Designation: E1226 – 12a

Standard Test Method for Explosibility of Dust Clouds[1]

This standard is issued under the fixed designation E1226; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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 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 and health practices and determine the applicability of regulatory limitations prior to use.*

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]

[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] 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.

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 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids

2.3 *VDI Standard:*

VDI-3673 Pressure Release of Dust Explosions[5]

2.4 *ISO Standard:*

ISO 6184/1 Explosion Protection Systems, Part 1, Determination of Explosion Indices of Combustible Dusts in Air[6]

3. Terminology

3.1 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}—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).

3.2.2 P_m—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 $P_{ex,a}$—the maximum absolute pressure produced during the course of a single deflagration test, n – $P_{ex,a} = P_{ex} + P_{ignition}$.

3.2.4 P_{max}—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 $P_{ignition}$—the absolute pressure in the vessel at the time of ignition.

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

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

3.2.8 $(dP/dt)_{max}$—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.

[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.

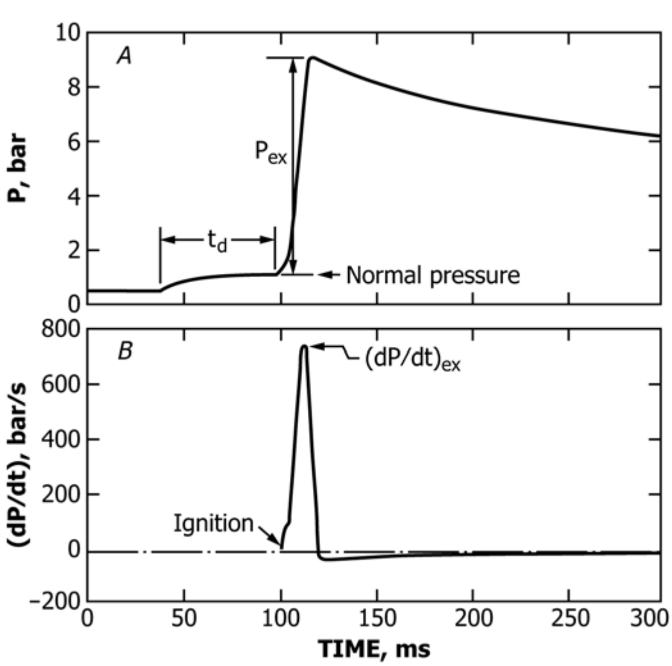

FIG. 1 Typical Recorder Tracings of Absolute Pressure, *P*, and Rate of Pressure Rise, *dP/dt*, for a Dust Deflagration in a 20-L Chamber

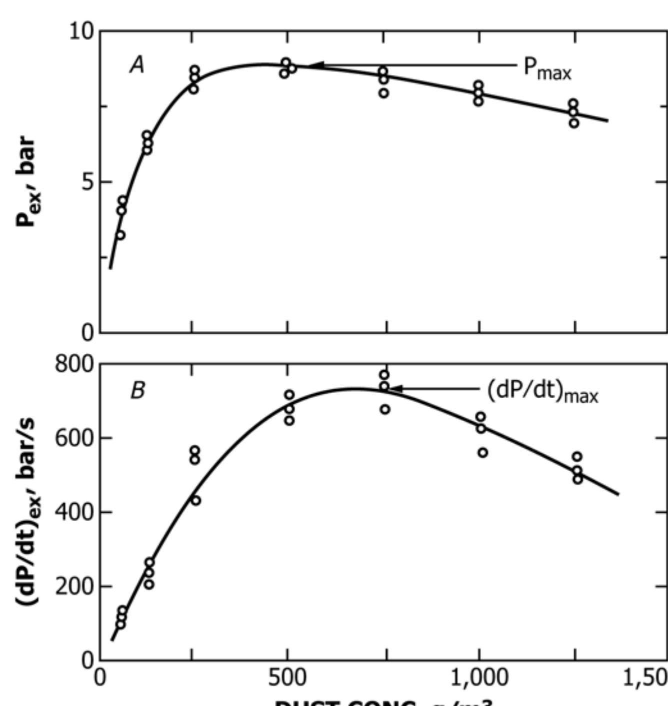

FIG. 2 P_{max} and $(dP/dt)_{max}$ as a Function of Concentration for a Typical Dust in a 20-L Chamber

3.2.9 *deflagration index, K_{St}*—maximum dP/dt normalized to a 1.0-m^3 volume. It is measured at the optimum dust concentration. K_{St} is defined in accordance with the following cubic relationship:

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

where:

P = pressure, bar,
t = time, s,
V = volume, m^3, and
K_{St} = bar m/s.

3.2.10 *explosible*—a material with a Pressure Ratio equal or greater than 2.0 in any test when tested using the Explosibility or 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.

3.2.11 *ignition delay time, t_d*—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 = $(P_{ex,a}-\Delta P_{ignitor})/P_{ignition}$

NOTE 4—When testing in the Siwek 20-L vessel (see Appendix X1) PR may be calculated using the corrected explosion pressure, n – 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, discrepancies have been observed between tests in 20-L and 1-m^3 chambers. A strong ignitor may overdrive a 20-L chamber, as discussed in Test Method E1515 and Refs (**1-3**).[7]

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 explosible when tested in a 1-m^3 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-m^3 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-m^3 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-m^3 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. 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

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

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

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.[8]

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.

