Journal of Loss Prevention in the Process Industries 48 (2017) 145–150

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Partial inerting of dust clouds using a modified standard minimum ignition energy device

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ARTICLE INFO

Article history:
Received 31 January 2017
Received in revised form
20 April 2017
Accepted 20 April 2017
Available online 25 April 2017

Keywords:
Minimum ignition energy
Partial inerting
Dust explosion

ABSTRACT

Partial inerting is an important but underutilized mitigation technique in which minimum ignition energy (MIE) of a dust cloud is increased through inerting, reducing the risk of an accidental dust explosion or more accurately, a dust deflagration. This technique has wide application potential in numerous chemical and general manufacturing industries. The Kühner MIKE3 is the predominant apparatus for measurement of the minimum ignition energy (MIE) of combustible dusts worldwide. The current version of the MIKE3 device is not specifically designed to measure partial inerting minimum ignition energies. The purpose of this work is to demonstrate that a properly designed add on purge device and technique can accurately produce partial inerting MIE results with an existing MIE device.

The purge device ensures complete purging of the Hartman dust dispersion tube with the desired gas concentration before experimentation. The same gas is then pulsed into the dispersion tube producing the dust dispersion for ignition testing. This approach leads to uniform testing conditions in the tube with respect to gas concentration which is essential for producing proper measurements. Additionally, experiments show the turbulence generated by the purging technique did not significantly affect the MIE measurements. Therefore, an important finding of this work is that purging the tube before partial inerting MIE testing results in a proper characterization of the relationship between the MIE and oxygen for the dust. The findings therefore demonstrate the need to amend existing or develop new standards for this type of dust testing. The effect of these modifications and techniques are demonstrated by the experimental determination of the partial inerting curve for Niacin (CaRo15) using the Kühner MIKE3 apparatus.

1. Introduction

In the process industries, dust explosions pose a threat to numerous powder manufacturing facilities (Bartknecht, 1989; Cashdollar and Hertzberg, 1986; Eckhoff, 2003; Yuan et al., 2015). For a dust explosion to occur, five key elements must be present known as the dust pentagon. The sides of the pentagon are dust fuel, oxygen from the air, dispersion, confinement and an ignition source. For the ignition source, a value exists which is the smallest amount of energy required for ignition of the dust in cloud form at a given temperature and pressure. This lowest energy is the minimum ignition energy or MIE of that dust (Abbasi and Abbasi, 2007; Eckhoff, 2003).

Precise measurement of the MIE is critical in determining the likelihood of a dust explosion. One common industrial method for reducing dust explosion potential is inerting the process where the dust occurs or might likely occur. Inerting is a common practice in the chemical industry for reactors, grinding, mixing processes, vessels, silos, mills, filling facilities, and dryers (Cashdollar and Hertzberg, 1986; Hoppe and Jaeger, 2005).

For combustible dust processes, often designers and operators fully inert the process or use no inerting at all. This decision is influenced by the value of the MIE and the equipment's ability to be effectively inerted. The decision to inert the process is significant because it comes with the risk of asphyxiation and proper precautions must be taken. It is a myth, assumed by many that complete oxygen removal is essential to prevent dust explosions (Amyotte, 2013, 2014).

Partial inerting is an intermediate technique which mitigates dust explosions and has a wide application potential in industry (Eckhoff, 2004; Hoppe and Jaeger, 2005). It involves reducing the

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http://dx.doi.org/10.1016/j.jlp.2017.04.022
0950-4230/

oxygen content with an inert gas (e.g. nitrogen, carbon dioxide, argon) which causes the MIE of the dust to dramatically increase with the addition of a few percent inert for many dusts. Hoppe and Jaeger (2005) discussed the implementation of partial inerting methods in the chemical processing industry. Therefore, it is observed that partial inerting provides a potential alternative to complete or no inerting. Some of the advantages of partial inerting are that it is more cost effective, safer with respect to asphyxiation, it can maintain product quality for certain products that require oxygen and it significantly reduces the vent area for explosions (USCSB, 2003; Eckhoff, 2004, 2009; Amyotte, 2013).

The earliest record of partial inerting to mitigate dust explosion potential was reported by Glarner (1984). Following this, a few studies have explored the concept of partial inerting (Glor and Schwenzfeuer, 1996; Zeeuwen, 1996; CREDIT, 1995). Glor and Schwenzfeuer (1996) experimentally investigated the effect of changing the oxygen content on the MIE for a number of common combustible substances. Additionally, they proposed a model to describe the MIE behavior of any dust as a function of the oxygen concentration. Eckhoff (2004) promoted partial inerting as an important parameter in dust explosion mitigation and the necessity to further exploit its potential.

The Kühner minimum ignition energy device is one of the standard devices used by experts worldwide for decades to conduct MIE testing of dust clouds (Glor and Schwenzfeuer, 1996; Ackroyd et al., 2011; Choi et al., 2015, 2016; Chunmiao et al., 2014; Iarossi et al., 2013; Marmo and Cavallero, 2008; Wu et al., 2009). To date, investigations in the area of partial inerting have mainly focused on the impact of nitrogen on MIE values rather than the experimental method used. Researchers have only briefly mentioned maintaining oxygen-nitrogen compositions in the Hartman tube consistent with the gas used for dust dispersion (Ackroyd et al., 2011; Choi et al., 2015). Ackroyd et al. (2011) filled the tube near the electrodes before testing, while Choi et al. (2015) reports the implementation of a purge through a small opening in the lid assembly at the top of the device. However, the experimental details on the employed purging techniques and their effectiveness have not been discussed in previous works.

