



Designation: E 1226 – 00^{ε1}

Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts¹

This standard is issued under the fixed designation E 1226; 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.

^{ε1} NOTE—Paragraph 9.2 was editorially corrected July 2003.

INTRODUCTION

The primary objective for the laboratory determination of the dust deflagration index, K_{St} , the maximum pressure, P_{max} , and the maximum rate of pressure rise, $(dP/dt)_{max}$, is the use of these values for the design of protection systems. These parameters provide a measure of the potential severity of a deflagration of a combustible dust-air mixture. These parameters are a function of many factors, such as the turbulence, concentration, and homogeneity of the dust-air mixture; the type, energy, and location of the ignition source; the geometry of the test vessel; the particle size distribution of the dust; and the initial temperature and pressure of the tested mixture. Therefore, it is necessary to develop a standard laboratory test method, the data from which can be referenced against data from large-scale testing. For information on the sizing of deflagration vents, see NFPA 68.

This test method describes procedures for explosibility testing of dusts in laboratory chambers that have volumes of 20 L or greater. It is the purpose of this test method to provide information that can be used to predict the effects of an industrial scale deflagration of a dust-air mixture without requiring large-scale tests.

1. Scope

1.1 This test method is designed to determine the deflagration parameters of a combustible dust-air mixture within a near-spherical closed vessel of 20 L or greater volume. The parameters measured are the maximum pressure and the maximum rate of pressure rise.

1.2 Data obtained from this test method provide a relative measure of deflagration characteristics. The data have also been shown to be applicable to the design of protective measures, such as deflagration venting (1).²

1.3 This test method should be used to measure and describe the properties of materials in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment that takes into account all of the factors that are pertinent to an assessment of the fire hazard of a particular end use.

¹ This test method is under the jurisdiction of ASTM Committee E-27 on Hazard Potential of Chemicals and is the direct responsibility of Subcommittee E27.05 on Dusts.

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² The boldface numbers in parentheses refer to a list of references at the end of this test method.

NOTE 1—The evaluation of the deflagration parameters of maximum pressure and maximum rate of pressure rise can also be done using a 1.2-L Hartmann Apparatus. Test Method E 789, has been published regarding this application; however, the use of these data in the design of deflagration venting and containment systems is not recommended.

1.4 *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:

D 3173 Test Method for Moisture in the Analysis Sample of Coal and Coke³

D 3175 Test Method for Volatile Matter in the Analysis Sample of Coal and Coke³

E 789 Test Method for Pressure and Rate of Pressure Rise for Dust Explosions in a 1.2-Litre Closed Cylindrical Vessel⁴

E 1515 Test Method for Minimum Explosible Concentration of Combustible Dusts⁴

2.2 NFPA Publication:

³ Annual Book of ASTM Standards, Vol 05.05.

⁴ Annual Book of ASTM Standards, Vol 14.02.

NFPA 68 Guide for Deflagration Venting⁵

2.3 VDI Standard:

VDI-3673 Pressure Release of Dust Explosions⁶

2.4 ISO Standard:

ISO 6184/1 Explosion Protection Systems, Part 1, Determination of Explosion Indices of Combustible Dusts in Air⁷

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 P_{ex} —the maximum explosion pressure (above the pressure in the vessel at the time of ignition) reached during the course of a single deflagration test (see Fig. 1).

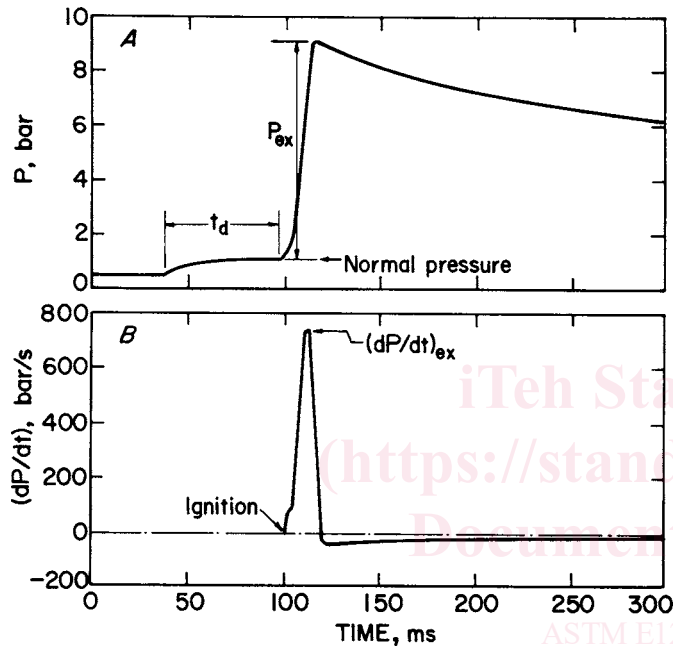


FIG. 1 Typical Recorder Tracings of Absolute Pressure, P , and Rate of Pressure Rise, dP/dt , for a Dust Deflagration in a 20-L Chamber

3.1.2 P_{max} —the maximum pressure (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.

3.1.3 $(dP/dt)_{ex}$ —the maximum rate of pressure rise during the course of a single deflagration test (see Fig. 1).

