Electrostatic spark ignition of sensitive dust clouds of MIE < 1 mJ

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ABSTRACT

Accidental electrostatic sparks in industrial plant handling powders/dusts occur whenever a non-earthed metal object that for some reason has been charged to a high voltage suddenly discharges its energy to earth via a an air gap of suitable length. When evaluating the electrostatic spark ignition hazard in an industrial plant the parameters of prime concern are the capacitance C of any plant item that may become charged tribo-electrically, the voltage U to which it may become charged, and the minimum electric spark ignition energy (MIE) of the dust of concern. Whenever $\frac{1}{2}CU^2$ > MIE there is a possibility of accidental electrostatic spark ignition. If MIE of the dust is very small, one must pay attention to even minor C values, i.e. minor plant items. The same applies to somewhat larger capacitances charged to only moderate voltages. Current standard apparatuses for determining MIE of dust clouds have a lower spark energy limit of a few mJ. In the present investigation, a new spark generator capable of producing synchronized capacitive sparks of energies down to about 0.03 mJ was developed and used for testing a selection of ignition-sensitive powders for MIE. Several of the materials tested were found to have MIEs 1-2 orders of magnitude lower than the lower energy limit (a few mJ) of current standard test apparatus.

Optimal electronic synchronization of dust cloud appearance and spark discharge as used in standard MIE testing yields conservative MIEs compared with those relevant for accidental electrostatic spark ignition in industrial plant. In practice, synchronization may be accomplished by the sudden appearance of an explosive dust cloud in a dust free spark gap that has already, by some accidental charging process, attained a voltage close to the natural breakdown voltage in air. When the explosive cloud enters the gap, the electrical field is distorted and the gap breaks down and ignition may result. In the present investigation, some experiments were conducted using even this method of synchronization, and MIEs in the 1 mJ range were found for some dusts even in this case.

There may be a need for a new standard test method for determination of MIEs of dust clouds in the < 1 mJ range.

Keywords: Dust explosion; Minimum ignition energy; Electric spark triggering

1 Current standard test methods for MIE of dust clouds and current approach to assessment of the electrostatic spark ignition hazard in the MIE < 1 mJ range

Current standard apparatuses for determining MIE of dust clouds have a lower experimental spark energy limit of a few mJ. It is well known, however, that clouds in air of many powders/dusts ignite quite readily when exposed to the smallest spark energies that these apparatuses can provide. It is then customary to just report the test result as e.g. "MIE < 3 mJ", assuming that resolution of true MIEs in the range < 3 mJ is not required for several reasons. One argument in favour of this approach, as pointed out by Glor (2006), is that the small objects of capacitances of the order of 1 pF encountered in industry normally have some sharp edges or corners, which give rise to charge drain by corona discharge as soon as the voltage of the object reaches the order of 7-10 kV. And more importantly, the time constant RC for 'leaking' any charge on such small capacitances to earth is very short (1 s) even when the resistance to earth is of the order of 10^{12} Ω (tera ohms).

This means that such small objects cannot be charged to any high voltages unless the charging process is very fast, i.e. the charging times have to be significantly shorter than the very short time constants for charge drainage to earth. If this were to be all that could be said, the resulting ultimate argument would be that accidental electrostatic spark discharges of energies below the order of 1 mJ would be unlikely in the process industries. Hence, the same safety procedures could be applied to any plant producing/handling powders/dusts of MIE < 3 mJ, irrespective of the actual MIE of the powder.

However, if MIE is in fact considerably lower than 1 mJ, certain situations can be envisaged where even minor unearthed plant items of very low capacitances, of the order of 1 pF, may be hazardous. This will be discussed separately below. Furthermore, with somewhat larger capacitances, of the order of 10 pF, even quite low voltages may give rise to incendiary spark discharges. It would seem, therefore, that being able to quantify MIEs in the sub 1 mJ range may sometimes be a relevant safety concern.

2 Mechanisms of electrostatic spark generation in industrial handling of powders/dusts

This topic has been extensively discussed by Glor (1988). Accidental electrostatic sparks in industrial plant handling powders/dusts are generated whenever an unearthed metal object that for some reason has been charged to a high voltage, suddenly discharges its energy to earth via an air gap of suitable length. In powder production and handling operations electrostatic charging of unearthed metal objects may be due to:

- direct tribo-electric charging of the object due to contact with moving powder particles.
- conduction of charge into the object from a charged powder mass at rest and in contact with the object.
- inductive charge displacement inside the object when being introduced into an electric field, generated by e.g. a heap of charged powder, without being in contact with the powder itself. This can lead to spark discharges between one of the parts of the object that carries excess charge and earth, even though the object as a whole does not carry any excess charge until the spark has passed. After the passage of the spark, if the object is no longer influenced by the external electric field, it may release its global excess charge in a second spark discharge to earth.
- the object, when exposed to internal charge displacement in an external electrical field, emitting or being hit by a stream of electrons or ions via corona discharges, as suggested by Kong (2006). Such corona discharges can e.g. take place from any sharp edges or points on the object and leave the object with a net charge, which can subsequently, when the object is no longer influences by the external electric field, be released in a spark discharge to earth.

