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Standard Test Method for Explosibility of Dust Clouds¹

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INTRODUCTION

Particulate solids of combustible materials present a significant risk of dust explosion if suspended in air and subjected to an ignition source. The methods of this standard can be used to determine if a dispersed dust cloud is “explosible” and, if so, to what degree it is explosible, that is, its “explosibility.” Knowledge that a dust may be explosible if dispersed as a dust cloud is important in the conduct of a process hazard safety review. Contained herein is an explosibility or go/no-go screening test procedure for the purpose of determining whether a dust sample is explosible.

If a dust is explosible, the explosibility parameters, maximum explosion pressure, P_{max} ; maximum rate of pressure rise, $(dP/dt)_{max}$; and explosibility index, K_{St} , are useful in the design of explosion prevention and control measures as described in national (NFPA) and international (ISO, CEN and others) explosion protection standards.

1. Scope

1.1 Purpose. The purpose of this test method is to provide standard test methods for characterizing the “explosibility” of dust clouds in two ways, first by determining if a dust is “explosible,” meaning a cloud of dust dispersed in air is capable of propagating a deflagration, which could cause a flash fire or explosion; or, if explosible, determining the degree of “explosibility,” meaning the potential explosion hazard of a dust cloud as characterized by the dust explosibility parameters, maximum explosion pressure, P_{max} ; maximum rate of pressure rise, $(dP/dt)_{max}$; and explosibility index, K_{St} .

1.2 Limitations. Results obtained by the application of the methods of this standard pertain only to certain combustion characteristics of dispersed dust clouds. No inference should be drawn from such results relating to the combustion characteristics of dusts in other forms or conditions (for example, ignition temperature or spark ignition energy of dust clouds, ignition properties of dust layers on hot surfaces, ignition of bulk dust in heated environments, etc.).

1.3 Use. It is intended that results obtained by application of this test be used as elements of an explosion risk assessment—a dust hazard analysis (DHA) that takes into account other pertinent risk factors; and in the specification of explosion prevention systems (see, for example NFPA 68, NFPA 69, and NFPA 654) when used in conjunction with approved or recognized design methods by those skilled in the art.

NOTE 1—Historically, the evaluation of the deflagration parameters of maximum pressure and maximum rate of pressure rise has been performed using a 1.2-L Hartmann Apparatus. Test Method E789, which describes this method, has been withdrawn. The use of data obtained from the test method in the design of explosion protection systems is not recommended.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

¹ This test method is under the jurisdiction of ASTM Committee E27 on Hazard Potential of Chemicals and is the direct responsibility of Subcommittee E27.05 on Explosibility and Ignitability of Dust Clouds.

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2. Referenced Documents

2.1 ASTM Standards:²

- D3173 Test Method for Moisture in the Analysis Sample of Coal and Coke
- D3175 Test Method for Volatile Matter in the Analysis Sample of Coal and Coke
- E789 Test Method for Dust Explosions in a 1.2-Litre Closed Cylindrical Vessel (Withdrawn 2007)³
- E1445 Terminology Relating to Hazard Potential of Chemicals
- E1515 Test Method for Minimum Explosible Concentration of Combustible Dusts

2.2 NFPA Publication:⁴

- NFPA 68 Standard on Explosion Protection By Deflagration Venting
- NFPA 69 Standard on Explosion Prevention Systems
- NFPA 654/652 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids Fundamentals of Combustible Dust

2.3 VDI Standard:⁵

- VDI-3673 Pressure Release of Dust Explosions

2.4 ISO Standard:⁶

- ISO 6184/1 Explosion Protection Systems, Part 1, Determination of Explosion Indices of Combustible Dusts in Air

2.5 ASME Code:⁷

- ASME Boiler and Pressure Vessel Code, Section VIII

3. Terminology

3.1 *Definitions*—For determination of terms relating to hazard potential of chemicals see Terminology E1445.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 $P_{ex, n}$ —the maximum pressure rise (above the pressure in the vessel at the time of ignition) produced during the course of a single deflagration test (see Fig. 1).