3.1.4 $(dP/dt)_{max}$ —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.

⁵ Available from National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

⁶ Available from Beuth Verlag, D-1000 Berlin, Federal Republic of Germany or from American National Standards Institute, 1430 Broadway, NY, NY 10018.

⁷ Available from ISO Case Postale 56, CH-1211, Geneva, 20, Switzerland or from ANSI.

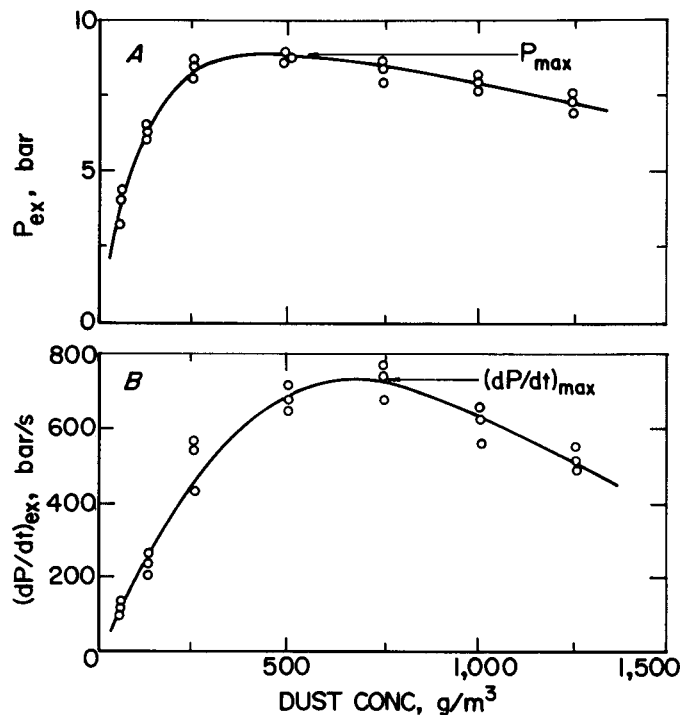


FIG. 2 P_{max} and $(dP/dt)_{max}$ as a Function of Concentration for a Typical Dust in a 20-L Chamber

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.

3.1.5 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.

3.1.6 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.

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 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 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 5000 or 10 000-J ignitor but not with a 2500-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-m³ chamber to determine if it is actually explosible.

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 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 STP 447A.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 μ m).

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

NOTE 3—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.

NOTE 4—It may be desirable in some cases to conduct dust deflagration tests on materials as sampled from a process because process dust streams 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.

9.4 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 5—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

⁸ STP 447A is available from ASTM Headquarters, 1916 Race St., Phila., PA 19103.

porosity (see Test Methods **D 3173** and **D 3175**), 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-m³ chamber (described in **ISO 6184/1** and **VDI 3673**) in order to use the nomograms (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:

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

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).

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

10.6 Dust deflagration data in the 1-m³ 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-m³ chamber are listed in Refs **(3)**, **(4)**.

10.7 In addition to the initial calibration and standardization procedure, at least one standard dust should be retested periodically to verify that the dispersion and turbulence characteristics of the chamber 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 6—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 $20.95 \pm 0.2\%$. Higher or lower oxygen content will affect the P_{max} and K_{St} values.

NOTE 7—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 8—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 or highspeed chart recorder. 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/m³ be tested (see **9.2**). This concentration may be systematically increased by an equivalent of 250 g/m³ (for example, 500, 750, 1000 g/m³ 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 one concentration on each side of the maximums.

NOTE 9—The $(dP/dt)_{max}$ and P_{max} values are normally obtained in the 500 to 1250-g/m³ range. In many cases the P_{max} and $(dP/dt)_{max}$ values are not found at the same concentrations.

11.12 If it is indicated that the optimum concentration for $(dP/dt)_{max}$ or P_{max} is less than 250 g/m³, the tested concentration may be halved; (125, 60, 30 g/m³) 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. 1A) or the highest value on the rate of pressure rise trace (Fig. 1B).

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 3.1.6).

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 $\pm 10\%$.

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 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).

