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Experimental investigations of the minimum ignition energy and the minimum ignition temperature of inert and combustible dust cloud mixtures

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HIGHLIGHTS

- Ignition sensitivity of a highly flammable dust decreases upon addition of inert dust.
- Minimum ignition temperature of a highly flammable dust increases when inert concentration increase.
- Minimum ignition energy of a highly flammable dust increases when inert concentration increase.
- The permissible range for the inert mixture to minimize the ignition risk lies between 60 to 80%.

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ABSTRACT

The risks associated with dust explosions still exist in industries that either process or handle combustible dust. This explosion risk could be prevented or mitigated by applying the principle of inherent safety (moderation). This is achieved by adding an inert material to a highly combustible material in order to decrease the ignition sensitivity of the combustible dust. The presented paper deals with the experimental investigation of the influence of adding an inert dust on the minimum ignition energy and the minimum ignition temperature of the combustible/inert dust mixtures. The experimental investigation was done in two laboratory scale equipment: the Hartmann apparatus and the Godbert-Greenwald furnace for the minimum ignition energy and the minimum ignition temperature test respectively. This was achieved by mixing various amounts of three inert materials (magnesium oxide, ammonium sulphate and sand) and six combustible dusts (brown coal, lycopodium, toner, niacin, corn starch and high density polyethylene). Generally, increasing the inert materials concentration increases the minimum ignition energy as well as the minimum ignition temperatures until a threshold is reached where no ignition was obtained. The permissible range for the inert mixture to minimize the ignition risk lies between 60 to 80%.

1. Introduction

Dust explosions are one of the major concerns in many industries that handle or process combustible bulk materials [1]. Many materials that are flammable in bulk form become explosible if dispersed as a cloud of fine particles in air. Thus, in industries that manufacture, transport, process and/or use combustible, dusts explosions present a real hazard to both staff and equipment. In order to prevent and mitigate the risk associated with these kind of incidences, the explosion parameters, such as maximum explosion pressure, maximum rate of pressure rise, deflagration index, minimum explosible dust concentration, minimum ignition energy (MIE) and minimum ignition temperature (MIT) have to be determined. Addition of inert substance to highly combustible substance can reduce the risk associated with combustible dust by decreasing the ignition sensitivity such as MIT and MIE.

This principle of inerting could be considered as inherent safety (moderation). In order to achieve an acceptable level of safety, the principles of inherent safety have to be kept in mind during the conceptual phase of an installation [2,3]. However, if the potential benefits of inherent safety are generally well recognized, its systematic application remains marginal and sometimes difficult [4,5]. The promotion of this concept must then be done both by industrialists and legislators, especially by the definition of new normative barriers based on these principles [6]. Amyotte et al.

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[7,8] described in detail how the inherent safety principles can be implemented in practice to prevent and mitigate accidental dust explosions in process plants, notably by using the moderation principle. Thus, mixing an inert solid or a less flammable material with a combustible dust can be regarded as a direct application of such principle, as it allows the use of the hazardous material in a less hazardous form. Industrial applications of such mixtures of combustible and inert powders are numerous. For instance, in the pet food industry, minerals are added to organic powders in order to enhance the palatability, to provide nutrients or to modify the appearance of the food. In the plastics or textile industries, mineral loadings are used to obtain thermally stable polymers or to improve the mechanical properties of the fibers, membranes or coatings. Another example is the addition of silicon dioxide as anti-caking agent in dried milk or icing sugar. In these cases, the presence of inert solid materials is required by the process or the consumer and has an influence of the flammability of the products. In the case of solid inerting, for instance, when rock dusts is mixed with coal in the mining industries [9,10] or when flame-retardants are added to foams or textiles, the main objective is to prevent the materials to ignite, but this addition can have significant effects on the fabrication process and the other properties of the final product.

It is therefore important to determine safety parameters such as the minimum ignition energy and the minimum ignition temperature of dust clouds and the explosion sensitivity as a function of the inert material and not for the pure flammable dust alone. The MIT is used to evaluate the probability of ignition by hot surfaces. Hot surfaces capable of igniting dust clouds exist in a number of situations in the industry (furnaces, burners and dryers of various kinds). The MIE provides the information to which types of sparks have to be considered as ignition sources.

Electric sparks and electrostatic discharges as well as hot surface are considered as one of the common source of ignition for dust explosions occurring in workplaces. Numerous researches have therefore been carried to determine both the MIT and MIE of single substance, but in the case of dust to dust mixtures, only few data is available [11–17].