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-m^3 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-m^3 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 ±10 % with the 1-m*^{3} *value and the* K_{St} *value must agree to within ±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-m^3 chamber. Once the specific dispersion procedures (that produce data comparable to those from the 1-m^3 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 ~28-µm) are:

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

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

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

10.6 Dust deflagration data in the 1-m^3 chamber at Basel, Switzerland are:

lycopodium:

$$P_{max} = 6.9 \text{ bar}$$
$$K_{St} = 157 \text{ bar m}/s$$

Pittsburgh seam bituminous coal:

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

Dust deflagration data for other dusts measured in the 1-m^3 chamber are listed in Refs (4, 5).

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.

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

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 ± 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 %.

11.4 Place a weighed amount of dust in the storage chamber or main chamber according to detailed instructions in the appendixes.

11.5 Place ignition source in the center of the apparatus.

11.6 Seal chamber, all valves must be closed.

11.7 Partially evacuate chamber so that after addition of dispersing air, the desired normal pressure in the chamber of 1 bar absolute will be reached prior to initiation of the deflagration test.

11.8 Actuate the timing circuit to conduct the test.

NOTE 12—The dust sample is automatically dispersed through a dispersion system in the chamber. The deflagration is then initiated when a defined ignition delay time has elapsed. This effective ignition delay time, t_d, is the length of time between the first pressure rise due to dust dispersion and the moment normal pressure has been reached in the chamber and ignition is activated (see Fig. 1). The length of this time defines the degree of turbulence and in many cases the concentration of the dust dispersed in the chamber at the moment of ignition.

11.9 The pressure time curve is recorded on a suitable piece of equipment, such as a storage oscilloscope, high-speed chart recorder, or electronic data acquisition system. The explosion data, P_{ex} and $(dP/dt)_{ex}$, can be obtained in accordance with Fig. 1.

11.10 After the test, open a valve to vent pressure from the chamber. Open the chamber, remove residue and thoroughly clean the chamber and dispersion system.

11.11 It is recommended that an initial concentration of 250 g/m^3 be tested (see 9.2). This concentration may be systematically increased by an equivalent of 250 g/m^3 (for example, 500, 750, 1000 g/m^3 etc.) until curves are obtained for both $(dP/dt)_{ex}$ and P_{ex} that clearly indicate an optimum value has been reached (see Fig. 2). Two additional test series are run at the concentrations where the maximums were found and at least one concentration on each side of the maximums.

NOTE 13—The $(dP/dt)_{\max}$ and P_{max} values are normally obtained in the 500 to 1250-g/m^3 range. In many cases the P_{max} and $(dP/dt)_{max}$ values are not found at the same concentrations. For materials containing high atomic weight elements (for example, metals) or inert components the optimum values may occur at larger concentrations and it is acceptable to use concentrations increments larger than 250 g/m^3 (for example 2000, 2500, 3000 g/m^3 etc.)

11.12 If it is indicated that the optimum concentration for $(dP/dt)_{\max}$ or P_{max} is less than 250 g/m^3 , the tested concentration may be halved; (125, 60, 30 g/m^3) until the optimum value is obtained.

12. Calculation

12.1 Pressure and rates of pressure rise are determined from pressure-time records. Fig. 1 is a typical record from which these values are obtained. The value of P_{ex}, for a test at a given concentration, is the highest deflagration pressure (absolute) minus the pressure at ignition (normally 1 bar), as shown in Fig. 1A. The value of $(dP/dt)_{ex}$ *for a given test is the maximum slope of the pressure trace (*Fig. 1*A) or the highest value on the rate of pressure rise trace (*Fig. 1*B).*

12.2 The reported values for P_{max} and $(dP/dt)_{max}$ are the averages of the highest values (over the range of concentrations) for each of the three test series (see Table X1.2). The highest value may not occur at the same concentration for each of the three test series.

12.3 The deflagration index, K_{St}, is calculated from $(dP/dt)_{\max}$ and the chamber volume, V, using the cubic relationship (see 3.2.11).

12.4 *Verification of Measurements:*

12.4.1 Time between the onset of dust dispersion and the electrical activation of the ignition source gives the ignition delay time, t_d. Variation between tests should not exceed ±10 %.

12.4.2 The highest *dP/dt* and *P* values are compared for each of the three test series (see Table X1.2). These values typically do not vary more than one concentration interval between test series. If the variation is greater, it should be evaluated whether tests need to be performed at additional concentrations in each series to ensure the maximum values are captured or whether a fourth series should be performed and the results of all four series should be considered.

The highest *dP/dt* and *P* values are compared for each of the three test series (see Table X1.2). These values should not vary more than one concentration interval between test series. If the variation is greater, the tests should be repeated.

12.4.3 If a low *dP/dt* is obtained, a weak deflagration may have occurred. Under these conditions, it is important that the *dP/dt* measurement is not taken from the ignition source but from the dust-air mixture itself (see Fig. 3).

12.4.4 The P_{max} and $(dP/dt)_{max}$ for the ignition source by itself must be established in the apparatus.

13. Explosibility or Go/No-Go Screening Tests

13.1 The objective of the screening test is to determine if the submitted dust sample is explosible or not. The test does not provide dust deflagration properties such as P_{max} and K_{St}.

