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Measurement of minimum ignition energies of dust clouds in the <1 mJ region

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Abstract

The lower energy limit of current standard test apparatus for determining the minimum ignition energy (MIE) of dust clouds is in the range of 1–3 mJ. This is a quite severe limitation because many dusts ignite readily at this energy level. A new spark generator, capable of producing synchronised sparks of very low energies and with an integrated system for measurement of spark energy, has therefore been developed and employed to a number of easily ignitable dusts.

Before testing the MIE of dust clouds, it was considered essential to calibrate the new spark generator against a gas of known MIE. For this purpose, a mixture of propane and air was selected. However, a comprehensive literature review revealed that the reported MIEs of this gas mixture vary significantly, depending on the spark discharge characteristics, including discharge duration. When taking these factors into account, it was concluded that the new spark generator yielded reasonable results for propane/air.

Applying the new spark generator to explosive dust clouds showed that a number of dusts do in fact have MIEs that are one to two orders of magnitude lower than 1 mJ. The new spark generator may therefore offer a basis for developing a standard test apparatus in the low-energy region.

When using a method of triggering the spark by the explosive dust cloud itself, which probably is a more industrially relevant process than synchronisation between the dust dispersion and sparkover, somewhat higher MIEs were found compared to those determined when using synchronised sparks. However, even with this method of spark triggering, MIEs below 1 mJ were found.

Keywords: Minimum ignition energy; Dust explosion; Spark generator

1. Introduction

Accidental dust explosions are a major concern in many industries handling combustible dusts [1]. In a hazard evaluation, the minimum ignition energy (MIE) is a central parameter, indicating the lower energy limit of sparks capable of igniting the dust cloud. Until about 1975, it was believed that MIEs for all dust clouds were above 10 mJ. With a spark generator capable of producing sparks of lower energies, however, Eckhoff [2] found that dust clouds could have MIEs of about 1 mJ. In the present paper, even lower MIEs are investigated, using sparks with energies that are two orders of magnitude lower.

Current standard tests for determination of MIE of dust clouds have several shortcomings when it comes to the industrial relevance of the results produced in the laboratory.

The primary objection is the fact that sparks with energies below 1 mJ are not available in current standard tests [3,4]. Precise knowledge about ignition energies for dust clouds below this value is therefore limited. Several gases have MIEs significantly below 1 mJ, reported, e.g. by Lewis and von Elbe [5]. Experimental ignition of quiescent gases is, however, significantly different from the ignition of a transient dust cloud. Because of gravitational settling of the dust particles, the ignition source must be triggered at a point in time when the dust concentration is within the explosive limits, and synchronisation between the generation of a transient dust cloud (dust dispersion) and sparking is essential when investigating the MIEs of dust clouds. The synchronisation represents a major challenge when working with low energy capacitive sparks, and this is reflected in the energy limit of current standard tests. The main reason is that switches and other circuit elements tend to introduce additional energy to the spark.

Routine testing has revealed that a significant fraction of industrial powders/dusts are found having MIEs below 1 mJ,

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but the true values remain unknown. However, using equipment different from the standard apparatus, but without giving any details about the discharge circuit, Bartknecht [6] reported MIE values of 0.1 mJ for aluminium and 0.01 mJ for sulphur.

A secondary objection to the industrial relevance of present standard MIE tests is that the explosive dust cloud is dispersed independently of the spark. This is probably quite different from the practical industrial situation, and thus very conservative with regards to safety limits. In practice, synchronisation of dust cloud and spark discharge is probably achieved by the dust cloud itself acting as the trigger of the spark. When the dust particles enter a spark gap with a preset static high voltage, breakdown may be triggered with a subsequent spark discharge. This process has been investigated by Randeberg and Eckhoff [7], and as opposed to conventional MIE tests the delay between dust dispersion and sparkover is not a degree freedom. In fact, this process of synchronisation offers an alternative test method that may be more similar to what takes place when electrostatic sparks cause ignition in industry. However, using this method of spark triggering generally yields MIE values somewhat higher than those from conventional tests.