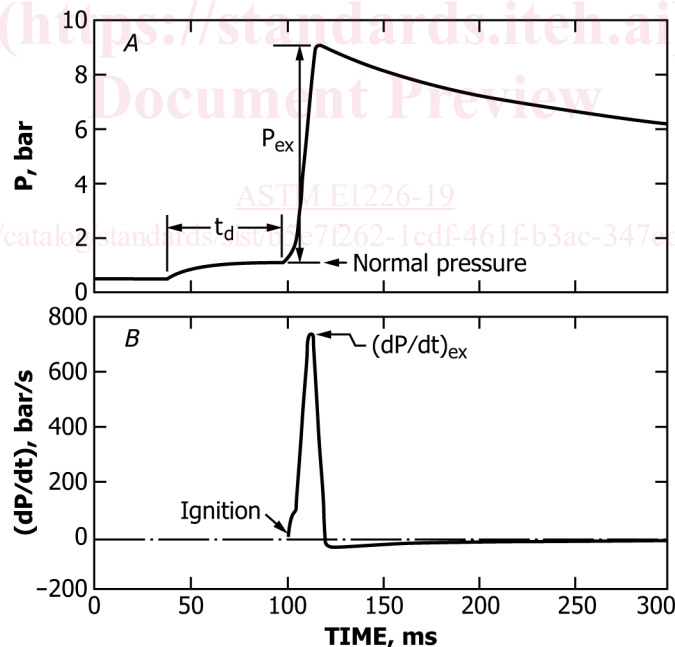


FIG. 1 Typical Recorder Tracings of Absolute Pressure, P , and Rate of Pressure Rise, dP/dt , for a Dust Deflagration in a 20-L Chamber

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The last approved version of this historical standard is referenced on www.astm.org.

⁴ Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, <http://www.nfpa.org>.

⁵ Available from Beuth Verlag, D-1000 Berlin, Federal Republic of Germany or American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

⁶ Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, <http://www.iso.ch>, or from Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

⁷ Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, <http://www.asme.org>.

3.2.2 P_m, n —maximum pressure rise produced during the course of a single deflagration test that is corrected for the effects of ignitor pressure and cooling in the 20-L vessel (see Sections X1.8 and X1.9).

3.2.3 $P_{ex,a}, n$ —the maximum absolute pressure produced during the course of a single deflagration test, n test:

$$P_{ex,a} = P_{ex} + P_{ignition}$$

3.2.4 P_{max}, n —the maximum pressure rise (above pressure in the vessel at the time of ignition) reached during the course of a deflagration for the optimum concentration of the dust tested. P_{max} is determined by a series of tests over a large range of concentrations (see Fig. 2). It is reported in bar.

3.2.5 $P_{ignition}, n$ —the absolute pressure in the vessel at the time of ignition.

3.2.6 $\Delta P_{ignition}, n$ —the pressure rise above $P_{ignition}$ caused by activation of the ignitor(s) with no dust present in the chamber.

3.2.7 $(dP/dt)_{ex}, n$ —the maximum rate of pressure rise during the course of a single deflagration test (see Fig. 1).

3.2.8 $(dP/dt)_{max}, n$ —maximum value for the rate of pressure increase per unit time reached during the course of a deflagration for the optimum concentration of the dust tested. It is determined by a series of tests over a large range of concentrations (see Fig. 2). It is reported in bar/s.

NOTE 2—Recorder tracings of pressure (absolute) and rate of pressure rise for a typical dust deflagration in a 20-L chamber are shown in Fig. 1. The maximum values, P_{max} and $(dP/dt)_{max}$ for a dust are determined by testing over a large range of concentrations as shown in Fig. 2.

3.2.9 *deflagration index*, K_{St}, n —maximum dP/dt normalized to a 1.0-m³ volume. It is measured at the optimum dust concentration. K_{St} is defined in accordance with the following cubic relationship:

$$K_{St} = (dP/dt)_{max} V^{1/3} \tag{1}$$

where:

- P = pressure, bar,
- t = time, s,
- V = volume, m³, and
- K_{St} = bar m/s.

3.2.10 *explosible*—*explosible*, n —a material with a Pressure Ratio equal or greater than 2.0 in any test when tested using the Explosibility or Go/No-go/Go/No-Go Screening Test described in Section 13.

NOTE 3—An explosible dust when dispersed in air is capable of propagating a deflagration, which could cause a flash fire or explosion depending on the level of confinement.