13.1.1 Conduct initial tests using a 5 kJ or greater ignition source.

NOTE 14—Using an ignition source of 10 kJ (two 5-kJ igniters) is recommended in order to minimize the possibility of a false negative. However, if the researcher has concerns that the test may have been

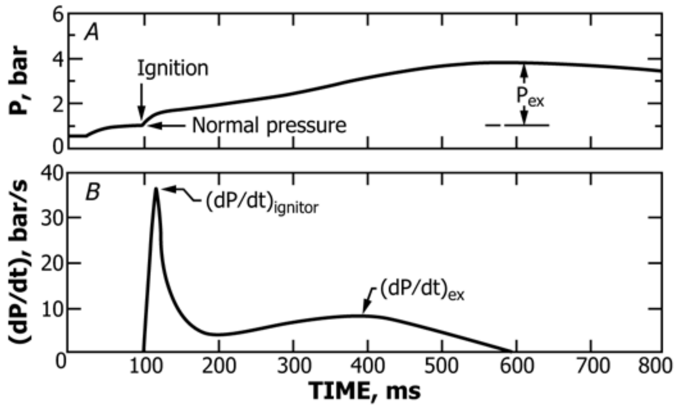

FIG. 3 Typical Recorder Tracings of Absolute Pressure, *P*, and Rate of Pressure Rise, *dP/dt*, for a Weak Dust Deflagration in a 20-L Chamber Using a 5000-J Ignitor

overdriven in the 20-L chamber, then see 5.4.

13.2 It is suggested to conduct screening test per 11 – 11.10and the following:

13.2.1 Conduct the first test at a dust concentration of 1000 g/m^3.

13.2.2 If the value of the explosion pressure ratio, PR is less than two when tested at the first dust concentration, then conduct an additional test at a second dust concentration, typically of 2000 g/m^3

NOTE 15—For many samples testing at concentrations of 1000 g/m^3 and 2000 g/m^3 is appropriate. It may be advisable to use different concentrations based upon the laboratories testing experience with similar samples. For instance, some materials containing high atomic weight elements (for example, metals) or mixtures of inert and combustible material can be explosible at higher concentrations. In such cases, it is advisable to test at higher concentrations. A laboratory may also choose to test at more than two concentrations.

13.2.2.1 If the value of the explosion pressure ratio, PR is greater than or equal to two at any concentration tested, then the dust sample is classified as "explosible" as a dust cloud under the test conditions.

13.2.2.2 If the value of the explosion pressure ratio, PR is less than two at all concentrations tested, then the dust sample is classified as "not explosible" as a dust cloud under the test conditions. (**Warning—**A material classified "not explosible" is not necessarily non-combustible. The same material when exposed to different conditions, such as elevated temperatures, external heat flux, presence of flammable vapors, size reduction or moisture, may undergo smoldering, flaming or deflagrative combustion either as a dust cloud or as layer. Additional analysis should be considered where adverse process or storage conditions exist or where there is a basis to believe the material has the potential to self-heat.)

NOTE 16—If testing in a Siwek 20-L vessel from Appendix X1 and using the corrected explosion pressure P_m to evaluate PR (see Note 4), the PR less than 2 criterion is equivalent to a criterion of P_m less than 1 bar(g) when the ignition pressure Pignition is nominally 1 bar(a) (between 940 and 1060 mbar(a)). More generally, the PR less than 2 criterion is equivalent to a criterion of P_m less than the ignition pressure $P_{ignition}$ for all values of $P_{ignition}$.

14. Report

14.1 Report the following information for explosibility screening tests:

14.1.1 Identification of the material tested; including type of dust, source, code numbers, forms, and previous history,

14.1.2 Particle size distribution of the sample as tested,

14.1.3 Moisture or volatile content, or both, of the as-tested material, if applicable,

14.1.4 Report the dust concentrations tested and resulting explosion pressure ratios (PR), or corrected explosion pressure P_m, and classification of whether or not the dust is explosible as a dust cloud.

14.1.5 Type and energy of the ignition source,

14.1.6 Test chamber used and any deviation from the normal procedure, and

14.1.7 If synthetic air was used for testing, then report the oxygen concentration of the air.

14.2 Report the following information for the explosibility parameters test:

14.2.1 Identification of the material tested; including type of dust, source, code numbers, forms, and previous history,

14.2.2 Particle size distribution of the sample as received and as tested,

14.2.3 Moisture or volatile content, or both, of the as received and as-tested material, if applicable,

14.2.4 Maximum pressure, maximum rate of pressure rise, and the concentrations at which these occur. Curves showing these data may also be included (see Fig. 2). It should be reported whether the maximum pressure is the directly measured value or a corrected value (such as in X1.8 and X1.9).

14.2.5 K_{St} value, rounded to the nearest integer,

14.2.6 Type and energy of the ignition source,

14.2.7 Test chamber used and any deviation from the normal procedure, and

14.2.8 If synthetic air was used for testing, then report the oxygen concentration of the air.

15. Precision and Bias

15.1 *Precision*—The following criteria should be useful for judging the acceptability of results. They are from X1.11 and X1.12 and Table X1.3

15.1.1 *Maximum Pressure, P_{max}:*

15.1.1.1 *Repeatability*—Duplicate measurements should agree within 5 %.

15.1.1.2 *Reproducibility*—Duplicate measurements at different laboratories should agree within 10 %.

15.1.2 *Maximum Rate of Pressure Rise, $(dP/dt)_{max}$ or Deflagration Index, K_{St}:*

15.1.2.1 *Repeatability*—Duplicate measurements should agree to within 30 % at K_{St} = 50 bar·m/s, 20 % at K_{St} = 100 bar·m/s, and within 10 % at K_{St} = 300 bar·m/s.

15.1.2.2 *Reproducibility*—Duplicate measurements at different laboratories should agree to within 30 % at K_{St} = 50 bar·m/s, within 20 % at K_{St} = 100 bar·m/s, and within 10 % at K_{St} = 300 bar·m/s.

15.2 *Bias*—Because the values obtained are relative measures of deflagration characteristics, no statement on bias can be made.

