Explosibility of a Urea Dust Sample

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Summary
The standard dust explosibility test is performed in a 20-L vessel with either one or two 5 kJ pyrotechnic igniters. The dust is deemed to be explosible if the ratio of the maximum deflagration pressure to the initial pressure exceeds some threshold value. This type of test is widely accepted and used. However, marginal dusts may be "over driven" in the 20-L standard test and yield a "false positive" result (i.e., indicate that the dust is explosible), even when such a dust is not capable of forming a dust cloud through which a flame would actually propagate any significant distance. This can be avoided by testing such dusts in a larger vessel, where the flame must propagate over a more reasonable distance in order to develop a maximum pressure sufficient to classify the dust as explosible. This article reports on urea dust testing where this type of result was obtained, but the approach taken in this work is applicable to other dusts as well.

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Keywords: explosibility; urea; combustible dust; Kst; overdriven

INTRODUCTION

The standard dust explosibility test is performed in a 20-L vessel with either one or two 5 kJ pyrotechnic igniters, per ASTM E-1226 [1]. Such tests are used to determine K_{st}, the deflagration index (product of the maximum rate of pressure rise and the cube root of the vessel volume), and P_{max}, the maximum deflagration pressure. This test is widely accepted and used, and was recently modified to include a dust explosibility screening option. The dust is deemed to be explosible if the ratio of P_{max} to the initial pressure (PR) exceeds a value of 2. However, a nominally nonhazardous dust (i.e., one not capable of forming a dust cloud through which a flame would actually propagate any significant distance) may be classified as an explosible dust with this standard 20-L test. The combination of a small test vessel with a very strong ignition source may yield a P_{max} sufficiently high that a dust which cannot actually propagate a flame is classified as explosible. Dusts which have very low K_{st} values (i.e., either due to the dust composition, particle size distribution, and/or particle shape) may be "over driven" in the 20-L standard test and yield a "false positive" result (i.e., indicate that the dust is explosible). In addition, some materials can decompose under these conditions and yield a measurable pressure increase but not pose an actual explosion hazard at larger scale. This can be avoided by testing low-K_{st} dusts in a larger vessel, where the flame must propagate over a more reasonable distance in order to develop a P_{max} value sufficient to classify the dust as explosible.

The downside to obtaining a false positive test result is that hazard prevention and mitigation resources would be directed to addressing the perceived combustible dust explosion hazard rather than to addressing actual hazards, thereby retarding risk reduction. That is, the generation of a false positive result is not an academic question, but one that can have a very real and negative impact on facility safety. It is noted that urea is identified as a combustible dust in the literature.

BACKGROUND

Going *et al.* [2] discuss the potential for over-driving dust combustion in the 20-L vessel with strong ignition sources in connection with Minimum Explosible Concentration (MEC) tests. They showed that overdriving would occur with large ignition sources, and concluded that a 2.5 kJ ignition source in the 20-L vessel would yield approximately the same result as a 10 kJ source in the 1 m^3 vessel. They recommended that if a dust did not ignite in the 20-L vessel with a 2.5 kJ ignition source but did at 5 kJ or 10 kJ, then a test should be run in the 1 m^3 vessel with a 10 kJ source to determine if the dust is actually explosible.

Proust *et al.* [3] performed a study of the measured K_{st} with both 20 L and 1 m^3 test vessels using a 10 kJ ignition energy in both vessels. The K_{st} parameter is denoted as the "deflagration index." It is the maximum rate of pressure rise (i.e., dP/dt_{max}) multiplied by the cube root of the test vessel volume and is a measure of the explosion severity. While the correlation in the results between the two vessels was reasonable, four of the dusts tested that had low K_{st} values in the 20-L vessel (sodium monochloroacetate, Lixivalt, Metco, and solid sewing residues) were found to be nonexplosible when run in the 1 m^3 vessel. Proust *et al.* suggested that a dust with a K_{st} of 45 bar·m/s as measured in the 20-L test would likely be shown to be nonexplosible when tested in a 1 m^3 vessel. Reference 4] also reported a good correlation between the K_{st} values measured for a range of vessel sizes (including 20 L and 1 m^3) for a dust with a high K_{st} (220 bar·m/s.

Rodgers and Ural [5] discussed the potential for the 20-L test to generate "false positives" for low K_{st} dusts, reviewed the data provided by Proust *et al.* [3] in this context, and discussed similar data for an additional dust.

TESTING

The tests described in this article were carried out by Fike Corp. (Blue Springs, MO).

Table 1. Urea product specification.

