A test for electrical ignitions of flammable dust clouds

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Abstract

The Atex Directive specifically includes the explosion hazards arising from the presence of flammable dusts. The European standards body CENELEC proposed a research project to develop tests for assessing the ignition hazard due to electrical apparatus used in hazardous dusty environments. This paper describes the work done on developing a test for electrical spark ignitions of explosive dust atmospheres. A prototype apparatus incorporating the dust explosibility vertical tube and the STA break flash apparatus has been developed. Tests using three dusts showed sulphur dust had ignition characteristics close to those of gas Group B, while other dusts were much less easily ignitable than methane. Round robin tests using a duplicate apparatus and the proposed test method produced results very close to those obtained using the original apparatus.

Keywords: Dust explosion; Electrical; Ignitions

European Directive 94/9/EC—the ATEX Directive—comes fully into force in June 2003 (DTI, 1994). The Directive applies to equipment and protective systems, among other things, that are intended for use in potentially explosive atmospheres. For the first time in regulations, explosion hazards arising from atmospheres containing flammable dusts are specifically included. Consequently, where appropriate, harmonised European standards are being prepared to specify methods for either preventing dust explosions or protecting against their effects.

The hazards arising from dusty environments are:

• ignition and explosion of a dust cloud by electrical or mechanical means,
• ignition and burning of a dust layer or accumulation,
• ignition of an explosive dust atmosphere by a burning deposit or burning nest.

To aid the development of standards CENELEC proposed a research project on electrical ignitions of dusty environments. The European Union funded this project (EU, 2001).

The partners in the project were the Health and Safety Laboratory (HSL), UK, Laboratorio Oficial J.M. Madariaga (LOM), Spain and Deutsche Montan Technologie (DMT), Germany. The objectives of the project were:

• To review the current state of the art in testing electrical apparatus in dusty environments through an enquiry directed at test houses, certification organisations and laboratories in Europe and the USA.
• To review current scientific and technical knowledge on ignitions of dust clouds and deposits.
• To develop a test apparatus and test method for assessing the ignition hazard of electrical apparatus intended for use in potentially explosive dust atmospheres.
• To develop a test apparatus and test method for assessing the ignition hazard of electrical apparatus intended for use in dusty environments where layers and accumulations of flammable dust may be present.
• To propose test procedures for standardisation.

This paper reports the work done on developing a test for ignitions of dusty atmospheres by electrical sparks.

Following a literature review, discussions with interested organisations and a study of the responses on
Electric sparks and arcs have long been known to be capable of igniting dust clouds. The minimum energy required for ignition varies with the properties of the dust, characteristics of the spark such as the spatial and temporal distribution of energy, and the geometry of the electrode gap, the electrode size and shape and the discharge triggering mechanism.

1. Literature review

At the start of the project a number of testing and certifying organisations and laboratories were contacted throughout the European Union and the USA. Enquiries were made of these organisations as to the current methods used for testing for ignition of flammable dusts by electrical apparatus, both as regards ignition of clouds by sparking and ignition of dust layers and accumulations by hot surfaces.

None of the eleven responses received described specific tests for electrical apparatus used in dust clouds. DMT suggested that gas–air mixtures should be used as substitutes for dust clouds, with the ignition energy of the gas–air mixture matching the ignition energy of the dusts. This type of substitute test is used in the testing of hand-held electrostatic spray guns according to EN 50 050: 1986 (EN, 1986). This standard specifies gas–air mixtures with ignition energies of 0.24 mJ (for paint spray guns) and 5 mJ (for powder spray guns) for use in ignition tests.

Underwriters Laboratories Inc. of the United States responded that their test method for intrinsically safe apparatus in dusty atmospheres was given in the Standard for Safety (Underwriters Laboratories, 1997), the Factory Mutual Research’s Approval Standard Class No. 3610: 1999(Factory Mutual Research, 1999) demands the same requirements as UL 913:

Intrinsically safe apparatus not enclosed in a dust-tight enclosure shall comply with the spark ignition requirements of some gases, e.g ethylene for metal dusts and propane or methane for coal and grain dusts and fibres and flyings.