16. Keywords

16.1 dust explosion; explosion pressure

APPENDIXES

(Nonmandatory Information)

X1. SIWEK 20-L APPARATUS

X1.1 *Survey*—The Siwek 20-L apparatus including the explosibility test chamber and associated instrumentation is shown in Fig. X1.1.[9] Additional details of the apparatus and its calibration relative to the 1-m^3 chamber can be found in Refs(**6-8**).

X1.2 *General Description:*

X1.2.1 Fig. X1.2 is a schematic of the test apparatus, associated instrumentation, and related time diagrams. Detailed drawings concerning the 20-L sphere, the perforated annular nozzle, and the pilot-activated outlet valve are shown in Figs. X1.3-X1.5. The most important part numbers are listed in Table X1.1.

X1.2.2 The test chamber is a hollow sphere made of stainless steel, with a volume of 20 L and designed for a continuous operating pressure of 30 bar. A water jacket serves to remove the heat generated by the deflagration as to maintain thermostatically controlled test temperatures. For testing, the dust is dispersed into the sphere from a pressurized dust storage chamber ($V = 0.6$ L) by means of the outlet valve and a perforated annular nozzle. The outlet valve is opened and closed pneumatically by means of an auxiliary piston.

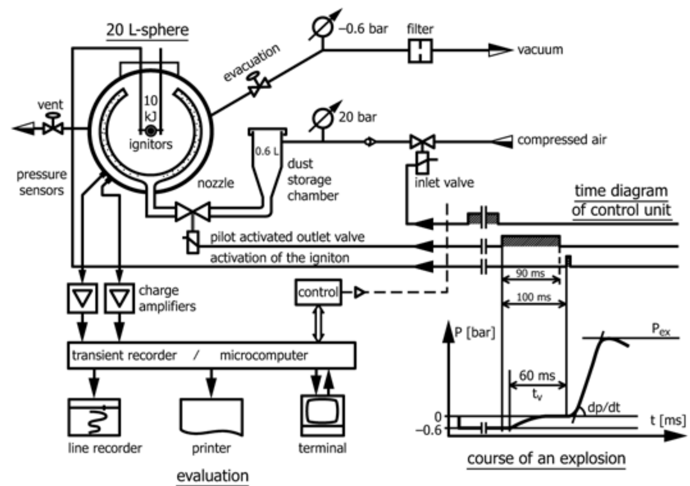

FIG. X1.2 Schematic of the Siwek 20-L Apparatus

X1.2.3 An alternative to the perforated annular nozzle is the rebound nozzle shown in Fig. X1.6.

X1.3 *Pre-evacuation*—Prior to dispersing the dust, the 20-L sphere is partially evacuated to 0.4 bar absolute. This evacuation of the 20-L sphere by 0.6 bar together with the air contained in the dust storage chamber (+20 bar; 0.6 L), results in the desired starting pressure (1 bar) for the test.

X1.4 *Ignition Source*—The standard ignition source is two pyrotechnic ignitors[10] with a total energy of 10 000 J (5000 J each). Each ignitor contains 1.2 g of the following composition: 40 % zirconium metal, 30 % barium nitrate, and 30 % barium peroxide. This source is initiated by a 1-A electric fuse head, with a delay time of less than 10 ms. The ignitors are placed in the center of the 20-L sphere, firing in the horizontal plane and in opposite directions.

X1.5 *Ignition Delay Time, (t_d)* —The inlet and outlet valve, the ignition, and the recording are controlled automatically. The degree of turbulence is mainly a function of the ignition

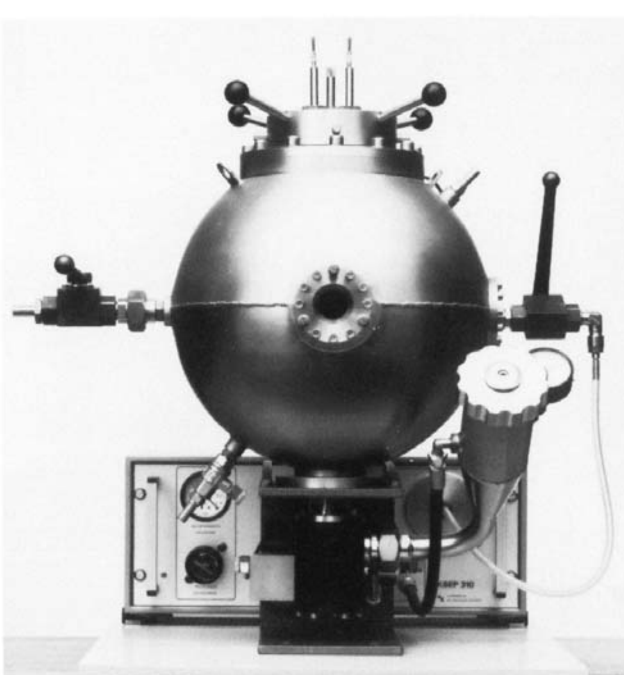

FIG. X1.1 Siwek 20-L Apparatus

[9] Available from Adolph Kühner AG, Dinkelbergstrasse 1, CH-4127, Birsfelden, Switzerland, or Cesana Corp., P. O. Box 182, Verona, NY 13478.

[10] The chemical ignitors are available commercially from Fr. Sobbe, GmbH, Beylingstrasse 59, Dortmund Nordrhein-Westfalen 44329, Germany or from Cesana Corp., PO Box 182, Verona, NY 13478.