This paper presents a simple modification to the Kühner MIKE3 device, which could also be applied to other devices which will result in accurate measurement of the partial inerting MIE. This work demonstrates the importance of adopting a proper test method in which the MIE Hartman tube is purged with the same gas composition used for the dust dispersion. The objectives of this study are to describe the device modifications and provide quantification of the proper procedures through demonstration of their impact on the experimental partial inerting MIE data.

2. Approach

2.1. Materials

The material used in this study is Niacin (CaRo 15), which is a material used for participation in the international round robin comparing minimum ignition energy devices (Kühner, 2015). The material is commonly known as Vitamin B_3 or Nicotinic acid ($C_6H_5NO_2$) and is a favorable calibration material due to its pharmaceutical level of chemical purity, low moisture absorbance, consistent particle size, and its low MIE (~1.7 mJ) at atmospheric conditions (Kühner, 2015; Sanchirico et al., 2015). The Niacin was obtained from Kühner AG pre-milled, homogenized and stored in an airtight package. The dust was tested as received, as is recommended in the Kühner international round robin. The MIKE3 device mentioned in this work was used to participate in this round robin, and our results were certified to be within the established tolerance range for the 54 international participants in the study.

Fig. 1 has been redrawn from inerting studies conducted by Glarner (1984) which shows the impact of oxygen content on the minimum ignition energy. The MIE − oxygen relationship for both Pea Flour and Lycopodium asymptotically approach the energy and concentration axis. The relationship between the MIE and oxygen concentration for any dust can be defined by two asymptotes - the Limiting Oxygen Concentration (LOC) and LIE (Limiting Ignition Energy) which was stated by Schwenzfeuer et al. (2001). For Lycopodium, there is a flatter energy level response around 21% oxygen (air). However, for Pea Flour, the MIE can vary significantly with small changes in oxygen around the composition of air. Melamine is quite linear in this semi log plot. From the behaviors of these materials it can be concluded that small variations in the composition of air may cause either a minor or major shift in reported MIE values and is highly dependent on the type of dust. This warrants the use of highly reliable gas concentrations for conducting standard as well as partial inerting MIE tests. The vertical small dashed lines in Fig. 1 show the composition range of air synthesized from Ultra High Purity (UHP) sources resulting in air nominally 21% oxygen, ±1%. Breathing air, zero grade air, and ultra zero air can also be nominally 21% oxygen with a possible low of 19.5% and an upper value of 23.5%, shown in Fig. 1 as larger dashed vertical lines. However, with UHP synthesized air the variability in oxygen composition and hence MIE values are greatly reduced compared to that of other types of air. For the data presented in this study, the gas compositions were tested with UHP synthesized air to ensure negligible compositional variability of the gas. Moreover, the gas strictly adhered to the standards of <0.1 ppm carbon dioxide and <0.36 ppm moisture. The gas compositions at which the MIE was tested in this study were (12% oxygen, 88% nitrogen), (14% oxygen, 86% nitrogen), (16% oxygen, 84% nitrogen), (18% oxygen, 82% nitrogen) and (21% oxygen, 79% nitrogen).

2.2. Experimental setup and modifications

Partial inerting experiments of this work were conducted in the Kühner MIKE3 Minimum Ignition Energy device (Fig. 2), which is used worldwide for testing the ignition sensitivity of combustible dusts. The dust dispersion system consists of a nozzle around which a dust sample is placed. The nozzle disperses the dust into a 1.2 L glass Hartman tube with an air pulse of 7 bar. A capacitive spark triggered between two tungsten electrodes is used to attempt ignition of the dust cloud formed after dispersion. The device can deliver ignition energy from 1 to 1000 mJ. The device capacitors allow energy levels of 1, 3, 10, 30, 100, 300 and 1000 mJ. The device permits variable inductance in the ignition circuit of 0 mH or 1 mH and adjustable ignition delay times of 90, 120, 150 and 180 ms. However, no minimum ignition energy device, including the Kühner MIKE3 is specifically designed to conduct partial inerting tests.

To overcome this limitation, an innovative modification of the device was made which utilizes a single gas source of desired composition to purge the tube and then drive the dispersion. Fig. 3 shows a schematic of the MIE device and highlighted modifications. Gas from a cylinder is split with one segment providing purging of the 1.2 L Hartman tube from the top through a purge device and the other segment connects in the standard way to the MIE device for dispersion. A needle valve on the flowmeter is used to regulate the purge gas flow to the Hartman tube. The purge device, shown in Fig. 4 is integrated into the flap valve at the top of the Hartman tube and has been specifically designed to provide a maximum flow of purging gas so as to not disturb the dust in the dust container at the bottom of the Hartman tube. For this work the purge flow rate was fixed at 10 L/min for 20 s which ensured complete purging of the 1.2 L Hartman tube. The purge device is fabricated from corrosion