



Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air¹

This standard is issued under the fixed designation E2019; 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.

1. Scope

1.1 This test method determines the minimum ignition energy of a dust cloud in air by a high voltage spark.

1.2 The Minimum Ignition Energy (MIE) of a dust-cloud is primarily used to assess the likelihood of ignition during processing and handling. The likelihood of ignition is used to evaluate the need for precautions such as explosion prevention systems. The MIE is determined as the electrical energy stored in a capacitor which, when released as a high voltage spark, is just sufficient to ignite the dust cloud at its most easily ignitable concentration in air. The laboratory test method described in this standard does not optimize all test variables that affect MIE. Smaller MIE values might be determined by increasing the number of repetitions or optimizing the spark discharge circuit for each dust tested.

1.3 In this test method, the test equipment is calibrated using a series of reference dusts whose MIE values lie within established limits. Once the test equipment is calibrated, the relative ignition sensitivity of other dusts can be found by comparing their MIE values with those of the reference dusts or with dusts whose ignition sensitivities are known from experience. **X1.1** of this test method includes guidance on the significance of minimum ignition energy with respect to electrostatic discharges.

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. Specific precautionary statements are given in Section 8.*

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

E582 Test Method for Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures

E789 Test Method for Dust Explosions in a 1.2-Litre Closed Cylindrical Vessel (Withdrawn 2007)³

E1226 Test Method for Explosibility of Dust Clouds

E1445 Terminology Relating to Hazard Potential of Chemicals

2.2 IEC Standards:⁴

1241-2-3, 1994 Electrical Apparatus for Use in the Presence of Combustible Dusts, Part 2: Test Method, Section 3: Method for Determining Minimum Ignition Energy of Dust-Air Mixtures

3. Terminology

3.1 *Definitions*—For additional definitions, see Terminology E1445.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *spark discharge, n*—transient discrete electric discharge, which takes place between two conductors, which are at different potentials. The discharge bridges the gap between the conductors in the form of a single ionization channel.

3.2.2 *minimum ignition energy (MIE), n*—electrical energy discharged from a capacitor, which is just sufficient to effect ignition of the most easily ignitable concentration of fuel in air under the specific test conditions.

3.2.3 *ignition delay time, n*—the time between the onset of dispersion of the dust sample into a cloud and the activation of the ignition source.

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 International Electrotechnical Commission (IEC), 3 rue de Varembe, Case postale 131, CH-1211, Geneva 20, Switzerland, <http://www.iec.ch>.

4. Summary of Test Method

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

4.2 Ignition trials of this dust-air mixture are then attempted, after a specific ignition delay time, by a spark discharge from a charged capacitor.

4.3 The stored energy discharged into the spark and the occurrence or nonoccurrence of flame are recorded.

4.4 The minimum ignition energy is sought by varying the dust concentration, the spark discharge energy and optionally the ignition delay time.

4.5 Ignition is determined by visual observation of a flame propagation away from the spark gap.

5. Significance and Use

5.1 This test method provides a procedure for performing laboratory tests to determine the minimum ignition energy of a dust cloud.

NOTE 1—For gases and vapors, see Test Method E582.

5.2 The data developed by this test method may be used to assess the spark ignitibility of a dust cloud. Additional guidance on the significance of minimum ignition energy is in X1.1.

5.3 The values obtained are specific to the sample tested, the method used and the test equipment used. The values are not to be considered intrinsic material constants.

5.4 The MIE of a dust as determined using this procedure can be compared with the MIE's of reference dusts (using the same procedure) to obtain the relative sensitivity of the dust to spark ignition. An understanding of the relative sensitivity to spark ignition can be used to minimize the probability of explosions due to spark ignition.

6. Interferences

6.1 Dust residue from previous tests may affect results. The chamber must be cleaned before a new product is tested.

6.2 Problems may arise due to electrical shortcircuits when using conductive materials.

7. Apparatus

7.1 *Test Apparatus*—Although a number of different test apparatuses are used in practice, they all have the following components in common: A test chamber, spark electrodes, and a spark generation circuit. Various configurations of the spark generation circuits are provided in the Appendix X1. The purpose of the test chamber is to produce a uniform, nonturbulent and known density dust cloud in air at the time of ignition. The clear plastic or glass Hartmann tube, typically 0.5 or 1.2 L, and the 20-L sphere apparatus have been found suitable for this test method. These vessels are described in Refs (1-4)⁵ and Test Methods E789 and E1226. These and

⁵ The boldface numbers in parentheses refer to the list of references at the end of this standard.

other suitable chambers can be used provided that the calibration requirements in 10.1 are met.