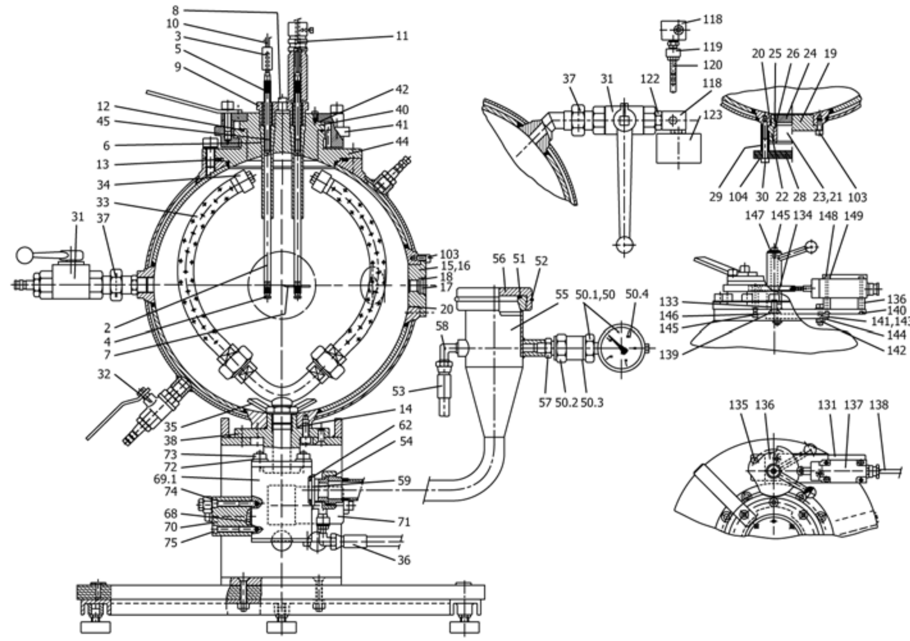

FIG. X1.3 Siwek 20-L Sphere

delay time, t_d, which is the time between the onset of dust dispersion and the activation of the ignition source (see Fig. X1.2). Therefore, for dust testing, the ignition delay time, t_d, has been standardized for the 20-L sphere to $t_d = 60 \pm 5$ ms.

X1.6 *Evaluation System*—In the evaluation unit, the measured values from the two pressure sensors are digitized with a high degree of resolution and stored in a read/write memory. Subsequently, the pressure data are evaluated by the microcomputer, point by point, and displayed on the screen together with the course of pressure versus time. The stored curves can also be recorded slowly on a normal *y/t*-recorder. As a safeguard against spurious measurements (auto-check), the system uses two independent pressure measuring channels.

X1.7 *Practical Determination of Deflagration Data:*

X1.7.1 The investigations must cover a wide range of concentrations, as shown in Fig. 2. In the first series, the maximum pressure and the maximum rate of pressure rise are determined. Starting with a dust concentration of 250 g/m^3 (5 g/20 L), the concentration is either increased in steps of 250 g/m^3 or decreased by 50 % of the previous value, until the maximum values for the explosion data [P_{max}, $(dP/dt)_{max}$] have clearly been covered.

X1.7.2 If within this first test series, the maximum values for the pressure and the rate of pressure rise are not observed, testing is to be continued with higher concentrations (>1500 g/m^3) until these maximum values have been clearly passed. Subsequently, two further test series have to be carried out.

X1.7.3 For the data, $P_{\max}$ and $(dP/dt)_{\max}$, the means from the maximum values of each series are reported (see Table X1.2). The K_{St} is calculated from the above mean by use of the following cubic relationship:

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

$$[\text{bar}/s]\,[\text{m}^3]^{1/3} = [\text{bar}\ m/s]$$

X1.8 *Correction for Explosion Pressures Exceeding 5.5 Bar:*

X1.8.1 Because of the cooling effect from the walls of the 20-L sphere, the values for $P_{ex} > 5.5$ bar are slightly lower than in the 1-m^3 vessel. Comparisons of pressure/time recordings show also that the pressure drop after the explosion is much faster in the 20-L sphere.

X1.8.2 To obtain results equivalent to the 1-m^3 vessel, this P_{ex} value may be corrected.

X1.8.3 Numerous correlation tests between the 1-m^3 vessel and the 20-L sphere have shown that the following equation may be utilized for this correction:

$$P_m = 0.775 P_{ex}^{1.15}$$

where:

P_m = corrected explosion pressure

X1.9 *Correction of the Explosion Pressure, P_{ex} < 5.5 Bar*—Due to the small test volume, the pressure effect caused by the pyrotechnic ignitors must be taken into account in the range of P_{ex} < 5.5 bar. A blind test, with the pyrotechnic ignitors alone, will give a pressure of approximately 1 bar if 10 000 J are used. But during a dust deflagration, with rising P_{ex}, the influence of the pyrotechnic ignitors will be minimized by the pressure effect of the deflagration itself.

X1.9.1 The following equation may be utilized for this correction:

$$P_m = 5.5 \left(\frac{P_{ex} - P_{CI}}{5.5 - P_{CI}} \right) bar$$

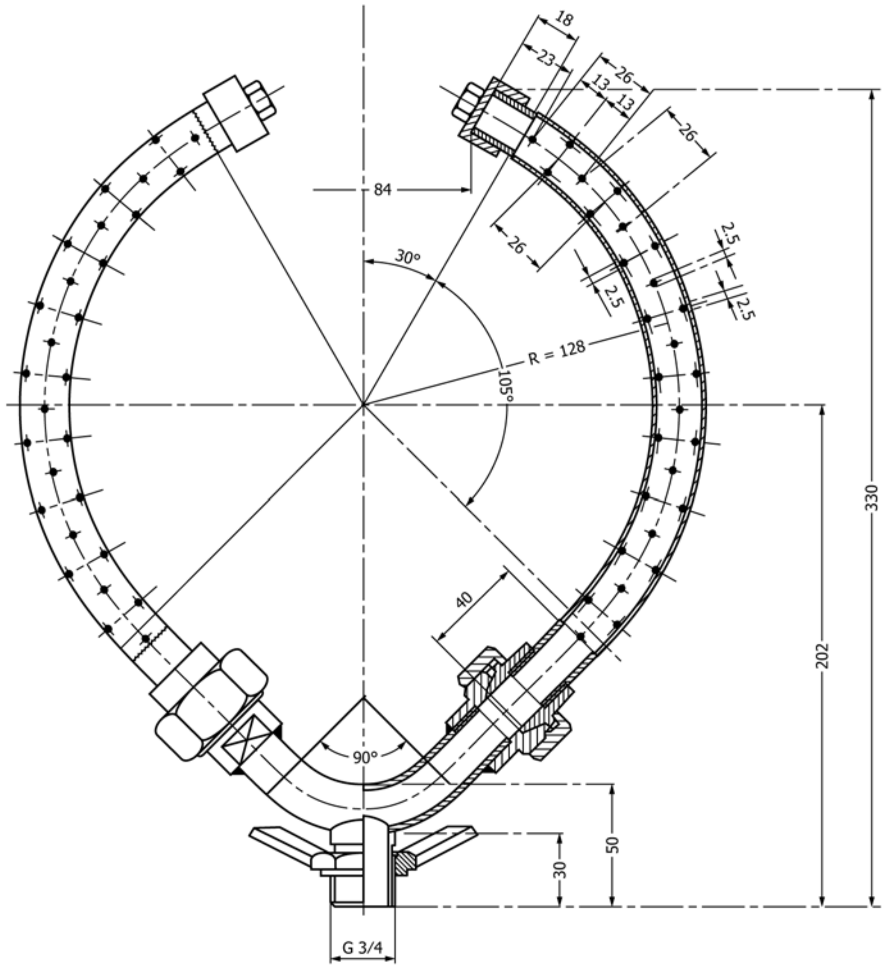

FIG. X1.4 Perforated Annular Nozzle With Dimensions in Millimetres

where:

P_m = corrected explosion pressure
P_{CI} = pressure due to chemical ignitors = 1.6 (IE/10,000),
IE = ignitor energy

X1.10 *Mild Dust Deflagration*—If a *dP/dt* of less than 150 bar/s is encountered, it may happen that the rate of pressure rise of the pyrotechnic ignitors is higher than that of the deflagration itself. It is therefore necessary to compare the pressure curve of the test with the pressure curve of the pyrotechnic ignitors (see Fig. 3 and Fig. X1.7). Typical values for pyrotechnic ignitors of E = 10 000 J are approximately 80 – 100 bar/s. It can be assumed that the pressure rise caused by the pyrotechnic ignitors is terminated after about 50 ms. Thus, the tangent may be drawn only 50 ms after ignition.

X1.11 *Standard Deviation:*

X1.11.1 This is valid for the 1-m^3 vessel as well as the 20-L sphere, when pyrotechnic ignitors are used as the ignition source. P_{max} can be determined with an accuracy of ±5 %, which is independent of the deflagration velocity.

X1.11.2 The accuracy of the K_{St} values shows a marked decrease towards lower values (see Table X1.3). In the upper range (K_{St} > 400 bar m/s), it is similar to that of the P_{max}.

X1.12 *Reproducibility:*

X1.12.1 *Maximum Deflagration Pressure, P_{max}*—For P_{max}, the average of duplicate tests obtained by each of several laboratories never differed by more than 10 %.

X1.12.2 K_{St} *– value*—For K_{St}, the average of duplicate tests obtained by each of several laboratories never differed by more than the values indicated in Table X1.3.