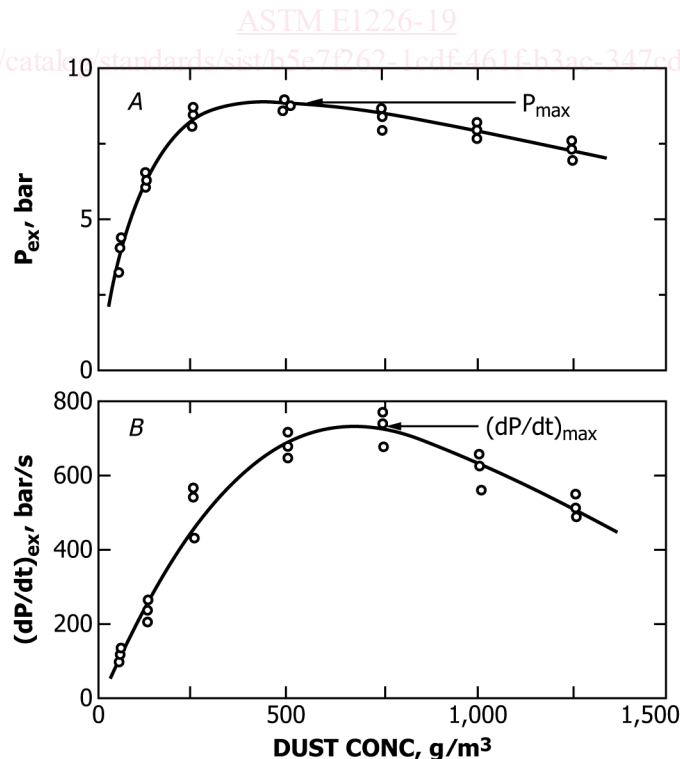


FIG. 2 P_{max} and $(dP/dt)_{max}$ as a Function of Concentration for a Typical Dust in a 20-L Chamber

3.2.11 *ignition delay time, t_d* , n —experimental parameter defined as the time interval between the initiation of the dust dispersion procedure (the time at which the dispersion air starts to enter the chamber) in an experimental apparatus and the activation of the ignition source (see Fig. 1). The ignition delay time characterizes the turbulence level prevailing at ignition under the defined test conditions.

3.2.12 *pressure ratio (PR)*, n —PR

$$PR = (P_{ex,a} - \Delta P_{ignitor}) / P_{ignition}$$

NOTE 4—When testing in the Siwek 20-L vessel (see Appendix X1), PR may be calculated using the corrected explosion pressure, n pressure:

$$n - PR = (P_m + P_{ignition}) / P_{ignition}$$

4. Summary of Test Method

4.1 A dust cloud is formed in a closed combustion chamber by an introduction of the material with air.

4.2 Ignition of this dust-air mixture is then attempted after a specified delay time by an ignition source located at the center of the chamber.

4.3 The pressure time curve is recorded on a suitable piece of equipment.

5. Significance and Use

5.1 This test method provides a procedure for performing laboratory tests to evaluate deflagration parameters of dusts.

5.2 The data developed by this test method may be used for the purpose of sizing deflagration vents in conjunction with the nomographs and equations published in NFPA 68, ISO 6184/1, or VDI 3673.

5.3 The values obtained by this testing technique are specific to the sample tested and the method used and are not to be considered intrinsic material constants.

5.4 For dusts with low K_{St} values, S_L values, discrepancies have been observed between tests in 20-L and 1-m³ chambers. A strong ignitor may overdrive a 20-L chamber, as discussed in Test Method E1515 and Refs (1-34).⁸ Conversely, more recent testing has shown that some metal dusts can be prone to underdriving in the 20-L chamber, exhibiting significantly lower K_{St} values than in a 1-m³ chamber (5). Ref (6) provides supporting calculations showing that a test vessel of at least 1-m³ of volume is necessary to obtain the maximum explosibility index for a burning dust cloud having an abnormally high flame temperature. In these two overdriving and underdriving scenarios described above, it is therefore recommended to perform tests in 1-m³ or larger calibrated test vessels in order to measure dusts explosibility parameters accurately.

NOTE 5—Ref (2) concluded that dusts with K_{St} values below 45 bar m/s when measured in a 20-L chamber with a 10 000-J ignitor, may not be explosive when tested in a 1-m³ chamber with a 10 000-J ignitor. Ref (2) and unpublished testing has also shown that in some cases the K_{St} values measured in the 20-L chamber can be lower than those measured in the 1-m³ chamber. Refs (1) and (3) found that for some dusts, it was necessary to use lower ignition energy in the 20-L chamber in order to match MEC or MIC test data in a 1-m³ chamber. If a dust has measurable (nonzero) P_{max} and K_{St} values with a 5000 or 10 000-J ignitor when tested in a 20-L chamber but no measurable P_{max} and K_{St} values with tests conducted using an ignition source less than or equal to 2500 J, it may be helpful to test the material in a larger chamber such as a 1-m³ chamber using at least a 10 000-J ignition source to further characterize the material's explosibility in dust cloud form.

6. Interferences

6.1 In certain industrial situations where extreme levels of turbulence may be encountered, such as the rapid introduction of expanding gases resulting from combustion in connected piping or operations where hybrid mixtures (combustible dusts and combustible gases or vapors) are encountered, the use of the deflagration indices based on this test method for the sizing of deflagration vents may not be possible.