7.2 *Spark Generation Circuit*—The Appendix describes some suitable forms of circuits, all of which shall have the following characteristics:

7.2.1 *Electrode Material*, such as tungsten, stainless steel, brass, or graphite.

7.2.2 *Electrode Diameter and Shape*, 2 ± 1 mm. For circuits in which high voltage is maintained across the spark gap prior to spark breakdown, a significant fraction of the energy stored in the capacitor may drain away as corona discharges from sharp electrode tips prior to the spark discharge. This is increasingly important at low stored energies. Electrodes with rounded tips can be used to reduce corona effects that can occur with pointed electrodes, which may give incorrect values of spark energy. If pointed electrodes are used, corona effects should be considered carefully.

7.2.3 *Electrode Gap*—The optimum spacing is typically of the order of 6 mm. For certain materials at low ignition energy values, however, the gap spacing may need to be reduced in order to initiate the spark. Under these circumstances, the spark gap can be reduced and the tests carried out with the largest gap possible, but the gap should not be less than 2 mm.

NOTE 2—The capacitance of the electrodes and associated high voltage cables between the storage capacitor and the electrodes should be as low as possible. It should be noted that cable capacitance may be of the order 40pF/m depending on its construction, which represents significant additional stored energy at low storage capacitance and high voltage. The stray capacitance of these components must be measured to determine if it needs to be taken into account when calculating the stored circuit energy.

NOTE 3—Insulation resistance between electrodes should be sufficiently high to prevent leakage currents prior to discharge. Typically, a minimum resistance between the electrodes of $10^{12} \Omega$ is required for a minimum ignition energy of 1 mJ, and $10^{10} \Omega$ for a minimum ignition energy of 100 mJ. Insulation resistance may decrease over time due to contamination of the surface with carbon and other materials. The resistance may be directly measured across the electrodes. Alternatively, a decrease may be inferred by the inability to hold constant voltage on the isolated storage capacitor for the timescale of a test.

NOTE 4—Almost all electrostatic discharges in plant installations are capacitive with negligible inductance. It has been found that for equal stored energies many dusts can be ignited more easily when a resistor or an inductance is placed in the discharge circuit to create longer duration sparks. Ideally, the MIE should correspond to circuits whose discharge duration has been optimized for the dust in question using, for example, an inductance.

8. Safety Precautions

8.1 Prior to handling a test 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. MIE-tests should be conducted in a ventilated hood or other area having adequate ventilation.

8.2 Before initiating a test, check and secure the apparatus, fittings and gaskets to prevent leakage.

8.3 All enclosures containing electrical equipment must be connected to a common ground.

8.4 The test method should not be used with recognized explosives, such as gunpowder or dynamite; pyrophoric substances; or, substances or mixtures of substances, which may under some circumstances behave in a similar manner without considering the special hazards. Where any doubt exists about the existence of a hazard due to explosive properties, expert advice should be sought.

8.5 Because the apparatus consists of a circuit with high voltage components, adequate safeguards must be employed to prevent electrical shock to personnel.

8.6 The operator should work from a protected location, such as from outside a closed fume hood, in case of vessel or electrical failure.

8.7 Care should be taken not to clean acrylic Hartmann tubes with incompatible solvents, which can lead to embrittlement and cracking.

9. Sampling

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.

9.2 Minimum ignition energy decreases with decreasing particle size (see Fig. 1). Although tests may be run on an “as-received” sample, explosible dust clouds often consist largely of sub-200 mesh dust, which accumulates in suspension when coarser bulk powder is handled. Therefore, it is recommended that the test sample be at least 95 % minus 200 mesh (75 μm). In general, the sample tested should be at least as fine as the dust at the location being considered, which, in some cases, may require testing of sub-325 mesh or even finer dust.

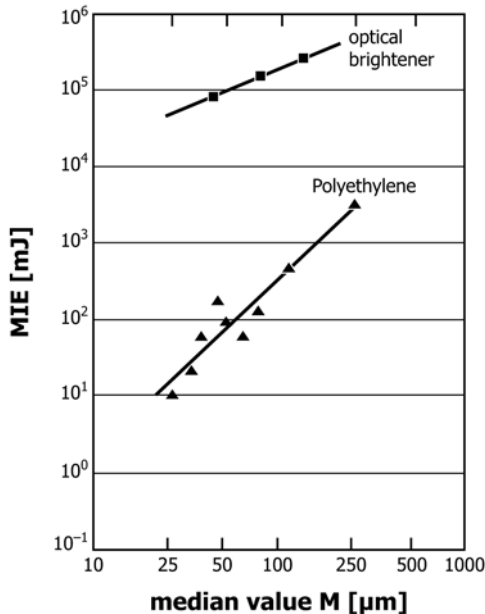


FIG. 1 Correlation of Median Particle Size and MIE (5)