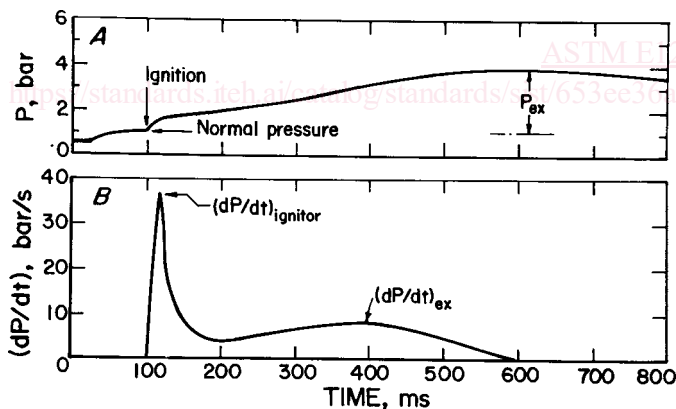


FIG. 3 Typical Recorder Tracings of Absolute Pressure, P , and Rate of Pressure Rise, dP/dt , for a Weak Dust Deflagration in a 20-L Chamber Using a 5000-J Ignitor

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

13. Report

13.1 Report the following information:

13.1.1 Complete identification of the material tested; including type of dust, source, code numbers, forms, and previous history,

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

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

13.1.4 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). This maximum pressure is the measured value; if a corrected maximum pressure is calculated (as in X1.8 and X1.9), this can also be listed,

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

13.1.6 Type and energy of the ignition source, and

13.1.7 Test chamber used and any deviation from the normal procedure.

14. Precision and Bias

14.1 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

14.1.1 Maximum Pressure, P_{max} :

14.1.1.1 Repeatability—Duplicate measurements should agree within 5%.

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

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

14.1.2.1 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.

14.1.2.2 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.

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

15. Keywords

15.1 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-m³ chamber can be found in Refs (5), (6), (7).

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.

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

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

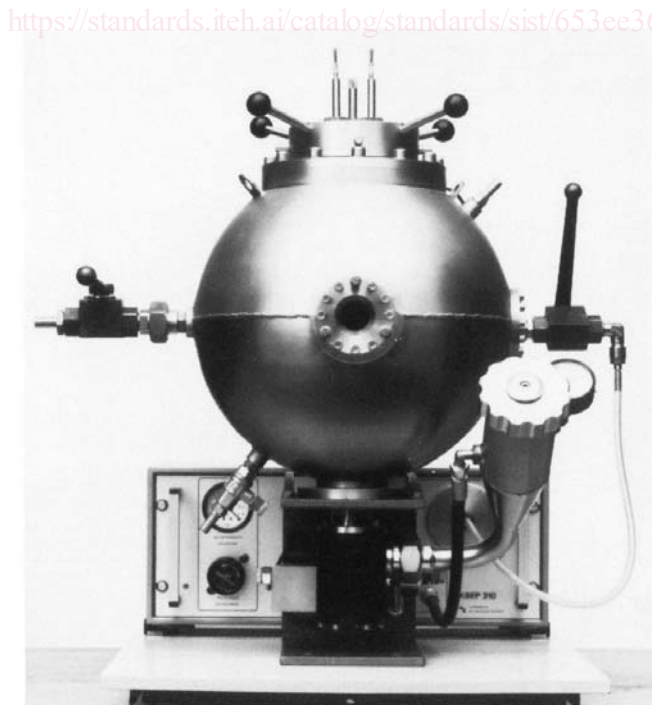


FIG. X1.1 Siwek 20-L Apparatus

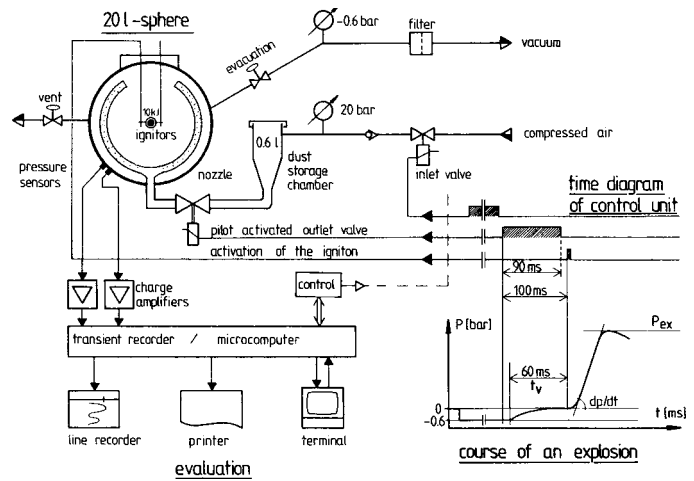


FIG. X1.2 Schematic of the Siwek 20-L Apparatus

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 ignitors¹⁰ 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 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

¹⁰ The chemical ignitors are available commercially from Fr. Sobbe, GmbH, Beylingstrasse 59, Postfach 140128, D-4600 Dortmund-Derne, Federal Republic of Germany or from Cesana Corp., PO Box 182, Verona, NY 13478.