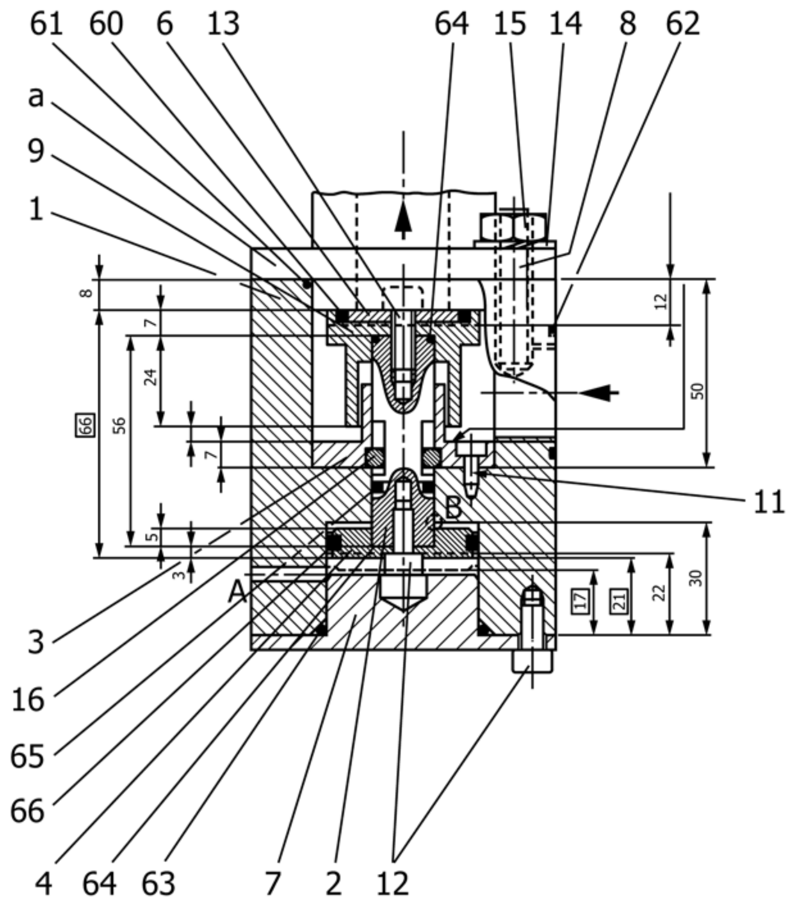

FIG. X1.5 Outlet Valves

TABLE X1.1 Listing of Drawings and Main Parts for the Siwek 20-L Apparatus

Fig. Number	Part Number	Nomenclature
X1.2	2	Ignition leads
X1.2	7	Pyrotechnic ignitors
X1.2	15	Measuring flange
X1.2	24	Sight glass
X1.2	28	Protective disk
X1.2	31	Ball valve (venting, vacuum)
X1.2	32	Ball valve (thermostat circuit)
X1.2	33	Perforated annular nozzle
X1.2	38	Bottom flange
X1.2	40	Top cover
X1.2	41	Bayonet ring for fast opening
X1.2	44	Top flange for wide opening
X1.2	50	Manometer with transfer diaphragm
X1.2	53	Pressure hose
X1.2	55	Dust storage chamber
X1.2	56	Cover of dust storage chamber
X1.2	69	Outlet valve
X1.2	70	Electromagnetic valve Type 123
X1.2	71	Electromagnetic valve Type 122
X1.2	123	Vacuum manometer
X1.2	132	Safety switch
X1.3	1	Tube bend
X1.3	2	Threaded bend
X1.3	3	Coupler
X1.3	10	Cap
X1.4	1	Valve body
X1.4	6	Disk
X1.4	7	Base-plate
X1.4	9	Face
X1.4	60–64	O-rings
X1.4	65–66	Rings

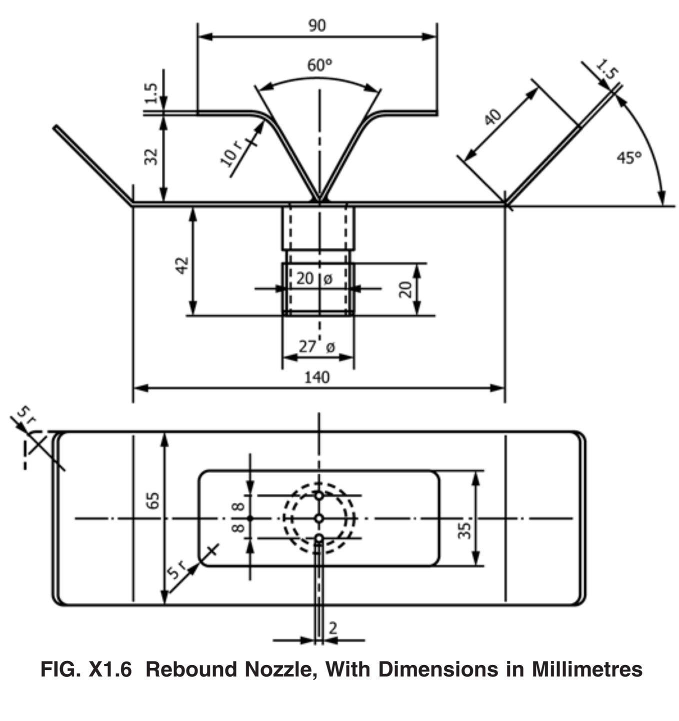

FIG. X1.6 Rebound Nozzle, With Dimensions in Millimetres

TABLE X1.2 Example for the Determination of P_{max} and $(dP/dt)_{max}$[A]

NOTE 1—20-L Apparatus, E = 10 000 J

Concentrations [g/m³]	250		500		750		1000		1250	
Explosion data	P_{ex} [bar]	dP/dt [bar/s]	P_{ex} [bar]	dP/dt [bar/s]	P_{ex} [bar]	dP/dt [bar/s]	P_{ex} [bar]	dP/dt [bar/s]	P_{ex} [bar]	dP/dt [bar/s]
Series 1	6.9	242	8.1	300	7.8	340	7.4	389	7.2	341
Series 2	7.3	281	7.8	342	8.2	369	7.6	346	7.0	324
Series 3	7.1	266	8.0	323	7.9	355	7.5	377	6.9	359

[A] The maximum values for each series are underlined:

P_{max} = (8.1 + 8.2 + 8.0) ⁄ 3 = 8.1 bar,
$(dP/dt)_{max}$ = (389 + 369 + 377) ⁄ 3 = 378 bar/s, and
K_{St} = (378 bar/s) $(0.02m^3)^{1/3}$ = 102 bar m/s.