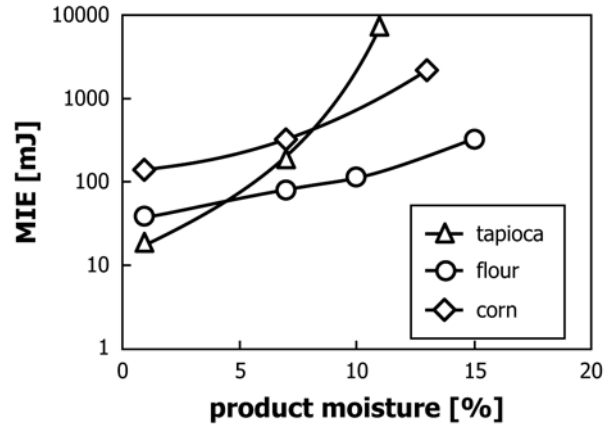


FIG. 2 Influence of the Humidity (Water Content) of Combustible Dusts (5)

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

NOTE 5—The operator should consider the thermal stability of the dust during grinding or pulverizing.

NOTE 6—In some cases, it may be desirable to conduct dust deflagration tests on material 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. When a material is tested in the as-received state, it should be recognized that the test results may not represent the most severe ignition hazards possible. Any process change resulting in a higher fraction of fines or drier product may result in a lower MIE for the product.

NOTE 7—The possible reduction of the particle size due to attrition by the dust dispersion system of the test apparatus should be considered.

NOTE 8—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. Materials consisting of a mixture of chemicals may be separated selectively on sieves and certain fibrous materials, which may not pass through a relatively coarse screen may produce dust deflagrations.

9.4 Minimum ignition energy for some dusts increases with increased moisture content (see Fig. 2). Dusts should be tested either in the dry state or approximating the moisture content under the handling conditions of interest. “Dry” samples should be transported to the test laboratory in sealed containers under dry air or nitrogen, and then stored in a desiccator. Desiccants, such as phosphorus pentoxide, may be more effective than silica gel in removing residual moisture.

NOTE 9—There is no single method for determining the moisture content or for drying a sample. Sample drying equally is complex due to the presence of volatiles, lack of or varying porosity (see Test Methods D3173 and D3175), 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 Calibration tests should be carried out on at least three different reference dusts. The results shall be within the following ranges (measured without inductance):

| | |
|-------------------------------|--------------------|
| Irganox 1010: ⁶ | MIE = 1 to 6 mJ |
| Anthraquinone: | MIE = 1 to 11 mJ |
| Lycopodium: ⁷ | MIE = 10 to 30 mJ |
| Pittsburgh coal: ⁸ | MIE = 30 to 140 mJ |

10.2 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 Test Description:

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

11.1.2 The combustible dust to be tested is dispersed in air at laboratory ambient test conditions in the test-apparatus, and the dust cloud is subjected to a spark discharge from a charged capacitor.

11.1.3 Ensure that the oxygen content of the dispersion air is $20.9 \pm 0.5\%$. Higher or lower oxygen content may affect the MIE result.

11.1.4 The energy discharged from the capacitor is calculated from the following formula:

$$W = 0.5 C(V_i^2 - V_f^2) \quad (1)$$

where:

- W = the discharged energy in joules [J],
- C = the total capacitance of the discharge circuit in farads [F], and
- V_i and V_f = the initial and final voltages of the charged capacitor in volts [V] as measured using an electrostatic voltmeter or equivalent very high impedance device.

11.1.5 It is necessary to take account of the following possible influences on the test:

11.1.5.1 Dust-air mixture dynamics/turbulence (a function of ignition delay time and dispersing pressure, etc.).

11.1.5.2 Dust concentration,

11.1.5.3 Voltage to which the capacitor is charged,

11.1.5.4 Capacitance of the discharge circuit capacitor,

11.1.5.5 Inductance of the discharge circuit,

11.1.5.6 Ohmic resistance of the discharge circuit, and

11.1.5.7 Materials and dimensions of the electrodes and the gap between the electrodes.

11.1.6 The final MIE result is reported for a dust cloud of optimum dust concentration for ignition and having the lowest turbulence level experimentally attainable. The optimum dust concentration cannot be obtained in one step; therefore, an iteration procedure is required. Examples include the following:

11.1.6.1 Start with a value of a spark energy that reliably will cause ignition of a given concentration in air of the dust

being tested. Then, the spark energy is reduced in steps, for example, factor of ~ 3 , at the given dust concentration until the dust cloud no longer ignites in any of ten tests at a given energy. Repeat the procedure at different dust concentrations until the lowest minimum ignition energy value is found (see Fig. 3).

