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Minimum ignition energy of mixtures of combustible dusts

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ABSTRACT

Most industrial powder processes handle mixtures of various flammable powders. Consequently, hazard evaluation leads to a reduction of the disaster damage that arises from dust explosions. Determining the minimum ignition energy (MIE) of flammable mixtures is critical for identifying possibility of accidental hazard in industry. The aim of this work is to measure the critical ignition energy of different kinds of pure dusts with various particle sizes as well as mixtures thereof.

The results show that even the addition of a modest amount of a highly flammable powder to a less combustible powder has a significant impact on the MIE. The MIE varies considerably when the fraction of the highly flammable powder exceeds 20%. For dust mixtures consisting of combustible dusts, the relationship between the ignition energy of the mixture and the minimum ignition energy of the components follows the so-called harmonic model based upon the volume fraction of the pure dusts in the mixture. This correlation provides results which show satisfactory agreement with the experimental values.

1. Introduction

The mixing of particulate solids is a common process that is used widely in various industries such as the manufacturing of pharmaceuticals, the food industry, etc. Mixing processes are found also in coal-fired and biomass co-firing plants in which mixtures are used to decrease the emission of carbon dioxide. If the powders are flammable, mixing processes may lead to fires and/or explosions. The minimum ignition energy of a dust cloud is used as a measure for the ignition sensitivity of a dust.

The severity of an explosion depends upon the maximum explosion pressure and maximum rate of pressure rise (Cashdollar, 2000). The minimum ignition energy (MIE) is defined as the lowest energy value of a high-voltage capacitor discharge that is capable of igniting an ignitable mixture.

Many empirical and theoretical studies on the minimum ignition energy (MIE) of pure dusts are available, yet only a few studies focus on dust mixtures (Bartknecht, 1989). Bartknecht explored the explosibility of cellulose when different kinds of gas are added to it. He found that a hybrid mixture that is composed of a non-explosive gas and a non-explosive dust can become an ignitable one.

Randeberg and Eckhoff (2007) developed a spark generator, which was capable of producing synchronized sparks of very low energies. It also included an integrated system to measure the spark energy and MIE for flammable dusts. Marmo and Cavallero (2008) investigated the MIE of clouds of fibers dispersed in air with special attention paid to the diameter and length of the fibers. Janes et al. (2008) measured the MIE values for several types of powder using two different explosion tubes: MIKE3 and Hartmann. Their research shows that the MIKE3 apparatus provides MIE results which are equal or lower than those measured with the Hartmann apparatus. Furthermore Azhagurajan et al. (2012) carried out experimental work on the MIE of nano and micro powders. His results show that the MIE of flash powder is reduced by a decrease in particle size. Dafaud et al. (2012) showed the effects of mixing small amounts of less combustible or non-combustible powders to a flammable dust cloud on ignition sensitivity and explosion severity. He observed that a small amount of highly flammable dust can strongly increase the ignitability of a less reactive dust. The models presented by Janes and Carson (2013) indicate that the bulk density difference between two mixture constituents sometimes results in sedimentation of the heavier dust. In addition Danzi et al. (2014) provided minimum ignition temperatures for different dust mixtures. These values were obtained by mixing a combustible dust

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with inert dust.

This paper is mainly concerned with measuring the minimum ignition energies for different types of combustible dusts and density as well as their mixtures. The results of this investigation are analyzed with a harmonic model that provides a reliable estimate for the MIE of mixtures. The purpose of this research is to validate this harmonic model for powder mixtures with a large range of densities and minimum ignition energies.

The paper is organized as follows. In Section 2, the experimental set up and the procedure are presented. Experimental results along with the analytical predictions are given in Section 3. Finally, the conclusions are summarized in Section 4.

2. Experiments

2.1. Apparatus and test procedure

The MIE is defined as the minimum energy released in a spark from an electrical circuit that ignites the dust cloud. Minimum ignition energy is determined with an electrical spark igniter as shown in Fig. 1 (Siwek and Cesana, 2001) and by following the method defined in the standard EN 13821 (CEN, 2003) and making use of a MIKE3 apparatus. All tests are performed at atmospheric pressure and room temperature.

The combustion chamber is a glass tube with a volume of 1.2 L, and is provided with a mushroom-shaped dust dispersion system. Dust dispersion is triggered by a compressed air blast at 7 barg. The air blast generates considerable turbulence and results in the creation of a dust cloud. A spark is drawn between two electrodes that are made of stainless steel. According to the standard, the spark gap is set at 6 mm. In this study, all tests were performed with an inductance of 1 mH.