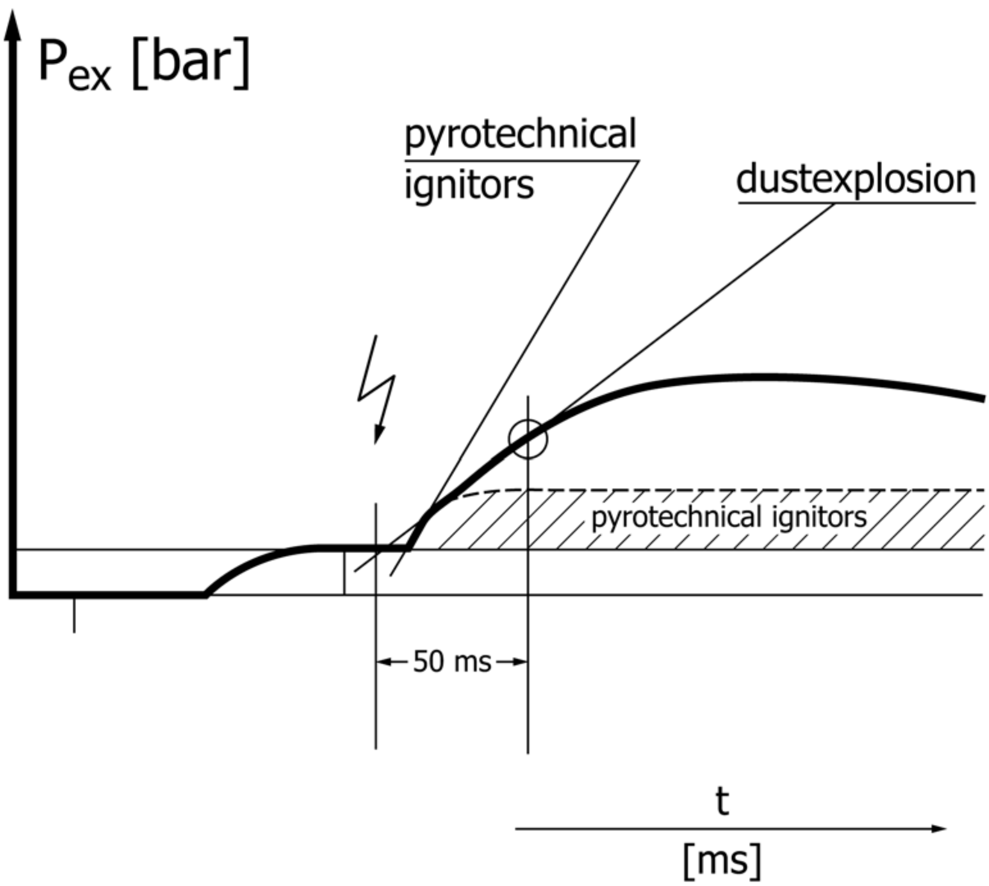

FIG. X1.7 Mild Dust Explosion

TABLE X1.3 Standard Deviation in the 20-L Apparatus

K_{St} [bar·m/s]	δ [±%]
50	30
100	20
200	12
300	10
≥400	5

X2. OTHER DUST EXPLOSIBILITY TEST CHAMBERS HAVING A VOLUME OF AT LEAST 20 L

X2.1 The chambers[11,12,13,14,15,16] have not yet completed the calibration process (see 10.2). Details of the chambers and test procedures will be added as each is calibrated as in Section 10.

X2.2 A partial list of other chambers used for dust testing is cited in Footnotes 10 through 15 with additional information given in Refs (**9-12**).

[11] 20-L chamber designed by Hercules, Cumberland, MD.

[12] Fike 20-L Dust Explosion Vessel manufactured by Fike Metal Products, Blue Springs, MO.

[13] Bureau of Mines 20-L Dust Explosibility Test Chamber. For more information, see Ref (**8**).

[14] 20-L chamber manufactured by Safety Consulting Engineers, Schaumburg , IL.

[15] Union Carbide 26-L chamber. For more information, see Ref (**9**).

[16] Proctor and Gamble 20-L chamber. For more information, see Refs (**10**) and (**11**).

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(**3**) Dastidar, A., and Amyotte, P., "Determination of Minimum Inerting Concentrations for Combustible Dusts in a Laboratory-Scale Chamber," *Transactions of IChemE*, Vol 80, Part B, 2002, pp. 287–297.

(**4**) Field, Peter, *Dust Explosions*, Elsevier Scientific Publishing Co., NY, NY, 1982, Appendix F.

(**5**) Bischoff, Hopf, Watermann and Schütz, *Forschungsbericht Staubexplosionen: Brenn und Explosions-Kenngrössen von Stauben*, Hauptverband der Gewerblichen Berufsgenossen schaften e.v, Bonn Federal Republic of Germany, 1980.

(**6**) Siwek, R., 20-L Laborapparatur für die Bestimmung der Explosions Kenngrösser brennbarer Stäube. (*20-L Laboratory Apparatus for the Determination of the Explosion Characteristics of Flammable Dusts*), Ciba-Geigy, Basel-Winterthur Engineering College, Winterthur, Switzerland, 1977.

(**7**) Siwek, R., Cesana, C., *Operating Instructions for the 20-L Apparatus*, 3rd revised edition, Adolf Künher, A. G., Birsfelden, Switzerland, August 1984.

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(**9**) Cashdollar, K. L. and Hertzberg, M, "20-L Explosibility Test Chamber for Dusts and Gases, *Review of Scientific Instruments,* Vol 56, pp. 596–602, 1985.

(**10**) Chippett, S. and Britton, L. G., A Method for Characterizing Dust Deflagration Behavior for Application to Vent Relief Design, *Particulate Science and Technology*, Vol 3, pp. 159–177, 1985.

(**11**) Cocks, R. E., and Meyer, R. C., Fabrication and Use of a 20 Litre Spherical Dust Testing Apparatus, Proctor and Gamble, Internal Report, Cincinnati, OH.

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(**15**) Dastidar, A., and Amyotte, P., "Determination of Minimum Inerting Concentrations for Combustible Dusts in a Laboratory-Scale Chamber," *Transactions of IChemE*, Vol 80, Part B, 2002, pp. 287–297.