11.1.6.2 Start as in 11.1.6.1 using a dust loading that is estimated to give $250\text{--}500\text{ g/m}^3$ and determine “go/no go” spark energies. Once a “limit” point is found for a particular concentration, repeat the procedure for higher and lower dust concentrations until a roughly parabolic curve is obtained for ignition energy versus dust concentration (see Fig. 4). Depending on the scatter evident in the curve, conduct ten repeat tests at the most ignitable dust concentration.

NOTE 10—Figs. 3 and 4 show both methods using Lycopodium as an example. Fig. 3 shows “go/no go” using the factor-of-3 method 11.1.6.1 and Fig. 4 shows the single curve comprising “go/no go” points (method 11.1.6.2).

11.1.6.3 The ignition delay time also may be varied step by step until the minimum value of the ignition energy is found.

11.1.7 These general procedures are applicable for all suitable circuits. The detailed procedures specific to each circuit are listed in the corresponding appendix.

11.1.8 The minimum ignition energy, MIE, lies between the highest energy, W_1 , at which ignition fails to occur in ten successive attempts to ignite the dust-air mixture, and the lowest energy, W_2 , at which ignition occurs once at least within ten successive attempts:

$$W_1 < MIE < W_2 \quad (2)$$

The ratio of the energy steps should be ≤ 3.3 , for example, 1 mJ, 3 mJ, 10 mJ, etc.)

11.1.8.1 In the method described in 11.1.6.2, the MIE normally is determined from the minimum of the spark energy versus concentration curve after the curve has been smoothed. If additional repeat tests are made at the most sensitive

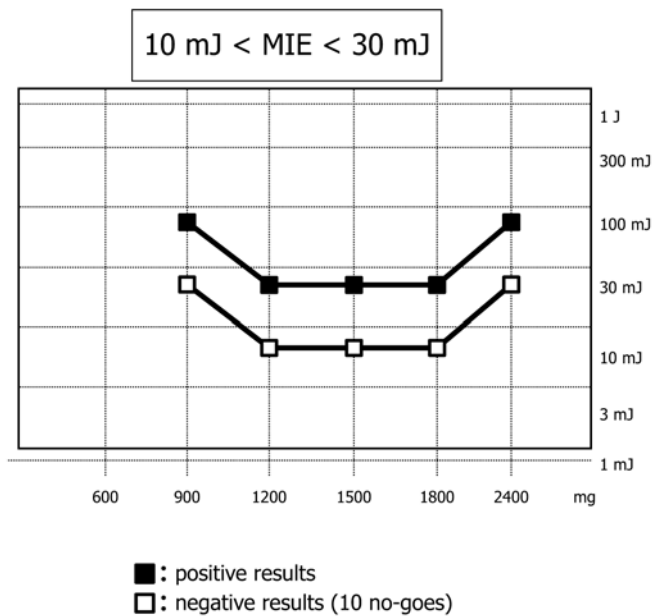


FIG. 3 MIE Test Results (10 mJ < MIE < 30 mJ)

⁶ Irganox 1010: Tetrakis-[Methylene(3,5-di-(tert)-butyl-4-hydroxyhydrocinamate)]methane, available source: Ciba Specialty Chemicals.

⁷ Lycopodium Clavatum: Lycopodium is a natural plant spore having a narrow size distribution with 100 % minus 200 mesh and a mass median diameter of $\sim 28\ \mu\text{m}$.

⁸ The Pittsburgh coal has $\sim 80\%$ minus 200 mesh, a mass median diameter of $\sim 45\ \mu\text{m}$, and 36 % volatility.

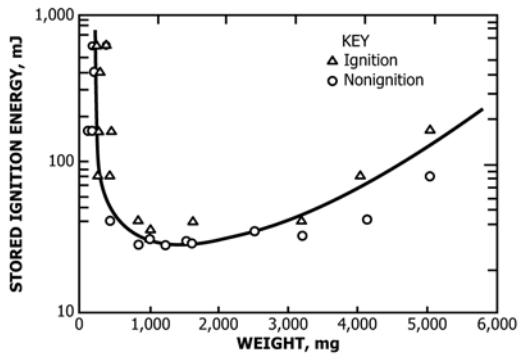


FIG. 4 MIE Test Results (MIE = 25 mJ)

concentration, the result may be smaller MIE values owing to the smaller ignition probability being investigated.

11.1.8.2 Example graphs of determined test results are shown in the following Figs. 3 and 4. In this example, the MIE shown in Fig. 3 is 10 to 30 mJ, and in Fig. 4 from the smoothed curve is 25 mJ.