7. Apparatus

7.1 The equipment consists of a closed steel combustion chamber with an internal volume of at least 20 L, spherical or cylindrical (with a length to diameter ratio of approximately 1:1) in shape.

7.2 The apparatus must be capable of dispersing a fairly uniform dust cloud of the material.

7.3 The pressure transducer and recording equipment must have a combined response rate greater than the maximum measured rates of pressure rise.

7.4 An example of a chamber and specific procedures that have been found suitable are shown in Appendix X1. This chamber has been calibrated as described in Section 10.

7.5 Examples of other test chambers that have not yet been calibrated are listed in Appendix X2.

⁸ The boldface numbers in parentheses refer to a list of references at the end of this standard.

8. Safety Precautions

8.1 Prior to handling a dust material, the toxicity of the sample and its combustion products must be considered. This information is generally obtained from the manufacturer or supplier. Appropriate safety precautions must be taken if the material has toxic or irritating characteristics. Tests using this apparatus should be conducted in a ventilated hood or other area having adequate ventilation.

8.2 Before initiating a test, a physical check of all gaskets and fittings should be made to prevent leakage.

8.3 All enclosures containing electrical equipment should be connected to a common ground. Shielded cables should be used.

8.4 If chemical ignitors are used as an ignition source, safety in handling and use is a primary consideration. Ignition by electrostatic discharge must be considered a possibility. When handling these ignitors, eye protection must be worn at all times. A grounded, conductive tabletop is recommended for preparation. Federal, state, and local regulations for the procurement, use, and storage of chemical ignitors must be followed.

8.5 All testing should initially be conducted with small quantities of sample to prevent overpressurization due to high energy material.

8.6 In assembling the electrical circuitry for this apparatus, standard wiring and grounding procedures must be followed. If a high-voltage spark circuit is used, it presents an electric shock hazard and adequate interlocking and shielding must be employed to prevent contact.

8.7 The operator should work from a protected location in case of vessel or electrical failure.

8.8 The vessel should be designed and fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII. A maximum allowable working pressure (MAWP) of at least 15 bar is recommended.

9. Sampling, Test Specimens, and Test Units—Test Units, and Storage

9.1 It is not practical to specify a single method of sampling dust for test purposes because the character of the material and its available form affect selection of the sampling procedure. Generally accepted sampling procedures should be used as described in MNL 32.⁹

9.2 Tests may be run on an as-received sample. However, due to the possible accumulation of fines at some location in a processing system, it is recommended that the test sample be at least 95 % minus 200 mesh (75 μm).

NOTE 6—It may be desirable in some cases to conduct dust deflagration tests on materials as sampled from a process because process dust streams or deposits may contain a wide range of particle sizes or have a well-defined specific moisture content, materials consisting of a mixture of chemicals may be selectively separated on sieves and certain fibrous materials which may not pass through a relatively coarse screen may produce dust deflagrations. When a material is tested in the as-received state, it should be recognized that the test results may not represent the most severe dust deflagration possible. Any process change resulting in a higher fraction of fines than normal or drier product than normal may increase the explosion severity.

9.3 To achieve this particle fineness (≥ 95 % minus 200 mesh), the sample may be ground or pulverized or it may be sieved.

NOTE 7—The operator should consider the thermal stability of the dust during any grinding or pulverizing. In sieving the material, the operator must verify that there is no selective separation of components in a dust that is not a pure substance.

9.4 The moisture content of the test sample should not exceed 5 % in order to avoid test results of a given dust being noticeably influenced.

NOTE 8—For most materials, dry samples will produce maximum P_{max} and K_{St} values. For some water reactive materials, such as reactive metals, maximum values may occur when some moisture is present.

NOTE 9—There is no single method for determining the moisture content or for drying a sample. ASTM lists many methods for moisture determination in the *Annual Book of ASTM Standards*. Sample drying is equally complex due to the presence of volatiles, lack of or varying porosity (see Test Methods [D3173](#) and [D3175](#)), weight change due to oxidation, and sensitivity of the sample to heat. Therefore, each must be dried in a manner that will not modify or destroy the integrity of the sample. Hygroscopic materials must be desiccated.

9.5 Retention and storage of dust samples can lead to aging which may affect explosibility results. Changes that may occur are, but not limited to: drying or absorption of moisture, loss of solvent or volatiles, surface oxidation, slow chemical/biological reactions or other decomposition mechanism. Appropriate measures should be taken to avoid aging of the sample prior to testing, so the sample remains representative of the material present in the industrial process to be protected. Dusts that are susceptible to aging effects after being sampled shall be preserved in a suitable atmosphere and stored under suitable temperature conditions until tested. Argon blanketing should be considered for dusts that are unusually reactive with moisture and oxygen, or both. Argon may be otherwise preferable to nitrogen as a blanketing gas, owing both to its larger density and to the slower rate at which oxygen will diffuse into opened or leaking sample containers.