In this present paper, six highly combustible dusts (toner, lycopodium, niacin, high-density polyethylene, cornstarch and brown coal) were mixed with three inert dusts (ammonium sulphate, magnesium oxide and sand) to determine their ignition sensitivity (MIT and MIE).

2. Materials and experimental work

2.1. Materials

Six combustible dusts namely cornstarch, lycopodium, toner, niacin, PE-HD and brown coal were mixed with three inert materials namely; ammonium sulphate, magnesium oxide and sand to determine both the MIT and MIE. The particle size distribution is one of the important properties that affect the ignition sensitivity of dust clouds. As a results of that, the particle size distribution of all the dust used was examined using a standard equipment (CAMSIZER). The equipment measures particle size distribution by laser diffraction. Figs. 1 and 3 show the particle size distributions for both combustible and inert dusts used. Furthermore, in order to reveal the surface structure of the particles, Scanning Electron Microscopy (SEM) images for all the dusts used were taken with different magnifications. The images provide the various shapes and pore size of each dust sample. For example, it could be seen that starch particle agglomerates together thereby increasing the individual particle size which could affect the global settling velocity. Figs. 2 and 4 also show the Scanning Electron Microscopy (SEM) images for both the combustible and inert dust respectively.

Table 1 summarizes data for various preparatory analysis and properties of the combustible dust. The parameters considered are the elemental analysis, median particle sizes, moisture content, heat of combustion and molecular formula of the dusts that were calculated from elemental analysis. Table 2 also lists the various preparatory analysis of the inert materials.

2.2. Sample preparation

A 250 ml glass bottle (transparent) was used for mixing the test samples. For every mixture combination, both the combustible dust and inert dust were weighed separately and then placed in a glass bottle. The bottle was shaken vigorously in all possible directions to get homogenous mixing, it was then left for some time for dust to settle down as a flying dusts. To prevent segregation of the finer dust from coarser one, a continuous slow tumbling of the bottle was further done to ensure complete homogeneity.

2.2.1. Measurement of the minimum ignition temperature

In this present paper a modified Godbert-Greenwald furnace was used. It mainly consists of a steel furnace tube, an air reservoir, a pressure regulator. The furnace tube is 42 cm long which is twice the length of the standard as described in EN50281 [19] and 3.5 cm inside diameter. It is heated externally by an electric coil of chrome wire. The furnace tube is mounted vertically in a mild steel case lined with glass wool and filled up with bulk wool to act as a thermal insulation. The furnace is vertical with an opening at the bottom. The upper end is connected to the dust holder by means of an adaptor. The dust is injected into the furnace by an air pulse, which is obtained by opening a solenoid valve to discharge the air stored in a reservoir. A mirror is placed at the bottom of the furnace which allows the operator to observe the inside of the furnace. A thermocouple is placed closed to the inner wall of the furnace that is connected to a PID temperature controller. Fig. 5 shows the experimental setup for MIT of dust mixtures test.

In order to test for the MIT of combustible and inert dust mixtures, the furnace tube was heated and fixed to the desired temperature (the maximum allowable temperature of the furnace used was 700 °C) and the amount of dust weighed beforehand was placed in the dust chamber. The air reservoir was filled with air up to the desired dispersion pressure and the dust sample was then dispersed through the furnace tube by the blast of air. The criterion for an explosion was an observation of a flame at the bottom open mouth of the furnace or within (with the help of the mirror). Both the pressure in the air reservoir (0.1–0.5 bar above atmospheric pressure) and the mass of dust (0.1–0.5 g) were varied until a vigorous explosion was obtained. The condition at which the vigorous explosion occurs was taken as the "best" explosion condition. This condition was maintained, the furnace temperature was lowered and testing continued until no flame was observed in for ten successive attempts as shown in Fig. 6. The difference in temperatures between explosion and no explosion was 5 °C. The lowest temperature at which ignition with flame occurred was taken as the minimum ignition temperature. As soon as the MIT was obtained, further tests were performed at a furnace temperature 5 °C below the MIT by varying both pressure and mass of dust mixtures to confirm the non-ignition state.

2.3. Measurement of the minimum ignition energy

The minimum ignition energy was measured using an electric spark igniter (Hartmann apparatus MIE III by the courtesy of Chilworth—DEKRA Company) according to a protocol similar to that defined in EN 13821 standards [20]. 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 was