12. Report

12.1 The report shall include the following information:

12.1.1 Appropriate identification of the material tested, including information, such as type of dust, source, code numbers, forms, and previous history.

12.1.2 Particle size distribution of the sample as received and as tested, if available. Statistical parameters derived from the distribution, such as, surface average or volume average diameter, may be used to summarize the distribution.

12.1.3 Moisture or volatile content, or both, of the as-received and as-tested material, if available.

12.1.4 The MIE as determined using the method in 11.1.6.1 or 11.1.6.2. Report the test procedure used and include appropriate tables plus the graph showing the MIE value.

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

12.1.6 Type of spark generating circuit and triggering method (see Appendix X1).

12.1.7 Tables of data, or a graph, or both.

13. Precision and Bias

13.1 Precision—Multiple tests at different labs should be within one energy range or, at most, two energy ranges.

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

14. Keywords

14.1 dust; minimum ignition energy; spark ignition

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF SPARK GENERATING SYSTEMS

X1.1 General—Sections X1.2, X1.3, X1.4 and X1.5 contain descriptions of four designs of spark generating circuit suitable for use in this test method. With any of these examples, it is possible to use different explosion vessels, provided that the dust dispersion is optimized and that suitable precautions are taken in order to prevent side effects occurring in comparatively large vessels from electrostatic charging phenomena during the dispersion of the dust. These phenomena include additional charging/discharging of the capacitor.

X1.1.1 If the storage capacitor is decoupled from the electrode during the charging process, the effect of the decrease in voltage that will occur due to the increase in capacitance when the connection to the electrode is made, should be taken into account in calculating the spark energy. In all calculations of energy the total capacitance of the discharge circuit should be used, and the voltage at time of discharge.

X1.2 Triggering by auxiliary spark using 3-electrode system.

X1.2.1 Fig. X1.1 illustrates the spark generating circuit of the test apparatus.

X1.2.2 The essential component is a 3-electrode spark gap. The two electrodes forming the main spark gap) are 2 ± 1 mm in diameter, their ends being reduced to a diameter of 2.0 mm

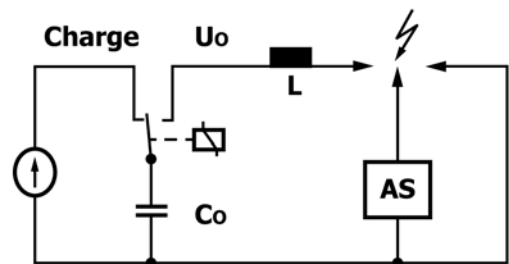


FIG. X1.1 Triggering by Auxiliary Spark Using three-Electrode System

over a length of 20 mm. The free end of the auxiliary electrode is angled toward the main spark gap, the length of this angled portion being 20 mm. This electrode arrangement is installed in an open top Hartmann tube and also is suitable for installation in other explosion vessels.

X1.2.3 Following the introduction into the mixture-generating device of the desired quantity of dust, the tube is placed in position. The test capacitor, C [20 to 10 000 pF], which stores the ignition energy, is charged by means of the high voltage charging unit (HVCU) across the charging resistance (R), which limits the charging current to 1 mA. The attempts to ignite the dust-air mixture are initiated by means of

the control facility (CF). Initiation of each attempt involves, first of all, triggering the device which disperses the dust into suspension, followed, after a predetermined interval by the auxiliary spark and with it, the triggering of the main spark discharge by the test capacitor.

X1.2.4 The energy of the auxiliary circuit is limited to not more than $\frac{1}{10}$ of the energy of the main discharging circuit.

X1.3 *Triggering by Electrode Movement:*

X1.3.1 Fig. X1.2 illustrates the spark generating circuit of the test apparatus.

X1.3.2 PTFE stoppers are fitted into the two electrode mounting ports in an open top Hartmann tube. These stoppers are bored in order to receive the electrodes in a manner permitting them to be moved. One of the electrodes, which is at earth potential, is attached to the measuring rod of a micrometer screw. The spindle of the micrometer is shortened, and is fastened to the modified Hartmann tube. The other electrode, to which the high voltage is applied is attached to the pushrod of a controllable, double-acting pneumatic piston [piston nominal diameter: 35 mm; operating pressure: 600 kPa], which has a working travel of 10 mm, attachment being through a PFTE insulating piece. The high voltage electrode is connected electrically to a capacitor with a value between 26 pF and 311 μ F. The voltage to which this capacitor is charged is indicated by means of an electrostatic voltmeter.

X1.3.3 After disconnecting the high-voltage generator from the capacitor circuit, the air to form a dust-air mixture by dispersing the dust into suspension to release from the pressure vessel, which is stored under pressure, being affected electro-pneumatically. After a delay, which is set with the aid of a timing device, the high voltage electrode is shot into the position defining the spark gap length, the energy stored in the capacitor, then being liberated at the spark gap.