⁹ MNL 32 — ASTM Manual on Test Sieving Methods is available from ASTM Headquarters, 100 Barr Harbor Drive, W. Conshohocken, PA 19428.

10. Calibration and Standardization

10.1 The objective of this test method is to develop data that can be correlated to those from the 1-m³ chamber (described in ISO 6184/1 and VDI 3673) in order to use the nomograms and equations (see 5.2).

10.2 Because a number of factors (concentration, uniformity of dispersion, turbulence of ignition, sample age, etc.) can affect the test results, the test vessel to be used for routine work must be standardized using dust samples whose K_{St} and P_{max} parameters are known in the 1-m³ chamber. Samples used for standardization should provide a wide range of K_{St} values. A minimum of five different dust samples are required over each of the following three K_{St} ranges: 1–200, 201–300, and >300 bar m/s. The P_{max} value for each dust must agree to within $\pm 10\%$ with the 1-m³ value and the K_{St} value must agree to within $\pm 20\%$.

10.3 In cases where the test apparatus will not be used to determine deflagration indices of dusts within certain dust classes, it is permissible to reduce the number of standardization dusts tested in these ranges.

10.4 The calibration and standardization procedure for a chamber will normally involve varying the dispersion procedure (especially the dispersion and delay time) so that the measured data are comparable to those from the 1-m³ chamber. Once the specific dispersion procedures (that produce data comparable to those from the 1-m³ chamber) have been determined, they are fixed for future testing.

10.5 Average measured values from three calibrated 20-L chambers for lycopodium dust (the reticulate form, *Lycopodium clavatum*, a natural plant spore having a narrow size distribution with a mean diameter of $\sim 28\text{-}\mu\text{m}$) are:

$$\frac{P_{max}}{(dP/dt)_{max} K_{St}} = \begin{matrix} = 7.0 \text{ bar} \\ = 555 \text{ bar/s} \\ = 151 \text{ bar m/s} \end{matrix}$$

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Data were obtained from two calibrated 20-L chambers for Pittsburgh seam bituminous coal dust ($\sim 80\%$ minus 200 mesh, $\sim 50\%$ minus 325 mesh, 36% volatility).

$$\frac{P_{max}}{(dP/dt)_{max} K_{St}} = \begin{matrix} = 7.0 \text{ bar} \\ = 430 \text{ bar/s} \\ = 117 \text{ bar m/s} \end{matrix}$$

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10.6 Dust deflagration data in the 1-m³ chamber at Basel, Switzerland are:

lycopodium:	$\frac{P_{max}}{K_{St}}$	= 6.9 bar
Pittsburgh seam bituminous coal:	$\frac{P_{max}}{K_{St}}$	= 157 bar m/s

	$\frac{P_{max}}{K_{St}}$	= 7.0 bar
	$\frac{P_{max}}{K_{St}}$	= 95 bar m/s

<u>Lycopodium:</u>	$\frac{P_{max}}{K_{St}}$	= 6.9 bar
	$\frac{P_{max}}{K_{St}}$	= 157 bar m/s

<u>Pittsburgh seam bituminous coal:</u>	$\frac{P_{max}}{K_{St}}$	= 7.0 bar
	$\frac{P_{max}}{K_{St}}$	= 95 bar m/s

Dust deflagration data for other dusts measured in the 1-m³ chamber are listed in Refs (47, 58).

10.7 In addition to the initial calibration and standardization procedure, at least one suitable dust should be retested quarterly to verify that the dispersion, turbulence, and ignition characteristics of the system have not changed.

11. Procedure

11.1 These general procedures are applicable for all suitable chambers. The detailed procedures specific to each chamber are listed in the corresponding appendix.

11.2 Inspect equipment to be sure it is thoroughly cleaned and in good operational condition.

NOTE 10—A high frequency of operation (20 to 40 explosions per day) can increase the operating temperature in some chambers to approximately 40 to 50°C. It has been determined that a reduction of up to 15% in P_{max} will result if the operating temperature in the chamber rises to this range.

11.3 Ensure that the oxygen content of the dispersion air is $20.9 \pm 0.5\%$. Higher or lower oxygen content will affect the P_{max} and K_{St} values.

NOTE 11—The oxygen content of some synthetic air cylinders may range from 19 to 26%.