The optimum spark discharge duration measured by Matsuda and Naito (1983), and estimated from the data in Boyle and Llewellyn (1950) and Line et al. (1959) were 0.1–1.0 ms, decreasing with the net spark ignition energy (Eckhoff, 1997).

Measurements by Parker (1985) showed that for some dusts there was a fairly distinct region where the discharge duration, produced the lowest ignition energies. With other dusts, however, no such region occurred. Parker used four dusts, and those with the higher ignition energies showed the optimum spark duration effect.

The physical length of the spark gap also has an effect on the ignition energy. Tests by Ballal (1980), using metal dusts and carbon, demonstrated that there was an optimum spark gap length for each dust, and that it increased as the ignition energy at the optimum gap length increased, although the result for carbon did not fit in with the results for the metal dusts. The optimum spark gaps fell in the range 2–7 mm. Measurements by Norberg, Zu, and Zhang (1988) showed the optimum spark gap length to be in the range 6–8 mm, for short duration capacitative sparks.

There is little published literature on research into the ignition of dusts by the type of circuits used in intrinsically safe apparatus, but two programs of work have been performed using the ‘make and break’ sparking apparatus.

The ‘make and break’ sparking apparatus is known as the break-flash apparatus and is described in BS-EN50020 (BS, 1995). Harper, Plain, Wilston, and Gibson (1997) used the standard disc and wires and fixed them vertically through the walls of a glass tube that
resembled the Hartmann tube that is used for dust explosibility testing. The sparking apparatus was positioned about 5 cm above the Hartmann dispersion cup. By repeated dispersion of the dust a continuous cloud was produced, with a concentration passing through the explosion range. Following calibration of the apparatus with methane, ten dusts were used with low ignition energies, as measured with capacitative sparks.

Of the dusts tested, only sulphur had a minimum igniting current less than that of methane. In a resistive current, at low voltage, the minimum igniting current measurements for sulphur followed the gas Group IIB data, and then passed through the gas Group IIA to gas Group I as the voltage increased. In an inductive circuit, the results for sulphur fell between gas Groups IIB and IIA. These measurements show that circuits certified as intrinsically safe for gases and vapours would not present an ignition risk for all but the most sensitive dusts.

A similar apparatus to that used by Harper et al. (1997) was devised by Tolson (Lunn, Rowland, & Tolson, 1999) to measure the ignitability of coal dust clouds when subjected to discharges produced by the IEC spark test apparatus. The equipment consisted of a circuit containing a variable power supply attached to an inductance of 1.1 Henry. The current in this circuit was made and broken using a modified version of the IEC spark test apparatus described in CENELEC Standard EN 50020. The main modifications were:

- the spark test apparatus was mounted horizontally;
- the disc electrode was copper instead of cadmium;
- the rotating electrodes were inside a Hartmann vertical tube apparatus.

The current in the circuit was set by adjusting the power supply voltage and the coal dust–air mixture produced by introducing a blast of air through a measured amount of coal dust placed in the dispersion cup at the base of the Hartmann apparatus. The concentration of coal dust in air could be changed by altering either the amount of the dust placed in the dispersion cup, or the air introduced by the blast. The current was progressively increased to give spark energies of from 50 to 300 mJ but there were no ignitions.

The test equipment was then validated using lycopodium–air mixtures. These are known to have ignition energies of about 8 mJ and were readily ignited with spark energies of 11 mJ which indicated that the apparatus was functioning correctly.

Coal dust–air mixtures were eventually ignited with a spark energy of 400 mJ; this was the maximum possible with the circuit used. Ignitions at this energy level were repeatable. This energy level is approximately 1000 times the level necessary for ignitions of methane–air mixtures.

Both the standard test for assessing dust explosibility and for measuring the Minimum Ignition Energy (MIE) utilise very similar designs of apparatus. The Hartmann tube—or vertical tube—consists of a 1.2 l tube, fitted with an ignition source that is either a high voltage continuous spark or a heating coil, with a means for introducing a blast of air to disperse a dust sample. The concentration of the dispersed dust is varied by changing the amount of dust placed in the tube prior to the test. By this means the potential explosion range of the dust is covered. If an explosion occurs the dust is considered to be flammable at ambient conditions.