X1.4 *Triggering by Voltage Increase (Trickle Charging Circuit):*

X1.4.1 Fig. X1.3 illustrates the spark generating circuit of the test apparatus.

X1.4.2 The trickle charging circuit is one of the simplest methods for producing sparks of known energy, which are required for determining the minimum ignition energy of dust-air mixtures.

X1.4.3 A high voltage dc supply slowly raises the potential of the capacitor until a spark occurs, the cycle then is repeated, giving a series of sparks each of approximately the same stored

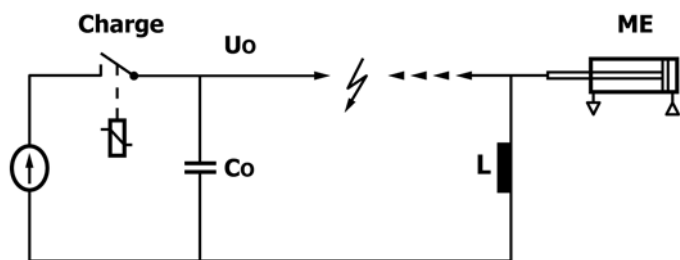


FIG. X1.2 Triggering by Electrode Movement

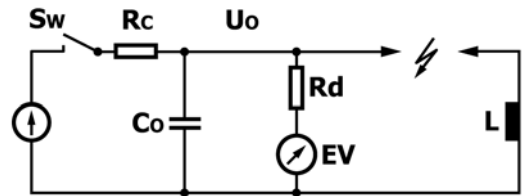


FIG. X1.3 Triggering by Voltage Increase (Trickle Charging Circuit)

energy. A current limiting resistor with a value between 10^8 and $10^9 \Omega$ is included in the circuit. The potential across the capacitor is measured by an electrostatic voltmeter with a decoupling resistor in series having a value between 10^8 and $10^9 \Omega$. Sparks of any energy level from 1 mJ upwards can be readily produced using this circuit by varying the value of the capacitor, and if necessary, the discharge voltage.

X1.4.4 The settings for sparks of the required energy are determined before any powder is placed in the ignition chamber. A capacitor of the appropriate value is chosen and a voltage in the range 10 kV to 30 kV selected. The voltage and electrode separation are then adjusted by trial until sparks of the stored energy on the capacitor, given by $0.5 CV^2$ occur at the electrodes. In this expression, V, is the voltage at which the spark occurs, and C is the total capacitance at the high voltage electrode, which can be measured using normal ac bridge methods. In order to make an ignition test, the high voltage electrode is grounded and the required mass of the prepared dust is placed in the dispersion cup. The dc voltage supply then is switched into the circuit, and as sparks start to pass between the electrodes, the powder is dispersed by an air jet. It is noted whether ignition occurs and flame propagates away from the spark gap.

X1.4.5 The first tests usually are performed with a high spark energy typically 500 mJ. If there is an ignition, the spark energy then is reduced in steps, and the test repeated until ignition does not occur, as described in 11.1.

X1.5 Triggering by auxiliary spark, using normal two-electrode system (trigger transformer in discharge circuit).

X1.5.1 Fig. X1.4 illustrates the spark generating circuit of the test apparatus.

X1.5.2 The basic circuit described by Eckhoff (6, 7) has been adopted by several U.S. companies for routine dust MIE measurements, as discussed by Britton(4). The diode "D" described by Eckhoff (6, 7) is omitted in some "routine MIE" circuit designs. A storage capacitor "C" is charged to voltage

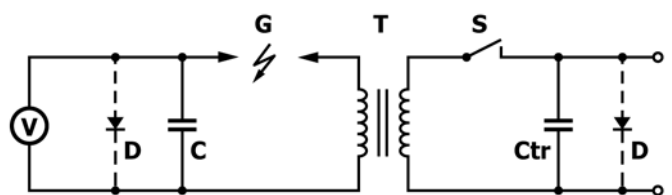


FIG. X1.4 Triggering by Auxiliary Spark, Using Normal Two-Electrode System (the Diode, D, Can Be Placed on Only One Side of the Transformer)