Parameter	Value (wt%)
Total nitrogen	46.0
Biuret	0.7–1.5
Conditioning agent	0.35–0.60
Moisture	0.1–0.4

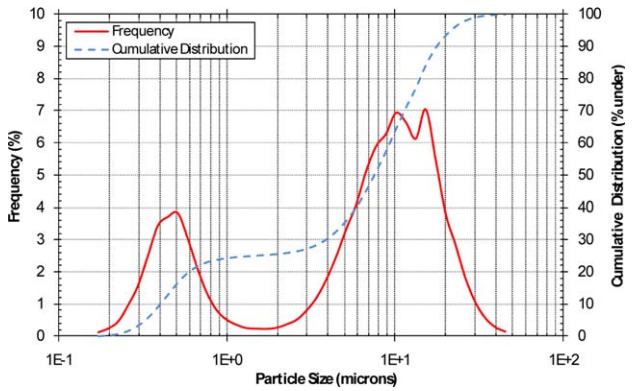

Figure 1. Urea particle size distribution. [Color figure can be viewed in the online issue, which is available at **wileyonlinelibrary.com**.]

Urea Dust Samples

Urea dust samples were provided by a North American fertilizer company. The product specification for the urea is given in Table 1. Chemical equilibrium analyses were carried out for a generic urea composition, and the maximum adiabatic pressure and temperature at an equivalence ratio of unity were calculated to be 8.0 bar and 2180 K, respectively.

The as-received urea dust sample was primarily in the 1.5 to 3.0 mm range and was ground and sieved to sub 200 mesh (< 75 μm) prior to testing. The particle size distribution following grinding and sieving is shown in Figure 1. The median particle size was approximately 7 μm. The 95th percentile particle size was approximately 22 μm, well below the 75 μm value specified by ASTM E-1226 [1].

The moisture content of the as-received material was determined to be 0.3% by weight; the sample was not dried further prior to testing. This moisture content is an order of magnitude less than the maximum 5% value specified by ASTM E-1226 [1].

Test Apparatus

Dust explosibility testing was conducted in the Fike Corporation 1 m^3 (1,000 L or 35 ft^3) chamber [2,6] shown in Figure 2. The chamber is spherical with an internal diameter of 1.22 m (4.0 ft) and a pressure rating of 21 bar. The two halves of the sphere are connected by twelve 51 mm diameter bolts.

Two variable resistance pressure transducers were used to measure the explosion pressure. Data from the instruments were collected by a high speed PC-based data acquisition system. The dust injection system for the 1 m^3 chamber consisted of a 5 L dispersion reservoir, a 19 mm pneumatically activated ball valve, and a rebound nozzle. To create a dust cloud, a weighed sample of dust was placed in the dispersion reservoir. The reservoir was pressurized with dry air to a gauge pressure of 20 barg. The chamber was partially evacuated to an absolute pressure of 0.88 bara. Activation of the ball valve dispersed the dust and air into the 1 m^3 chamber through the rebound nozzle and raised the chamber pressure to about 1 bara.

Figure 2. 1 Cubic meter test vessel. [Color figure can be viewed in the online issue, which is available at **wileyonlinelibrary.com**.]

Figure 3. 20 liter test vessel. [Color figure can be viewed in the online issue, which is available at **wileyonlinelibrary.com**.]

The igniter was activated 0.6 s after activation of the ball valve. The ignition sources used for the tests were 5 and 10 kJ pyrotechnic igniters manufactured by Fr. Sobbe of Germany. They were activated electrically with an internal fuse wire and delivered their energy in about 10 to 20 ms. The 5 kJ igniter by itself produced a pressure rise of 0.02 bar in the 1 m^3 chamber. Multiple 10 kJ igniters were used for higher ignition energies. All of the igniters were positioned at the center and pointed down. The chamber was thoroughly cleaned before each test so that there would be no residual contamination from previous tests. Laboratory tests were also conducted in the Fike 20-L chamber, which is shown in Figure 3. The test procedures and instrumentation for the 20-L chamber were similar to those for the 1 m^3 chamber.

Table 2. Summary of tests (20 L, 10 kJ).

Concentration (g/m^3)	P_{max} (bar)	K (bar·m/s)
500	2.9	5
750	5.1	21
1,000	5.4	17
1,250	4.8	17
1,500	4.4	15

Table 3. Summary of tests.

Vessel	Igniter	Result
20 L	Two 5 kJ	Ignition
20 L	One 5 kJ	No ignition
1 m^3	Two 5 kJ	No ignition
1 m^3	Two 10 kJ	No ignition

Results

Tests were first run in a 20-L chamber using two 5 kJ Sobbe igniters as the ignition source. The results from these tests are given in Table 2.