The MIE, defined as the lowest capacitively stored electrical energy that just ignites the most ignitable dust/air following discharge across a spark gap, is measured in an apparatus similar to the vertical tube. A capacitor of known capacitance is charged to a specified high voltage and then discharged across a gap through a dust cloud dispersed by an air blast. The energy of the spark discharge is lowered in steps, and at every step tests are performed across the exploitable range. This continues until no ignition occurs at any dust concentration.

2. Development of the proto-type test apparatus

The literature survey and discussions with users and manufacturers indicated that an acceptable way forward was to combine the vertical tube apparatus familiar from dust explosibility testing and measurement of MIEs with the spark test apparatus and its associated test method. The vertical tube is an accepted way of producing an explosive dust cloud for testing purposes, for example the MIKE 3 apparatus for MIE measurements (Adolf Kuhner, 1997). The spark test apparatus (STA) is an accepted means of testing the igniting capabilities of electrical circuits for gases. This combination has the advantages that there is expertise throughout the world in using both types of test and the apparatus and test procedure would fit well into an established series of tests for dust ignitability and explosibility. A research apparatus on similar lines has been used successfully by two groups of workers in the United Kingdom and this work had demonstrated that the proposed test was technically feasible.

In addition, a new version of the spark test apparatus for circuits up to 20 A has been developed under an EU funded contract SMT4-CT98-2217 (EU, 1999).

A prototype apparatus was constructed using the Spark Test Apparatus (STA) as described in EN50 020 (BSI, 1995) as modified in project SMT4-CT98-2217. The dust dispersion chamber is based on the principles, and where practicable, the dimensions of the MIKE 3 minimum ignition apparatus. Photographs of the apparatus are shown in Fig. 1–3.
The apparatus thus consists of the STA disc and trailing electrode system mounted horizontally inside a vertical Hartmann-type tube with a mushroom shaped dispersion system in the base. Successive blasts of air at timed intervals disperse dust placed in the base to produce a cloud around the STA disc and the location of the sparks. Provision is made to pass a gas/air mix through the chamber for calibration of the STA. The number of turns of the STA motor are counted and displayed with a provision to automatically end the test when a preset count is reached. An ignition detector mechanism based on detection of the negative pressure following ignition has been developed.

Tests have been carried out with three dusts, lycopodium, calcium stearate and sulphur. The research has been aimed at devising a workable test method that takes into account the variables that may affect the ignition result. Ignition of dusts by electrical means is a complex mechanism involving the potential for many variables to effect the outcome. In view of the need to produce a test system that is reproducible and can be used universally the procedure has to be kept as simple as possible, and some of the variables involved need to be confined to standardised settings. Otherwise the operation becomes too complicated and unwieldy and not workable in practice. Following the development research work a test procedure has been produced that gives reproducible results.

3. Test procedure

A maximum particle size and drying procedure have been defined (63 µm and 105 ºC for 1 h are values commonly used in the past), but care has to be taken as experience with the MIKE 3 apparatus has shown that
drying can cause some dusts to be desensitised. Testing with both the dried and as found dusts may, therefore, be necessary.

It is especially important that a sufficiently wide range of dust concentrations is used to ensure that the optimum concentration for ignition for a particular dust is passed through during the test. During a test, however, the dust concentration reduces with time as the dust falls out of suspension and, provided sufficient dust is used initially, this ensures that the optimum concentration is passed through at some point although it is likely to be present for a limited time only. A study of the relationship between the explosibility characteristics and concentration of a number of different dusts shows a fairly flat profile between a concentration of about 250 g/m$^3$ and about 1000 g/m$^3$ for a lot of the dusts with only a few having a significant peak.

The air blasts used to disperse the dust are dry (bottled air is suitable) and the reservoir pressure is defined (the MIKE 3 uses 7 bar but 3 bar proved satisfactory for dusts tested here).