“ V_i ” as measured by a very high impedance ($>10^{13}$ ohm) voltmeter such as a field-mill voltmeter. Voltage “ V_i ” is typically less than 2500 V and incapable of causing spark breakdown of the gap “G”. When “C” is fully charged, the stored energy $W=0.5CV_i^2$. To effect spark breakdown, a “trigger” capacitor “ C_{Tr} ” is discharged through the primary of transformer “T” which results in a transient high voltage across the secondary and spark breakdown of gap “G”. When this occurs, the storage capacitor “C” partly discharges through the spark gap. If the voltage remaining on “C” = V_f , the change in energy W (Joules) = $0.5C(V_i^2 - V_f^2)$, where C is given in Farads and V in volts. The total energy discharged through the spark gap is assumed equal to W plus a minor contribution from trigger capacitor “ C_{Tr} ”. Various combinations of “C” and “ V_i ” allow the stored energy to be continuously varied up to at least 1000 mJ. One such circuit (4) uses a switched bank of five capacitors (0.001, 0.01, 0.05, 0.1 and 0.5 μ F) with a maximum voltage $V_i = 2500$ V. The trigger capacitor “ C_{Tr} ” (0.47 μ F) is initially charged to 165 V and is discharged through an

automobile ignition coil producing an open-circuit secondary voltage of the order 13 kV. The energy initially stored on “ C_{Tr} ” is 6.4 mJ, but in view of circuit losses (principally the transformer) the nominal contribution to spark energy is assumed to be 5 mJ for reporting purposes, that is, ignition energy W_{tot} (mJ) = 5 + 1000 W. Closure of switch “S” is electronically timed to coincide with formation of an optimized dust cloud. For routine measurements the optimum time delay between dust dispersion and switch closure is pre-set based on a large series of tests demonstrating that the lowest MIE results are obtained.

X1.5.3 The net spark energies generated for various combinations of C and V are determined in the conventional way by measuring current and voltage at the spark gap as functions of time and integrating the power-versus-time curve. The function of the diode D is to produce unidirectional discharges only. The diode has been placed on either sides of the circuits, parallel to the capacitor.

X2. SIGNIFICANCE OF MINIMUM IGNITION ENERGY

X2.1 Although it is not within the scope of this test method to specify limits or safety precautions as functions of the measured minimum ignition energies, it is appropriate to give some guidance on the significance of the measured values in relation to the safety of industrial installations.

X2.2 Several discharge types need to be considered, and they include the following:

| | |
|-------------------|--|
| Glow corona | from pointed or small radius conductors |
| Brush | from bulk powder or insulating solids |
| Cone | from highly insulating bulk powder or granules |
| Propagating brush | from polarized insulating surfaces |
| Spark | from two conducting, charged materials |

X2.2.1 Detailed description of these discharges, and their occurrence, can be found in Ref (8). Their ignition capabilities are indicated in Table X2.1 in relation of minimum ignition energies measured by the present method.

X2.3 Sparks are the most potent type of electrostatic discharge and are capable of igniting a wide range of flammable mixtures. The basic precaution against the occurrence of

incendive spark discharges is to ensure that all conducting parts of the plant and equipment and conductive products are securely grounded.

X2.4 In order to give a wide margin of safety, and to allow for variations of resistance over a period to time, a resistance to earth of less than $10^6 \Omega$ is advocated for conducting items.

X2.5 The maximum safe electrical resistance (R) between a conducting part and earth can be determined from the maximum electrostatic charging current (I) in the system.

X2.6 It is well established that spark discharges that occur at 100V or less do not cause ignition primarily because the gap across which the spark passes is much smaller than the quenching distance.

X2.7 Using Ohm’s law and a maximum voltage of 100V, the maximum safe resistance is given in the following equation:

$$R = \frac{100 V}{I} \quad (X2.1)$$

X2.8 The maximum charging current for most types of operations is 10^{-6} A so that the maximum safe resistance to earth in these cases is $1 \times 10^8 \Omega$. In very energetic operations, charging currents may reach 10^{-4} A. In such instances, the maximum safe resistance would be $1 \times 10^6 \Omega$.

X2.9 In cases where proper grounding cannot be achieved, the minimum ignition energy can be used to determine whether grounding is essential. From knowledge of the charging rate, the electrical capacitance, duration of operation, and leakage resistance, it is possible to calculate the maximum amount of energy that can be stored. This calculation then can be compared with the lowest minimum ignition energy from the

TABLE X2.1 Ignition Capabilities of Various Types of Electrostatic Discharge

| Discharge Type | Spark Equivalent Energy, (mJ) | Ignition Capability |
|------------------------|-----------------------------------|---------------------------------------|
| Corona | up to 0.1 | dust-air mixtures will not be ignited |
| Brush | up to 1 mJ ^A | Hybrid mixtures may be ignited |
| Conical pile discharge | Increases with volume of material | Most combustible dusts may be ignited |
| Propagating brush | Typically up to several J | Most combustible dusts may be ignited |
| Spark | No sensible limit | Any combustible dust may be ignited |

^A In case of ignition of gases, values up to 8mJ have been reported (9).

materials handled in the plant. Alternatively, if maximum potential that can occur is limited by a fixed, narrow gap across which any spark will pass, for example, in some rotating machinery, such as rotary valves, similar calculations can be made and compared with the measured minimum ignition energy. In all these cases, it is essential that the minimum ignition energy of the most sensitive materials being handled or processed is used in the comparisons.

