Contents lists available at ScienceDirect

Process Safety and Environment Protection

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

Dust explosions: How should the influence of humidity be taken into account?

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ABSTRACT

In this work, the influence of humidity on dust explosions of metallic (aluminium) and organic materials (icing sugar, polyethylene and magnesium stearate) has been studied. The impact of pre-humidification of powders on their ignition sensitivity, their volume resistivity and charge decay time has been assessed. The influence of humidity on explosion severity has also been studied by two methods: on the one hand, the dust sample was stored in a controlled workstation at constant relative humidity; on the other hand, the dry dust was dispersed in a humidity controlled atmosphere in the vessel.

As expected, the effect of humidity strongly depends on the chemical nature of the particles. Experiments on powders volume resistivity and charge decay time have shown typical trends but have especially pointed out the inadequacy of some standards. Inhibition phenomena have been verified for polyethylene and magnesium stearate, whereas both inhibition and promotion have been observed for icing sugar and could be explained by an evolution of sucrose structure. Dry aluminium dust explosions in humid atmosphere show that water vapour inerts the explosion. However, when aluminium is stored at controlled humidity, the maximum rise of pressure rate increases with the water content, which is probably due to hydrogen generation.

Keywords: Dust explosions; Ignition sensitivity; Equilibrium relative humidity; Static electricity; Standards

1. Introduction

Like fire and ice, humidity and dusts explosions have often been considered as antagonistic forces. A glance at case histories and statistics tends to corroborate this assertion. For instance, Count Morozzo's account of the first quoted dust explosion in a flour warehouse in Turin on the 14 December 1785, mentioned that this accident could be attributed "to the extraordinary dryness of the corn" due to a "remarkably dry" weather (Eckhoff, 2003). Li et al. (1995) also underlined that statistics on dust explosions in the United States from 1979 to 1986 clearly show that most of the accidents occurred during winter months when the atmosphere has the lowest humidity content.

However, the relationship between dust explosivity and powders moisture content (and thus equilibrium relative humidity) is not as univocal as it superficially seems. If humidity could affect the ignition and explosion processes, notably by dust agglomeration, thermal sink, inerting or hindering oxygen transfer to particle surface, it could also have a promoting effect (Laurent, 2003). In particular, fermentation for grain dusts and oxidation–reduction reactions of metal powders with water are phenomena generating combustible gas, which should not be neglected in risk analyses (Otsuka and Itagaki, 2004).

Despite these facts, the overwhelming majority of standards and procedures related to dust explosion characterisation neglects the impact of humidity and only specifies that the equilibrium relative humidity should be checked and noted down, as for instance IEC 1241-2-1 (MIT) or IEC 1241-2-3 (MIE) (IEC standard, 1994a, 1994b).

In this work, the effects of both water activity (linked to equilibrium relative humidity) and ambient humidity on dust explosions characteristics have been checked. Natural and synthetic organic compounds but also metal powders have been tested. The proportion of electrostatic discharges as ignition sources in dust explosion accidents being significant (Planas-Cuchi et al., 1997), notably for plastic compounds,

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Received 12 February 2008; Received in revised form 17 July 2008; Accepted 14 August 2008
0957-5820/$ – see front matter
doi:10.1016/j.psep.2008.08.001

Nomenclature

a_w	water activity
d_x	particle diameter at which x% of the particles are smaller (μm)
$d_{3,2}$	Sauter's mean diameter—diameter of a sphere having the same volume to surface area ratio as the particle (μm)
ERH	equilibrium relative humidity
P_m	maximum overpressure (bar)
P_{max}	maximum of the maximum overpressures over a wide range of concentrations (bar)
$(dP/dt)_m$	maximum rate of pressure rise (bar s^{-1})
$(dP/dt)_{max}$	maximum of the maximum rates of pressure rise over a wide range of concentrations (bar s^{-1})
τ	charge decay time (s)

Table 1 – Particles sizes of the powders

Samples	d_{10} (μm)	d_{50} (μm)	d_{90} (μm)	$d_{3,2}$ (μm)
Aluminium	3	7	13	3
Icing sugar A	7	22	41	7
Icing sugar B	17	45	76	12
Magnesium stearate	3	6	15	3
Polyethylene	34	136	249	58

the influence of humidity on electrostatic properties has also been investigated.