On the other hand, a new spark generator developed by Randeberg et al. [8] offers the opportunity to generate capacitive sparks that can be synchronised with the dust cloud, also in the energy range below 1 mJ. This enables MIE testing similar to the conventional methods even in the <1 mJ range, down to about 0.03 mJ.

The scope of the present paper is to present MIE values for easily ignitable dusts using both the method of electronic synchronisation of dust dispersion and sparkover, and the method of spark triggering by the explosive dust cloud itself. In addition, an investigation of MIE for mixtures of propane and air using the new spark generator has been performed, enabling calibration of the spark generator by comparison of MIE data with literature values.

For the sake of completeness, it should finally be briefly mentioned that von Pidoll et al. [9] have suggested that MIE should perhaps be replaced by the concept of minimum required charge transfer for ignition. Whereas their concept is appropriate for one-electrode discharges, where voltage measurement cannot be performed, it is less clear if it is a better concept than MIE for spark discharges.

2. Experimental

2.1. Explosion vessel

The mechanical parts of the explosion vessel and dispersion system are similar to the MIKE apparatus from Kühner [10], and are previously described in detail by Randeberg and Eckhoff [7]. The dust is dispersed by opening a valve and emptying a 50 cm^3 pressurised air reservoir at 7 bar(g), as shown in Fig. 1. In most of the tests the dust was placed in a dust reservoir downstream of the air reservoir, forcing the particles through the nozzle, thus reducing agglomeration. However, some of the dusts had to be placed in the bottom cup of the explosion chamber because of clogging of the pipe and nozzle.

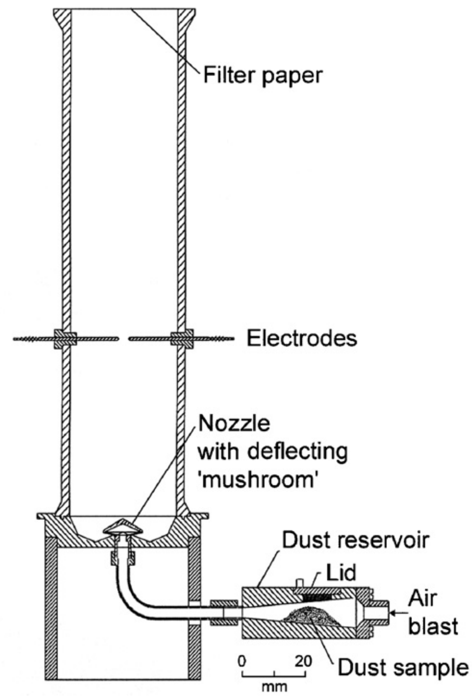

Fig. 1. Cross-section of the dust dispersion system and explosion chamber. The air blast is generated by emptying a 50 cm^3 pressurised air reservoir, fitted with a solenoid valve, upstream of the dust reservoir. Further details are given in Ref. [7].

When doing ignition tests with propane gas, a gas mixing arrangement was used. By adjustment of the flows of propane and air, the gas concentration was monitored by a gas analyser (Servomex 1400). When the propane concentration of the gas flowing into the explosion chamber was equal to that of the gas flowing out of the chamber at the top, the concentration inside the explosion chamber was considered to have the same value. All experiments were done at room temperature and atmospheric pressure.

2.2. Spark generator and energy measurement system

The new spark generator used in the present experiments yields low-energy capacitive sparks, similar to the ones resulting from electrostatic discharges. An integrated system for measurement of spark voltage and current as functions of time offers the opportunity to determine the spark energy. Sparks are generated by using a high voltage pulse to charge a discharge capacitor, which is subsequently discharged when the breakdown voltage of the electrode gap is reached. A charging resistor is used to ensure that no significant amount of energy is supplied to the spark during its lifetime.

The spark voltage is measured using a high-voltage probe (Tektronix P6015), and the current is measured differentially using two conventional scope probes across the current measurement resistors. The spark energy is taken as the product of spark current and voltage, integrated over the duration of the spark, typically about 0.1 μs, minus energy losses to the current measurement resistors. The resistive losses become increasingly significant with increasing capacitance and spark current. The