Simultaneous measurement of ignition energy and current signature for brush discharges

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Abstract. Accurate prediction of the probability of ignition arising from charged insulators is a crucial element of risk assessment in process industry. Incendiary brush discharges can occur when a large or grounded conductor approaches a charged insulator in the presence of a flammable atmosphere. This paper describes ignition tests based on an IEC standard method and simultaneously recorded temporal distribution of current released in the discharges, using a discharge probe integrated with the ignition probe. Ignition and non-ignition results are compared with peak discharge current and charge transferred in the discharge. No clear ignition threshold was found for either of these parameters. No major differences were found between igniting and non-igniting waveforms.

1. Introduction

Accurate prediction of the probability of ignition arising from charged insulators is a crucial element of risk assessment in process industry. Incendiary brush discharges can occur when a large or grounded conductor approaches a charged insulator in the presence of a flammable atmosphere and have long been studied by various authors, for example [1], [2], [3], [4]. It is not possible to calculate the brush discharge energy in the way that can be done for sparks. It is customary to evaluate brush discharges in terms of an “equivalent energy” given by the Minimum Ignition Energy (MIE) of the flammable atmosphere which they will ignite. It is known that for brush discharges it is not just the total released energy that is of importance in determining whether or not an ignition will occur. Even if the total energy released in the discharge exceeds the MIE, there may not be an ignition [4]. There has been much discussion about the parameters that are important, such as polarity of the source, peak discharge current and waveform, and charge transferred in the discharge. The latter has been used in standards for evaluation of ignition risk from ESD from insulating surfaces, with limits of 60nC for Group I or IIA, 30nC for Group IIB and 10nC for Group IIC apparatus [5], [6]. A common method for measurement of charge transferred in the discharge is to collect it in a capacitor and measure the voltage produced. This method, however, does not give the ESD waveform and fails when an ignition occurs, as the flame plasma provides a conduction path for the charge to ground [3].

The probe design and electrode shapes and sizes, and the gap across which the discharge occurs, also have an effect [7]. For these reasons, in recent research the current waveform of the discharge has often been measured, and von Pidoll et al. have investigated the use of the magnitude of the charge transferred in the discharge for incendivity evaluation [8]. We are not aware, however, of any
published measurements of the electrostatic discharge current waveform simultaneously with an ignition test.

In this paper we describe ignition tests based on an IEC standard method [9] and simultaneously recorded temporal distribution of current released in the discharges, measured using a discharge probe integrated with the ignition probe. While it is known that shielded probe designs capture the discharge current more efficiently [10], we have chosen to use an unshielded design as this enabled use of a standard probe and is most commonly used by other workers.

2. Methodology

The ignition tests with simultaneous discharge current measurements were performed with a modified ignition probe designed according to IEC 61340-4-4 [9]. The probe design allowed an ethylene - air mixture to flow through the probe inside a containing wall, past a grounded spherical electrode. The gas mixture used was as specified in [9] with volume concentration of 5.4% ethylene and MIE of 0.14 mJ. When a discharge occurs to the electrode at the centre of the gas flow, and its energy content is high enough, an ignition of the gas mixture can occur.

With the standard probe it was not possible to measure the electrostatic discharge current occurring to the grounded probe at the time of the ignition. In the modified ignition probe used in this work, the ground connection to the probe was cut. A resistance consisting of 8 parallel 6.81Ω resistors was inserted in-between the discharge electrode and ground giving a resistance to ground of 0.85Ω in series with the ESD current, in a manner that minimized the high frequency impedance in order to maintain the waveform shape.

An oscilloscope used to detect the discharge current was connected to the ignition probe by a 50Ω coaxial cable in parallel with the resistors. As the ESD current flowed through the parallel resistors to ground the voltage developed across these resistors was recorded by the oscilloscope. Waveform parameters such as peak current could be directly measured from the digitized current waveform. Charge transferred in the discharge was calculated by integration of the discharge current over the full duration of the waveform, i.e. to the point at which the current flow became insignificant.

The test object was a highly insulating polypropylene tray, charged by rubbing with a polyester fabric. The charging level of the test object was not controlled or measured during the tests, but all charging of the test object and tests were done by the same person and in a similar way.

Each ignition test was performed in a manner similar to [9] except that the ignition probe was kept in a fixed position during the entire experiment, while the charged brush discharge source (a charged plastic tray) was moved towards the probe.

![Figure 1: Peak current as function of the total charge transfer for brush discharge ignition trials.](image-url)
3. Results and discussion

Figure 1 shows the peak current and charge transferred in all our igniting and non-igniting test results. The charge transfer given is that of the first single brush discharge occurring. If more than one brush discharge occurred in the test, those after the first were not recorded. Ignitions are represented as solid triangles on the graph. Non-ignitions are shown as hollow circles.