2. Experimental equipments and tests procedures

2.1. *Samples characteristics and preparation*

Experiments were carried out with four materials chosen for their various natures: icing sugar—a natural organic powder, polyethylene dust and magnesium stearate: synthetic organic compounds and aluminium powder: a metal.

Aluminium powders were provided by Goodfellow with 99% purity and a specific maximum particle size of 15 μm. Icing sugar was provided by Erstein and polyethylene (PE) powders were provided by Innovene; various particle-size distributions were obtained by sieving. Magnesium stearate was supplied by Sigma-Aldrich. The particle-size distribution of the dusts was determined by using a laser diffraction analyzer (Mastersizer, Malvern Instrument). The samples were characterised by the d_{10}, d_{50} and d_{90} quantiles of the volumetric distribution as indicated in Table 1; the d_x diameter, being defined as the size at which x% of the particles are smaller. The Sauter mean diameter $d_{3,2}$, defined as the diameter of a sphere having the same volume to surface area ratio as the particle, is also indicated in Table 1.

Table 2 – Explosion sensitivity of the dried powders

Samples	d_{50} (μm)	MIT (°C)	MIE (mJ)	MEC ($g\,m^{-3}$)
Aluminium	7	900	13	30
Icing sugar	22	380	18	50
Magnesium stearate	6	420	4	30
Polyethylene	136	480	500	60

Scanning electron microscope (SEM) was also performed on powders samples to characterise the particles shapes and the surface roughness (Fig. 1).

Aluminium particles are rather ellipsoidal than spherical and their surface is quite smooth. Icing sugar is composed of crystal-shape particles, whereas magnesium stearate powder looks like flakes. Polyethylene pellets are rather spherical with a porous and highly irregular surface.

The samples were systematically dried at 50 °C under vacuum during 2 h before handling. Two methods were used to demonstrate the influence of the equilibrium relative humidity (ERH) on aluminium dust explosions: (i) the dry dust was dispersed in a humidity controlled atmosphere in the explosion vessel, or (ii) the dust sample was stored in a controlled workstation (glove box) at constant relative humidity during a sufficient period of time allowing the equilibrium to be reached.

The relation between the water activity – ratio between the vapour pressure of water in the compound to the vapour pressure of distilled water under the same conditions; similar to the equilibrium relative humidity in percent divided by 100 – and the water content in the powder is called adsorption isotherm. It was characterised by using an electromagnetic suspension microbalance (Fig. 2). The time to equilibrium was also determined.

2.2. *Explosion sensitivity*

At first, the minimum ignition energy (MIE), minimum ignition temperature (MIT) and minimum explosible concentration (MEC) have been determined on dried samples. The measurement of minimum ignition temperature has been carried out thanks to a Godbert-Greenwald furnace (Chilworth Technology), whereas the minimum ignition energy and minimum explosible concentration have been determined by using a modified Hartmann tube (Kühner AG) (Siwek and Cesana, 1995). Tests were carried out in accordance with the principles of IEC standards 1241-2-1 and 1241-2 3. The 20 L sphere apparatus has also been used to confirm MEC data. The results of the various tests performed on dried powders are listed in Table 2.

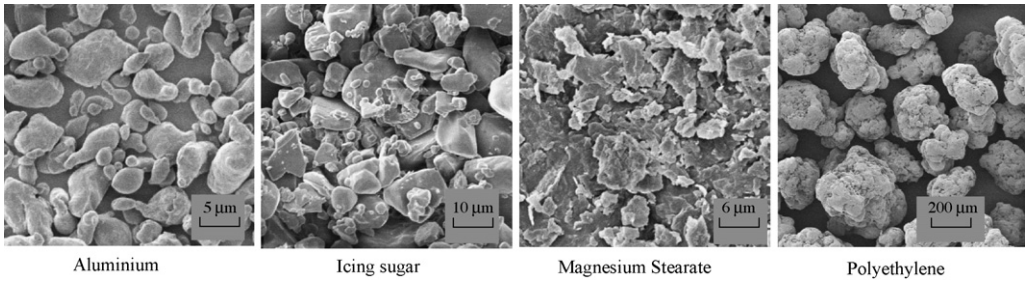

Fig. 1 – Images by SEM of aluminium, icing sugar, magnesium stearate and polyethylene particles.