Journal of Loss Prevention in the Process Industries 44 (2016) 424–432

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Effect of dust dispersion on particle integrity and explosion hazards

Pranav Bagaria [a], Jiaqi Zhang [a], Entao Yang [b], Ashok Dastidar [c], Chad Mashuga [a, *]

[a] Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, 77843-3122, USA
[b] Tianjin University, Nankai District, Tianjin, 300072, China
[c] Fauske & Associates, LLC, IL, 60527, USA

A R T I C L E I N F O

Article history:
Received 29 August 2016
Received in revised form
1 November 2016
Accepted 1 November 2016
Available online 3 November 2016

Keywords:
Dust explosion
20-L standard explosion apparatus
Dispersion system
De-agglomeration (particle-breakage)
Particle size distribution
Nanomaterial

A B S T R A C T

Dust explosion hazards can be described with parameters such as MIE, MEC, P_{max}, K_{st} etc., which are known to depend on particle size distribution within a dust cloud. Literature has shown the dispersion system (outlet valve, in particular) in a standard 20-L dust explosion apparatus breaks the dust into smaller particles leading to explosion parameters not necessarily corresponding to the original size. This study uses a novel dispersion system in a 36-L dust explosion apparatus to eliminate the mechanical shearing from the outlet valve and investigates its effect on dust particle integrity. The study also aims to observe the role of dispersion stages (nozzle and dispersion cloud turbulence) on particle breakage and compare the performance of our dispersion system to that of a standard 20-L apparatus. In addition, the role of dust dispersion concentration on particle breakage is examined. Anthraquinone, Acetaminophen (Paracetamol) and Ascorbic Acid are used to accomplish the goals of the study. Finally, the effect of dispersion on a nanomaterial is investigated using Carbon Nanofibers (CNFs).

Anthraquinone, Acetaminophen and Ascorbic Acid show that even in the absence of an outlet valve, significant particle breakage occurs. This demonstrates the major role of both the dispersion nozzle and cloud turbulence in particle breakage. In addition, the experiments revealed dispersion concentration to be an important factor in particle breakage and helped establish the inverse relation between particle breakage and dust dispersion concentration. Nanomaterial experiments with CNFs show significant de-agglomeration in the dispersion cloud followed by re-agglomeration.

1. Introduction

Numerous studies have investigated explosion parameters such as P_{max}, K_{st}, MEC, LOC etc. for various dusts using a standard 20-L spherical dust explosion vessel in accordance with standards described in both Europe and America (International Standards Organization (ISO) Method 6184/1; National Fire Protection Association (NFPA) Standard 68; ASTM International Method E1226, E1515; German Society of Engineers (VDI) Method 3673, British European Standard (BSEN) 14034) (Eckhoff, 2006; Di Sarli et al., 2014). These standards describe the dust explosion testing vessel as a closed chamber having at least a 20-L volume with a spherical or near cylindrical geometry (length/diameter ratio ~ 1) and having a uniformly dispersed cloud and atmospheric conditions before ignition. Most studies reporting dust explosion parameters use a standard 20-L spherical explosion device in which according to the standard procedure, the dust is stored in a dust container (located outside the explosion vessel) and a dispersion nozzle is fixed inside the vessel. The explosion vessel is then evacuated to approximately 0.4 bar and the dust container is pressurized to approximately 21 bar with compressed air, and is then released to carry the dust from the dust container through the outlet valve and dispersion nozzle into the vessel, creating a uniform dust cloud at ambient pressure (see Fig. 2a.). Ignition is provided by a small explosive igniter at the center of the vessel after a delay of ~60 m s, while the Data Acquisition System (DAQ) captures the deflagration pressure as a function of time. The dispersion nozzle (typically a rebound nozzle or annular perforated nozzle) facilitates a uniform, turbulent dust cloud inside the spherical explosion vessel.

Kalejaiye et al. (2010) investigated the uniformity of the dust cloud formation with three different dusts using a rebound and annular nozzle inside the 20-L explosion vessel with the help of the Pittsburgh Research Laboratory's optical probe which was placed at

* Corresponding author. 3122 TAMU Room 205, College Station, TX, 77843-3122, USA.
E-mail address: mashuga@tamu.edu (C. Mashuga).

http://dx.doi.org/10.1016/j.jlp.2016.11.001
0950-4230/

six different locations. They found the degree of dust dispersion for both nozzles is similar and that good dust dispersion uniformity is achieved by both nozzles based on transmission data at six different locations. However, they noted that the received transmission data was lower than theoretically predicted by Bouguer's law. They investigated this by measuring the particle size for pre and post-dispersion. They showed the particle size reduces to about 50% of its original size and cited the grinding/shearing action from the outlet valve as the main reason with the dispersion nozzle and cloud turbulence having minimal effect on particle breakage. Du et al. (2015) used a transparent 20-L spherical chamber along with a high speed camera and an image processing technique to study the behavior of dust dispersion using carbonaceous (wheat flour) dust. Their qualitative analysis based on transmission data and turbulence levels categorized the dust dispersion as three distinct stages: injection stage, stabilization stage and sedimentation stage. They concluded that good dust cloud uniformity is achieved during the stabilization stage. Moreover, they noted that the duration of the stabilization stage varies with dust concentration, thus a variable ignition delay would be required to achieve identical turbulence and record accurate explosion results. They also showed that an increase in dust concentration leads to a plateau in transmission data indicating the dust is not fully dispersed, especially at high concentrations. Sanchirico et al. (2015) studied the effect of typical dispersion nozzles (rebound nozzle and annular perforated ring nozzle) on particle breakage using six different dusts in a 20-L vessel. They found the rebound nozzle has a more prominent role than the annular perforated nozzle in particle breakage. They also showed the effect of dispersion pressure on particle integrity and concluded higher dispersion pressure leads to increased particle breakage.

