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Igniter-induced hybrids in the 20-l sphere

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A B S T R A C T

Dust explosibility is traditionally described by two parameters, namely the maximum explosion pressure, P_{max}, and the deflagration index, K_{St}, usually determined through testing in a closed, pressure-resistant spherical vessel, either 20 L or 1 m^3 in volume. These parameters constitute key variables in the design of explosion protection systems, such as venting, suppression or isolation systems.

The potential for overdriving dust combustion with pyrotechnical igniters in the 20-l sphere has been recognized, discussed and analyzed for many years, notably in the determination of the minimum explosible and limiting oxygen concentrations, which has led to specific guidelines regarding the ignition source strength in ASTM standards.

The current paper presents new experimental evidence that the energy provided by pyrotechnical igniters may, in some instances, physically alter the dust being tested in the 20-l sphere. K_{St} values can be several times greater in the small vessel compared to those measured in the 1-m^3 chamber. Further visual evidence is provided to show that high energy ignition can produce a turbulent flame region, possibly consisting of a hybrid mixture of flammable gas (or vapor) and dust, which can propagate faster than the corresponding pure dust. The experiments suggest that K_{St} values measured in the 20-l sphere may no longer be representative of a dust deflagration in a real process environment. We recommend additional tests in a 1-m^3 chamber when a dust exhibits a low flash point, or when it's K_{St} is above 300 bar m/s in the 20-l sphere.

1. Introduction

A dust explosion occurs when an airborne combustible dust cloud encounters an effective ignition source. The resulting pressure and temperature increase can severely injure people and damage surrounding equipment and buildings, and therefore needs to be prevented or controlled.

The severity of a dust explosion is described by two parameters, the maximum explosion pressure P_{max} and the deflagration index K_{St}, where the latter is the product of the maximum rate of pressure rise and the cube root of the vessel volume. P_{max} and K_{St} are determined through testing in a closed, pressure-resistant spherical vessel: a known quantity of dust is dispersed in the vessel and the resulting dust cloud is ignited after a certain delay by pyrotechnical igniter(s) placed at the center of the vessel. P_{max} is determined based on the maximum pressure reached during the deflagration test, while K_{St} is calculated using the slope of the steepest part of the pressure-versus-time curve recorded during the deflagration.

A 20-l sphere apparatus, as well as a modified testing protocol, have been developed by Siwek (1977) as an alternative for the 1-m^3 chamber introduced by Bartknecht (1981) in order to achieve cheaper and faster tests. Several modifications (volume of the dust container, ignition delay time, dispersion systems) were made so the results found in the 20-l sphere would match the results of the 1-m^3 chamber (Fig. 1). However, the same pyrotechnical igniters were used to perform explosion tests.

The potential for overdriving dust combustion with pyrotechnical igniters in the 20-l sphere has been recognized, discussed and analyzed for many years (Cashdollar and Chatrathi, 1992; Mintz, 1995; Cashdollar, 2000; Going et al., 2000; Cloney et al., 2013;

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Nomenclature

ASTM	American Society of Testing and Materials
K_G	Deflagration Index for Gases (bar.m/s)
K_{St}	Deflagration Index for Dusts (bar.m/s)
LOC	Limiting Oxygen Concentration (% O_2)
MAIT	Minimum Auto Ignition Temperature (°C)
MAP	Mono Ammonium Phosphate
MEC	Minimum Explosible Concentration (g/m^3)
MIC	Minimum Inerting Concentration (g/m^3)
P_{max}	Maximum Explosion Pressure (barg)
PPC	Pulverized Pittsburgh Coal
SBC	Sodium Bicarbonate

Gao et al., 2013). The current paper presents new experimental evidence that the strong pyrotechnical igniters employed for dust explosibility testing may physically alter some dusts being tested in a 20-l sphere in such a way, that a flammable gas (or vapor) and dust hybrid mixture is formed prior to the actual arrival of the flame front.

Section 2 of the present article summarizes previous studies relative to the effect of ignition energy on dust explosibility. The effects of pyrotechnical igniters on the initial pressures and temperatures in the 20-l sphere and in the 1-m^3 chamber are reviewed in section 3. Section 4 presents new experiments carried out in the two vessels for the same dusts, showing large discrepancies in K_{St} values. Finally, section 5 discusses the experimental evidence obtained and proposes three alternative ignition/combustion mechanisms for the dusts tested.