A calibration procedure needs to be carried out before the equipment can be used. The STA part is calibrated using the same procedure defined in EN 50 020:1995 (BSI, 1995) for methane (24 V d.c., 110 ma, 95 mH inductance). Once calibration using methane has proved satisfactory then a fixed weight of a standard dust can be introduced and the STA electrical parameters set to a defined value. The tests have shown that lycopodium dust with a voltage of 24 V and a current of 10 A is a suitable combination. Ignition should occur within a stipulated number of STA motor turns displayed on a counter.

Once the apparatus is fully calibrated, a thorough clean to remove all traces of lycopodium is required before the test dust is introduced. The electrical equipment to be tested is connected to the STA. A relay that operates upon commencements of the test is used as an interface to prevent heat damage to the tungsten wires when stationary. The test is run for 400 turns of the STA or until ignition occurs and is repeated a number of times with different initial quantities of dust so that a wide range of concentrations is covered. During the research work 400 turns proved successful on the three dusts repeated for seven different starting weights of dust. Blowing out of the chamber with an airline is sufficient after a test before fresh dust is added. This procedure is repeated until the defined count is reached or an ignition occurs.

In summary the test procedure is:

1. Calibrate the STA with a methane/air gas mixture using the procedure in EN 50 020.
2. Calibrate the full apparatus using lycopodium (10 A, 24 V).
3. Dismantle and clean the chamber.
4. Add 2.5 g of the prepared test dust.
5. Connect the electrical equipment to be tested.
6. Run the test for 400 counts of the STA or until ignition occurs.
7. Blow out the chamber with an airline (dry air).
8. Repeat 6) and 7) using 5, 7.5, 10, 12.5, 15, 17.5 g of dust.

4. Results

The results from a validation test using an 8.3% methane mixture are shown in Fig. 4, where they are compared to the ignition curves for resistive circuits published in EN 50 020 (BSI, 1995). The present measurements are close to, but slightly above, the Group
(methane) curve and indicate that the apparatus is giving reliable results.

Three dusts have been tested using a resistive circuit—calcium stearate, lycopodium and sulphur. The ignition results based on the proposed draft test method are shown in Fig. 5 in a comparison with the published current voltage ignition curves from EN 50 020 (BSI, 1995). Both lycopodium and calcium stearate show ignition conditions higher than the methane curves. Sulphur, however, is much easier to ignite, and falls close to the ignition curve for IIB gases—typically ethylene. This result supports previous work that shows ignitions of sulphur falling on or close to the IIB ignition curve.

Fig. 5. Ignition results for lycopodium, calcium stearate and sulphur dusts compared to published ignition curves.

5. Round robin tests

5.1. Tests at LOM

In the tests performed by LOM, around 25 V were used for the motor supply, about 28 air pulses were obtained for 400 revolutions and various resistor combinations were used to obtain the desired spark intensities. A calibration check with methane at 8.3% was performed, with ignition obtained at 0.120 A. Three dust samples delivered by HSL were tested: lycopodium, calcium stearate and sulphur. Dust weights ranged from 2.5 to 20 g.

5.2. Tests at DMT

The tests were carried out with lycopodium, calcium stearate and sulphur, as provided by HSL. The revolutions of the wire holder of the wolfram wire were set to 80 min⁻¹. The tests were stopped in case of non-ignition after 400 revolutions. The ignition current was varied at a given voltage by altering the corresponding resistance. By this means, the power was reduced for each following test until an ignition of the dust–air mixture did not occur. The current that just did not lead to an ignition of the dust-air mixture is recorded as well as the current that just led to an ignition.

The weight of the dust was increased step by step and the powder was reduced if necessary. The tests were carried out with lycopodium and calcium stearate with a weight of 1.25, 2.5 and 5 g. Larger weights of dusts did not seem to be practical because they could not be dispersed completely. For 7.5 g, for instance, a major part of the dust remained in the dispersing device. Weights of up to 15 g were used for the tests with sulphur dust. The sulphur dust adhered to all the surfaces in the interior of the test apparatus following initial dispersal. The sulphur was dried up to remaining humidity of 0.08%. The lycopodium and the calcium stearate were kept in the same status as they were delivered.