The discharge energy values at which tests can be performed are: 1000, 300, 100, 30, 10, 3 and 1 mJ. The MIE lies between the lowest energy value (E_2) at which ignition occurred and the energy (E_1) at which in at least 10 successive experiments no ignition was observed. Thus, the determined energy range is named the minimum ignition energy of a combustible dust in a mixture with air.

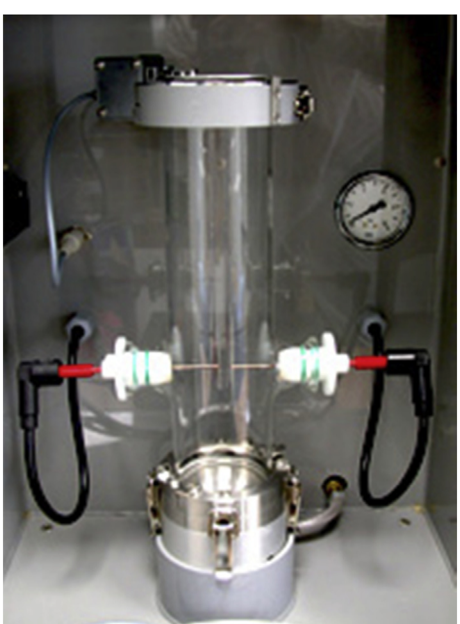

Fig. 1. Experimental apparatus.

The MIE is usually stated as a range of values rather than a single value. But in order to compare the MIE of the different combustible powders more clearly, we use only a single value. This value can be estimated using the probability of ignition as stated below (CEN, 2003):

$$\log MIE = \log E_2 - I[E_2].\frac{(\log E_2 - \log E_1)}{(NI + I).[E_2] + 1} \quad (1)$$

I[E2] is the number of tests with successful ignition at E2 and (NI + I) [E2] stands for the total number of tests at the energy level of E2. The values obtained using the above formula will have a maximum uncertainty of 1 mJ.

2.2. Material tested

In order to investigate the explosion sensitivity, seven different dusts are used, which are listed in Table 1. These dusts were chosen according to their particle size distribution, density and flammability. In order to ensure the ability of the chosen powders to ignite, some guidelines were followed. Since high moisture content in the dust restricts the efficiency of the ignition, the moisture content of the selected dusts should be in an acceptable range. Hence, Sebuku coal was first dried and the moisture content was set at maximum 3% for the tests.

The selected powders were milled and sieved to produce a sufficiently fine fraction for the experiments. The particle size distributions, d50 which is known as the median value, were determined by laser diffraction analysis according to ISO 13320.

3. Results and discussion

In Fig. 2 the experimental results for four types of dusts are shown as a function of the dust concentration. A solid dot indicates ignition and a hollow dot shows that there was no ignition at that specific concentration and energy value. It can be seen that Cacao, for example, is able to ignite at 1000 mJ within the whole range of concentration, whereas at 300 mJ it is not capable of ignition at any concentration. Using Equation (1), the MIE of cacao is equal to 350 mJ. Similarly, it can be seen that the MIE of the South African coal cannot be determined by using the Mike3-apparatus. Table 2 shows a summary of the obtained results for various pure dusts. It is observed that in this classification of dusts based on energy, zirconium is an extremely combustible powder whereas South African coal, having a MIE of more than 1000 mJ, is rather insensitive to electrostatic discharge ignition.

According to the IEC standard (IEC, 1994) the conformity between two sets of equipment is obtained when MIE values differ less than a factor of 3. Also based on the mentioned formula, the MIE of lycopodium is 4 mJ which lies between 3 and 10 mJ. This is in good agreement with the defined value in the ICE standard of 5–15 mJ. Therefore the reliability of the MIE value obtained through this apparatus and Equation (1) would be confirmed.

Sebuku and South African coals were selected as a first mixture because of their large difference in minimum ignition energy and their similar density. The minimum ignition energy of Sebuku-South African coal mixture is depicted as a function of the Sebuku concentration in Fig. 3. As the MIE of South African coal is more than 1000 mJ, ignition can only be established by adding at least 27% Vol Sebuku coal to 73% Vol South African coal (i.e. 25% wt. Sebuku/75% wt. South African coal).

There is a strong decrease in MIE when increasing the Sebuku mass in the range of 0–35% volume. In contrast, there is a slight fall in MIE when the Sebuku concentration is greater than 35%. Evidently, the minimum ignition energy of a Sebuku/South African