Work by Du et al. (2015), Kalejaiye et al. (2010) and Sanchirico et al. (2015) suggest the results from a standard 20-L explosion apparatus can be misleading. Mittal (2014) examined the dependence of P_{max} and K_{st} on dust size. This work showed as the dust size decreases, both the P_{max} and K_{st} increases to a certain value and thereafter decreases with further decrease in particle size. Thus, the 20-L explosion apparatus dispersion mechanism, which breaks the dust particles due to shear/grinding from the outlet valve and possibly the nozzle (Kalejaiye et al., 2010; Sanchirico et al., 2015), can lead to misleading results. It can be overestimating or underestimating the explosion risk depending on the initial particle size of the dust being tested. It was suggested that a novel dust dispersion mechanism that offers minimal particle breakage and can help in procuring more representative explosion/flammability parameters is needed (Kalejaiye et al., 2010; Sanchirico et al., 2015). The effect of the dispersion stages (nozzle, dispersion cloud) on particle breakage is important but not yet quantified. Since different dust concentrations have different dispersion behavior, the relation between dust concentration and particle breakage needs to be verified. In addition, with an increase in industrial scale use of nanomaterials, the behavior of nanomaterial dusts post-dispersion also needs to be analyzed for explosion risk assessment.

In this study, we offer a novel dust dispersion system in which dust does not pass through the outlet valve, thus receiving minimal mechanical grinding and shearing. We studied the effect of this dispersion system on particle integrity and attrition in our 36-L dust explosion apparatus. In addition, we performed the following:

- Comparison of the performance of our dispersion system to a standard 20-L system
- Quantification of the particle breakage from the rebound nozzle and dispersion cloud turbulence
- Dependence of particle breakage on dust concentration
- Analysis of post-dispersion behavior of nanomaterials

2. Experiments

2.1. Apparatus

Dispersion studies were carried out using a novel dispersion system in a custom 36-L dust explosion apparatus. The apparatus is calibrated to yield results in agreement with a standard 20-L and 1-m^3 apparatus (Castellanos et al., 2010). Our 36-L explosion apparatus and a standard 20-L explosion apparatus are similar not only in terms of generated results but the dispersion pressure, ignition delay and turbulence at ignition. The 36-L explosion vessel consists of seven main parts (see Fig. 1.): (1) Vacuum System, (2) Air Reservoir, (3) Fast Acting Valve, (4) Dust Container, (5) Rebound Dispersion Nozzle, (6) Igniters, (7) Pressure Transducers (Castellanos, 2013; Zhang et al., 2015).

The procedure starts with loading the dust into the dust container, and installing the rebound nozzle, igniters and flanged lid. A customized LabVIEW™ program evacuates the vessel to 10.3 psi, then supplies compressed air to the air reservoir to achieve 314.7 psi. This air is then released via a fast-acting valve actuated for 50 ms. This released compressed air carries the dust from the container through the nozzle into the vessel to make a turbulent dust cloud at 14.7 psi absolute. 25 ms after valve closure, the igniters are activated (Castellanos et al., 2014; Jiang et al., 2014).

In this study, only the dispersion dynamics of our novel dispersion system and that of a standard 20-L apparatus was investigated without ignition. The difference between our dispersion system in this apparatus and that of a standard 20-L apparatus is shown in Fig. 2. In our dispersion system, the dust is stored just below the 36-L vessel and does not pass through the outlet valve (which was reported as the main reason for de-agglomeration by Kalejaiye et al. (2010)). This setup enabled us to investigate the particle breakage due to the nozzle, the dispersion cloud, and the combination of both.

2.2. Materials

For this study, Anthraquinone, Acetaminophen, and Ascorbic Acid were selected as study materials because each has a different range of particle breakage based on hardness (elasticity), fracture toughness, initial particle diameter, and other physical properties

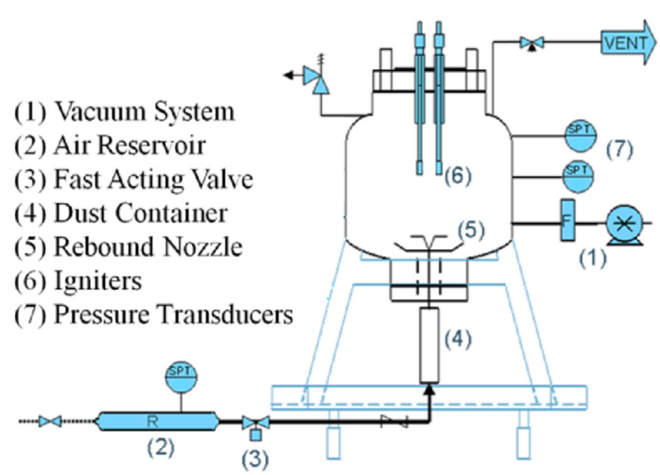

Fig. 1. Schematic of 36-L dust explosion apparatus. Reprinted with permission from Zhang, J., Chen, H., Liu, Y., Elledge, H., Mashuga, C. V., & Mannan, M. S. (2015), "Dust Explosion of Carbon Nanofibers Promoted by Iron Nanoparticles," *Industrial & Engineering Chemistry Research*, 54(15), 3989–3995. Copyright 2015, American Chemical Society.