X2.10 The assessment and control of the other types of discharge require expert knowledge, but general guidance is available (10).

X2.11 Spark discharges from charged, ungrounded metal parts of plant and equipment often are capacitive. To assess the ignition hazard in the case of such sparks, minimum ignition energy values should be determined by using a simple, plain capacitive discharge circuit. In some cases, the repeatability and reproducibility of results from such circuits can be improved by the inclusion of an inductance of 1 mH in the discharge circuit. It should be noted, however, that this modification normally produces more incendive sparks than a plain capacitive discharge circuit and, therefore, lower minimum ignition energy values. This can lead to the adoption of precautions that are not strictly necessary, with the attendant costs.

X2.12 Experimental investigations on a great number of dusts, using other ignition sources than electric sparks, indicate that the ranking order to the ignitibilities of dust clouds, obtained by using the present test method for minimum ignition energy, also is valid for other types of ignition sources.

Differences in the characteristics of energy release are responsible for the differences in the total amount of energy required for igniting a given mixture by various ignition sources. A well known example of the problem of drawing conclusions based only on a comparison of total energies is the attempt to assess the incendivity of brush discharges in the case of dust clouds.

X2.13 Previous experiments have shown that brush discharges can ignite explosible gas mixtures of minimum spark ignition energies of 4 mJ; however, so far it has not been possible to demonstrate that dust clouds of considerably lower minimum electric spark ignition energies than 4 mJ can be ignited by brush discharges. One reason for this could be that in the case of brush discharges the discharge time is different.

X2.14 Determination of energies required for igniting dust clouds is possible as far as ignition by electric sparks in concerned, provided the measurement method satisfies the requirements stated earlier. In principle, the spatial and temporal distribution of the energy in the discharge constitutes the basic characteristic of the incendivity of any discharge; however, an equivalent energy can be ascribed to a discharge by equating it to the energy of a spark discharge that gives the same incendivity as the discharge being considered.

X2.15 The problem of determining equivalent energies for mechanical sparks is discussed elsewhere (5,11).

X2.16 The considerations above only are applicable to combustible dusts. When it comes to the incendivity of spark discharges in mixtures of a dust cloud and an explosible gas, the technical literature should be consulted (12). In case of doubt, the value for the gas alone should be used.

REFERENCES

- (1) Field P., "Dust Explosions," *Handbook of Powder Technology*, Vol 4 Elsevier, Amsterdam, 1982.
- (2) Eckhoff, R.K., "Dust Explosions in the Process Industries," Section 5.3, pp. 411–426, Butterworth-Heinemann, Oxford, 1991.
- (3) Dorsett, H.G., Jr., Jacobsen M., Nagy J., and Williams R.P., U.S. Bureau of Mines, RI 5624 "Laboratory Equipment and Test Procedures for Evaluating Explosibility of Dusts," 1960.
- (4) Britton, L.G., "Using Material Data in Static Hazard Assessment," *Plant/Operations Progress*, Vol 11, No. 2, 1992.
- (5) Bartknecht, W. "Dust Explosions—Course, Prevention, Protection," Springer Verlag, New York, NY 1989.
- (6) Eckhoff, R. K., "Towards Absolute Ignition Energies for Dust Clouds," *Combustion and Flame* 24, 1975, pp. 53–64.
- (7) Alvestad, B., "An Electric Spark Generator for Determination for Minimum Ignition Energies for Dust Clouds," Chr. Michelsen Institute Research Report, No. 803301–3, November 1980.
- (8) Luettgens, G. and Glor, M., "Understanding and Controlling Static Electricity," Expert Verlag, Ehningen bei Böblingen, 1989.
- (9) Britton, L.G., "Avoiding Static Ignition Hazards in Chemical Operations" AIChE, New York, 1999.
- (10) Jaeger, N. and Siwek, R., "Prevention and Mitigation of Potential Hazards Due to the Handling of Powders During Transportation, Charging, Discharging and Storage," *Process Safety Progress*, Vol 17, No. 1, Spring 1998.
- (11) Eckhoff, R. K., "Dust Explosions in the Process Industries Second Edition," Section 7.10, pp. 517–522, Butterworth-Heinemann, Oxford 1997.
- (12) Britton, L.G., "Estimating the Minimum Ignition Energy of Hybrid Mixtures," *Process Safety Progress*, Vol 17, No. 2, Summer 1998.

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