the carbon black. Dufaud et al. [20] performed experiments on mixtures of pharmaceutical dusts (magnesium stearate, niacin, antibiotic) and their solvants (ethanol, diisopropyl ether, toluene). They noted that the effect of hybrid mixture presence was more pronounced for the less explosible antibiotic than for niacin or magnesium stearate.

These different explosion behaviours of hybrid mixtures must be related to the explosibility of the pure fuels. Therefore, it is of great significance to clarify the effects of the explosibility of pure fuels on the explosibility of hybrid mixtures. Accordingly, more reasonable mitigation and prevention measures for hybrid explosions can be adapted.

With this aim, two different organic dusts (lycopodium and polyethylene) and two different flammable gases (methane and ethylene), which constitute four different hybrid mixtures (lycopodium/methane, lycopodium/ethylene, polyethylene/methane, polyethylene/ethylene), were selected in the present paper. The maximum explosion pressure, $P_{ex,}$ and the maximum explosion rate of pressure rise, $(dP/dt)_{ex,}$ of the pure fuels and the four different hybrid mixtures were measured under initial high turbulence conditions over a wide range of composition concentrations (volume concentration y for gas, and mass concentration c for dust). Explosion behaviours of the four different hybrid mixtures were analysed and compared with each other. Combined with the explosibility of the pure fuels, the possible reasons for the different explosion behaviours between the four different hybrid mixtures were pointed out. Accordingly, the effects of the explosibility of pure fuels on the explosibility of hybrid mixtures were clarified.

2. Experiments

2.1. Experimental apparatus

The experiments were performed in a standard 20 L spherical chamber meeting standard EN 14034 [21]. A schematic diagram of the apparatus is shown in Fig. 1. The chamber structures are not described here owing to their wide application in dust explosion research. Instead, there follows an outline of the experimental methods employed for three different media:

1. For hybrid mixture: in order to accomplish the hybrid mixture explosion experiments, after the dust was first placed in the 0.6 L container the premixed gas/air mixture at 2 MPa pressure was added using the partial pressure method. The dust was then dispersed through a rebound nozzle into the vacuum chamber at −0.6 bar via the premixed gas/air mixture. The ignition delay time was 60 ms.
2. For pure dust: when conducting the dust/air explosion experiments, the dust was first placed in the 0.6 L dust container, followed by the addition of the compressed air at 2 MPa pressure. The dust was then dispersed into the vacuum chamber at −0.6 bar by the compressed gas.

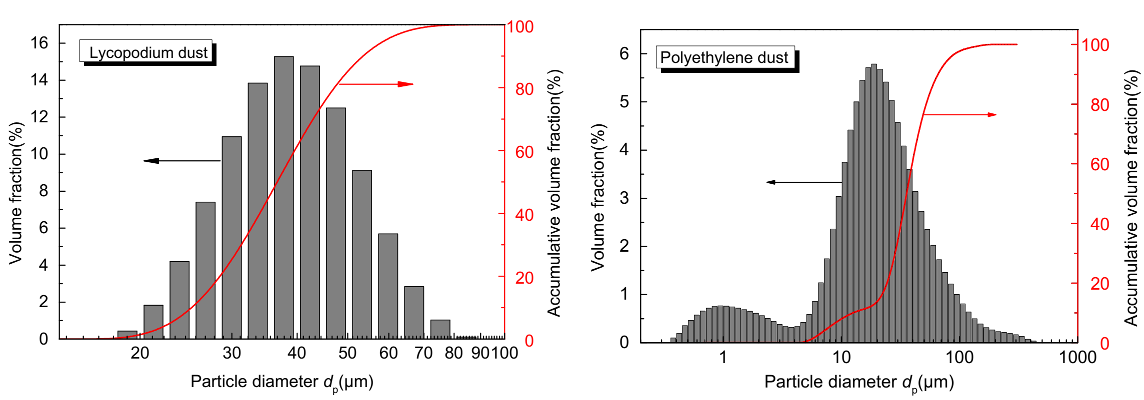

Fig. 2. Particle size distribution of lycopodium dust and polyethylene dust.