The maximum explosion pressure (P_{max}) was found to be 5.4 barg (78 psig) at a dust concentration of 1000 g/m^3. The maximum K value[1] was found to be 21 bar·m/s at a dust concentration of 750 g/m^3. This result is consistent with the identification of urea as a combustible dust in the literature. A K_{st} value of 21 bar·m/s is very low and is well below the 45 bar·m/s limit that Proust *et al.* [3] suggested would likely be shown to be nonexplosible when tested in a 1 m^3 vessel.

The 20-L test was repeated with a single 5 kJ igniter at concentrations ranging from 750 to 1250 g/m^3 (i.e., across the concentration range including that yielded the highest P_{max} and K values in the tests with two 5 kJ igniters). These tests showed no ignitions; the pressure ratio was 1.2 or less. Hence, when the ignition energy was reduced from 10 kJ to 5 kJ, the urea dust did not ignite. The recommendation provided by Going *et al.* [2] is to test in a 1 m^3 vessel for this condition to determine if the dust is actually explosible.

A test was next carried out at 1,000 g/m^3 in a 1 m^3 vessel using two 5 kJ igniters (i.e., the same ignition source which yielded a measurable K_{st} value in the 20-L vessel). No ignition was detected. This test was repeated twice using two 10 kJ igniters (i.e., doubling the ignition energy). No ignition was detected in these tests, and the pressure ratio was 1.03 (i.e., essentially no pressure rise). Hence, in the 1 m^3 vessel, the urea dust would not ignite even with an extremely strong ignition source.

Discussion

Table 3 summarizes the urea dust tests performed and results obtained. The results obtained in the 1 m^3 vessel demonstrate that the 20-L test with two 5 kJ igniters represented an over-driven system. The dust was not ignited in the larger vessel even when the ignition energy was doubled. This was also demonstrated in the 20-L test vessel in that the dust was not ignited by a single 5 kJ igniter. Based on these results, it is concluded that urea dust does not pose a credible combustible dust explosion hazard.

DISCUSSION

The relevant ASTM standard (ASTM Standard E-1226, "Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts", paragraph 5.4) states that:

> *"For hard-to-ignite dusts with low K_{st} values, a very strong ignitor may overdrive a 20 L chamber, as discussed in E 1515 and Ref* 2. *If a dust has measurable (nonzero) P_{max} and K_{st} values with a 5,000 or 10,000-J ignitor but not with a 2,500-J ignitor in a 20 L chamber, this may be an overdriven system. In this case, it is recommended that the dust be tested with a 10,000-J ignitor in a larger chamber such as a 1 m^3 chamber to determine if it is actually explosible."*

The ASTM Standard "E-1515" referenced in the text above is the ASTM "Standard Test Method for MEC of Combustible Dusts" [7], and "Ref. 2" is provided as Ref. 6 in this article. The approach adopted in this testing program is consistent with the ASTM E-1226 recommendation cited above. The tests carried out here actually go significantly further than the ASTM recommendation, in that it was demonstrated that the urea dust would not ignite in the 20-L vessel with a 5 kJ igniter (i.e., double the lower value cited in the ASTM recommendation) nor in the 1 m^3 vessel with a two 10 kJ igniters (i.e., double the energy cited in the ASTM recommendation).

CONCLUSIONS AND RECOMMENDATIONS

Based on these results, it is concluded that the urea dust tested does not pose a credible dust explosion hazard at ambient temperature and pressure conditions since flame could not actually propagate through a dust cloud comprised of this material. The results obtained in the 20-L test vessel were the result of overdriving the combustion reaction. Testing in the 1 m^3 vessel allowed the actual nature of the urea dust to be properly characterized.

For the urea dust examined, there is not a need to institute combustible dust explosion hazard prevention and/or mitigation strategies to address urea dust within buildings or other similar enclosures (e.g., stringent housekeeping, explosion venting, etc.).

The authors of this article are unaware of any accidental urea dust explosions, although it is possible such an event has occurred which was not reported in the literature. The lack of known accidental urea dust explosions is, of course, consistent with the results reported in this article.

However, it is noted that urea dust could potentially ignite due to contact with very hot surfaces. Equipment operating with high internal or external surface temperatures could therefore pose a potential explosion hazard. Ignition in this fashion could pose a burn injury hazard. Controls to address the hazard of hot surface ignition should therefore be considered where applicable. In addition, urea dust may also pose other hazards unrelated to combustible dust considerations (e.g., health hazards).

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[1]The term 'K' is used here to denote the volume scaled maximum rate of pressure rise (bar·m/s) for a single test, with the term "K_{st}" being reserved for a value based on repeated tests.

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