2. Effect of ignition energy on dust explosive properties: previous experimental investigations

2.1. Effect of ignition energy on deflagration index

Zhen and Leuckel (1997) were among the first to recognize, describe and study the effects of pyrotechnical igniters on dust explosions. They conducted dust explosion tests in a 1-m^3 chamber with cornstarch using 10-kJ and 75-J pyrotechnical igniters. Values of K_{St} are consistently higher for a 10-kJ ignition energy. The authors proposed that pyrotechnical igniters may accelerate the burning rate during an explosion due to volumetric and/or multi-point ignition effects. The extent of this overdriving is related not only to the energy of the igniters, but also to the reactivity of the mixture.

Proust et al. (2007) measured the K_{St} of different dusts in both a 20-l sphere and a 1-m^3 cylindrical chamber using a 10-kJ ignition energy in each case. While the correlation in the results between the two vessels was reasonable, four of the tested dusts had low K_{St} values in the 20-l sphere (sodium monochloroacetate, Lixivalt, Metco, and solid sewing residues), but were found to be non-explosible when tested in the 1-m^3 chamber. The authors suggested that a dust with a K_{St} below 45 bar m/s as measured in the 20-l sphere test would likely be shown to be non-explosible when tested in a 1-m^3 chamber.

More recently, Thomas et al. (2013) conducted screening explosibility tests per ASTM E1226 with urea dust in both a 20-l sphere (with either 1 or 2 × 5 kJ igniters) and Fike 1-m^3 chamber (with either 1 or 2 × 10 kJ igniters). They determined that the urea dust was explosible in the small vessel, but not explosible in the large vessel (Table 1). They concluded that the "false positive" result obtained in the 20-l sphere was the result of overdriving the combustion process, while testing in the 1-m^3 chamber allowed the urea dust to be properly characterized. They recommended testing low-K_{St} dusts in a vessel larger than 20-l, in which the flame must propagate over a certain distance in order to develop a maximum explosion pressure P_{max} value sufficiently high to classify the dust as explosible.

Gao et al. (2013) conducted tests in a 20-l sphere to examine the effect of four different igniters on the explosibility of 1-Octadecanol ($C_{18}H_{38}O$) powder, which melting, flashing and boiling points are respectively 60, 195 and 345 °C. They observed that varying ignition energy influenced P_{max}, and more significantly K_{St} (Fig. 2). The maximum reactivity is reached at a dust concentration of 500 g/m^3, with K_{St} varying from 49 bar m/s (2.5-kJ electrostatic ignition) to 167 bar m/s (10-kJ pyrotechnical ignition).

2.2. Effect of ignition energy on minimum explosible and limiting oxygen concentrations

Going et al. (2000) present a comparison of minimum explosible

Table 1
Results of screening tests with urea in the 20-l sphere and Fike 1-m^3 chamber at varying ignition energies (Thomas et al., 2013).

Vessel volume (m^3)	Igniter energy (kJ)	Result
0.020	5	No ignition
0.020	10	Ignition P_{max} = 5.4 bar K_{max} = 21 bar.m./s
1	10	No ignition
1	20	No ignition

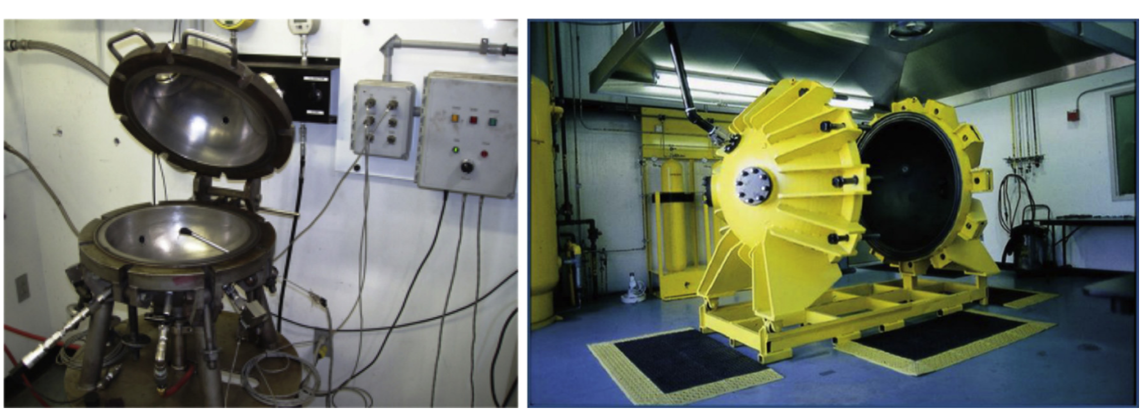

Fig. 1. Photo of 20-l sphere (left) and 1-m^3 chamber (right) operated by Fike Corporation.