The calibration of the test apparatus was carried out with a 8.3 vol% methane–air mixture. The ignition current was set to 110 mA with a voltage of 24 V. The circuit has an air coil with an inductance of 95 mH. Wolfram wires with a diameter of 0.2 mm were used for the calibration. Problems arose when calibrating the test apparatus had to be sealed particularly during calibration to have an exact gas concentration.

The DMT measurements plus those of HSL and LOM are shown in Fig. 6 and listed in Table 1.

6. Discussion

Because of the more complex nature of dust clouds and the greater number of variables when compared to
gases and vapors there was a concern that applying the STA test to dust clouds would give less consistent results. The results obtained and the practical experience gained whilst developing the test method show this not to be the case. The dusts proved to behave in a repeatable manner during development of the test and the partners measured very similar ignition conditions during the round robin tests. Contamination of the cadmium disc by the test dust did not seem to have any effect on the sensitivity of the test.

DMT found that the cadmium electrode wore away rapidly and the abrasion was so extreme after 40 single tests that the cadmium electrode could not be used anymore. The abrasion was mainly visible by splintering. Due to this high cadmium emission, corresponding work protection measurements were necessary for the tests. While executing the tests and cleaning test apparatus the testing officers had to wear a respirator with a P 3-filter and gloves. All three electrodes delivered by HSL were too soft for the wolfram wire of 0.38 mm diameter used.

The attrition was so intensive that the electrode had to be exchanged after each test series.

HSL’s experience was, however, different. The wear rate and subsequent amount of cadmium deposited was not excessive during the HSL tests and the same disc was used for the verification tests using methane and all three dusts before being regarded as worn out.

Excessive wear problems experienced by DMT of the cadmium discs may be due to the material being too soft. The discs used in the apparatus supplied by HSL were the last remaining stock of undetermined composition. It is possible they could be softer than the one used by HSL. It is important that a reduced amount of overlap between wire and disc (0.5 mm rather than the 1 mm for the standard wires) is used to compensate for the increased stiffness of the thicker wire. Endurance tests of 20,000 turns were carried out during the development of the high current STA for project SMT4-CT98-2217 (EU, 1999) with negligible erosion of disc or wires. Testing bodies such as the UK Electrical Equipment Certification Service (EECS) have used this higher current version successfully. The use of cadmium as a disc material poses a potential health risk but the use of similar extract system and precautions as are required for the standard STA equipment should be adequate.

Although the composition of the dust cloud at the moment of ignition is unknown this is true of other dust ignition tests that use the same method of dust dispersion. The procedure has been developed to ensure that there is a very high probability that the most easily ignitable mixture is traversed as dust concentrations change and that it will be subjected to the spark. The highly satisfactory agreement obtained by the partners using

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**Table 1**

<table>
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<tr>
<th>Voltage (V)</th>
<th>HSL Current (A)</th>
<th>LOM Current (A)</th>
<th>DMT Current (A)</th>
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<tbody>
<tr>
<td>Lycopodium</td>
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<tr>
<td>23</td>
<td>9.67</td>
<td>8.995</td>
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<td>30</td>
<td>4.15</td>
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<tr>
<td>Calcium stearate</td>
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<td>8.995</td>
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Fig. 6. Comparisons of measurements using the test apparatus.
this apparatus and method indicates that the procedure is satisfactory in this regard.

Based on the dusts tested and the results of the round robin tests the equipment can be used as a viable test for individual pieces of electrical equipment. Based on a comparison of the results obtained with the curves for gases and vapors in the European Standard EN 50 020 (BSI, 1995), then there seems to be a good possibility of using the equipment to produce similar curves for various dust groups. The results with sulphur dust fall very close to the curve for ethylene and show that some dusts are very sensitive and equipment would have to be certified accordingly. The results obtained using a similar experimental apparatus by Harper et al. (1997), further verify that the HSL test produces reproducible results.

On the other hand the lycopodium and calcium stearate results indicate that a less stringent classification for these and probably a great many more dusts would be appropriate. The fact that their MIKE 3 MIE values are fairly different when the STA apparatus produces almost identical results suggests that dusts may lend themselves to groupings.

References