Peak discharge current varied between about -0.3 A and -1.4 A, and charge transferred in the discharge varied from about -20 nC to -110 nC. There did not seem to be any clear relationship between peak current and charge transferred in a discharge.

There were no ignitions below -60 nC charge transferred. This result is in line with generally accepted charge transfer threshold values for discharge incendivity. Most ignitions occurred between about -90 nC and -110 nC. However there were only 5 ignitions in total out of 62 tests. It may be necessary to do many more trials before any threshold for ignition could be reliably established. The situation is similar with regard to ignitions and peak current flowing in the discharge, with ignitions occurring between about 0.5 A and 1.3 A peak current.

Figure 2. Five igniting waveforms (left) compared with five non-ignition waveforms (right)

Typical waveforms were unidirectional and very similar in shape with duration around 70-100 ns and risetimes around 10-40 ns (Figure 2). There is some indication that there may be small differences between igniting and non-igniting waveforms, with some of the latter having shorter risetime and duration and a slightly less rounded shape. Further work with a greater number of tests will be required to clarify these apparent differences have significance.

No clear threshold between igniting and non-igniting regimes was found for charge transfer or for peak discharge current. Only a small number of ignitions were obtained (5 in 62 tests). This is consistent with ignition by electrostatic brush discharges having a large probabilistic element and that a large number of tests would be required to adequately demonstrate an ignition threshold, or determine factors leading to ignition with reasonable certainty. The 61340-4-4 ignition test method requires no ignitions to be found with at least 200 tests, presumably with this in mind. Gibson and Harper [3] proposed that a probability of less than 1 in 1000 discharges under laboratory test conditions may be acceptably safe for use in most industrial situations. They commented that in specialised conditions such as low humidity, continuous charge generation and flammable atmosphere continuously present, this may not be valid. They suggested that using a normal distribution function, 0.001 probability could be predicted by extrapolating from data from 0.01 probability and above. Furthermore, data produced using clean dry material surfaces may not be representative where surface contamination or other factors may change the characteristics and incendivity of discharges from the surface. Buhler et. al. [11] have found that with some materials ignitions occurred under 50% humidity conditions whereas at 20% humidity there were none.

It should also be noted that in these experiments, if more than one brush discharge occurred, only the first would be recorded. If further discharges occurred within a short time period they could, however, be expected to contribute to an ignition.
These considerations make the study of simultaneous measurement of electrostatic discharge waveforms and ignition tests of great interest and it is hoped that further work will explore some of these issues in more detail.

4. Conclusions
Simultaneous ignition tests with measurement of the electrostatic brush discharge waveforms have been demonstrated. Igniting and non-igniting discharge waveforms were found to be very similar with unidirectional shape, risetimes around 10-40ns and duration around 70-100ns. Small differences between igniting and non-igniting waveforms have been noticed but their significance is undetermined.

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References
[1] Gibson N and Lloyd FC. 1965 Incendivity of discharges from electrostatically charged plastics. Brit. J. App. Phys. V16
[2] Gibson J and Harper D J. 1981 Evaluation of electrostatic hazards associated with non-conducting materials. J. Electrostat. 11 27-41
[3] Gibson J and Harper D J. 1988 Parameters for assessing the electrostatic risk from non-conductors – a discussion. J. Electrostat. 21 27-36
[4] Glor M and Schenzfeuer K, 2005 Direct ignition tests with brush discharges, J. Electrostat. 63 463-468
[5] British Standards Institute. Electrical equipment for explosive atmospheres – Part 0: General requirements. BS EN 60079-0:2004
[6] British Standards Institute. Non-electrical equipment for potentially explosive atmospheres – Part 1: Basic method and requirements. BS EN 13463-1:2001
[7] Salmela H, Paasi J, Kalliohaka T and Fast L, 2005 Measurement of air discharge from insulating electrostatic dissipative and conducting materials with different ESD probes. J. Electrostat. 63 539
[8] von Pidoll U, Brzostek E and Froechtenigt H-R. 2004 Determining the incendivity of electrostatic discharges without explosive gas mixtures. IEEE Trans. Ind. App. V40, 6 1467-75
[9] IEC 61340-4-4 Standard test methods for specific applications - Electrostatic classification of flexible intermediate bulk containers (FIBC)
[10] Chubb J N. 2006. Measurement of charge transfer in electrostatic discharges. J. Electrostat. 64 (5) 301-5
[11] Buhler C, Calle C, Clements S, Ritz M and Starnes J. 2006. Test methodology to evaluate the safety of materials using spark incendivity. J. Electrostat. 64 744-51