When assessing the electrostatic spark ignition hazards in industrial plant the parameters of prime concern are the capacitance C of any plant item that may become charged, the voltage U to which it may become charged, and the minimum electric spark ignition energy (MIE) of the dust of concern. According to simple basic theory the charging of a plant item of capacitance C to a voltage U implies that an electrical energy of $\frac{1}{2}CU^2$ is stored in the plant item. If this energy is discharged to earth across an air gap of suitable length, a spark discharge will result, with $\frac{1}{2}CU^2$ being the upper theoretical limit of the energy dissipated in the discharge. Whenever $\frac{1}{2}CU^2 >$ MIE there is a possibility of accidental electrostatic spark ignition.

Table 1. Stored electrical energies ½CU^2 in non-earthed items of different capacitances C, charged to different voltages U. From Lüttgens and Glor (1989).

Charged object	Capacitance (pF)	Potential (kV)	Energy (mJ)*
Single screw	1	5	0.01
Flange, nominal width = 100 mm	10	10	0.5
Shovel	20	15	2
Small container (~50 litres)	50	8	2
Funnel	50	15	6
Person	300	10	15
Drum (200 litres)	200	20	40
Road tanker	1000	15	100

* approximate values

Table 1 gives some examples of combinations of capacitances and voltages and resulting theoretical spark energies for typical plant items. If MIE of the dust is very small, incendiary electrostatic sparks may in principle be generated even by minor plant items of very low capacitances of the order of 1 pF, e.g. a single unearthed metal screw. However, for reasons discussed above (Glor, 2006), neither tribo-electric charging by contact with moving particles, nor charging by charge migration from charged settled powder will be fast enough to present a spark discharge hazard in the case of such very small capacitances.

However, based on the description of the phenomenon of "electrostatic induction" described by Lüttgens and Wilson (1997) it is possible to envisage a type of situation where the charging is fast enough. Consider a small elongated metal object (tramp metal) that enters an earthed metal silo together with an electrically insulating powder being fed into the silo. If the powder has acquired a significant charge on its way to the silo, the settled powder in the silo may give rise to a strong electric field. When the small falling metal object enters this field the electrons inside it may become displaced by influence/induction. If one end of the metal object approaches the earthed silo wall whilst this electron displacement exists, a spark discharge may take place. Because of the very short discharge times to be expected (< 10 µs), the spark gap length will stay approximately constant during such a spark discharge. For example, an object approaching an earthed wall at 20 m/s will move only 0.2 mm during 10 µs.

Lüttgens *et al.* (2005) present a brief report on a dust explosion in a silo, which was attributed to this type of spark discharge. The silo was part of an assembly of 14 silos, made of aluminium, and used for intermediate storage of a plastic dust. Following several years of production without any accidents, a dust explosion unexpectedly occurred during discharge of one of the silos. At the moment of the explosion only about 20 per cent of the silo volume was filled with powder. After careful investigation, all ignition sources but an electrostatic spark discharge had been ruled out. However, the exact mechanism of generation of the electrostatic spark was not identified until part of the shaft of an aluminium spade was found close to the silo wall, just below the powder surface. It was concluded that excess charge accumulated on this object due to influence, was discharged as a spark when the object approached the silo wall.

Sparks of very low energies may not only be generated by very small charged capacitances. They may also result from discharge of somewhat larger capacitances, of the order of 10 pF, which have been charged to only moderate voltages, of the order of a few kV. This would clearly also present an increased ignition risk with dusts of very low MIEs. With C equal to 10 pF, and U equal to only 2 kV, the stored energy ½CU^2 equals 0.02 mJ, i.e. the order of the MIEs of some very spark-ignition sensitive dust, as shown in the present paper. Clearly, with only 2 kV across the spark gap, the gap length has to be quite short, but with dusts of MIE << 1 mJ, the quenching distances are also most probably very small, as indicated by Figure 1.

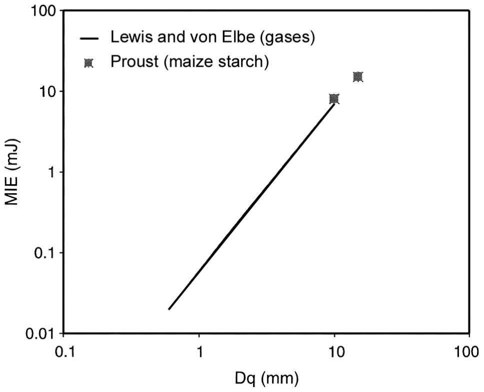

Figure 1. Correlation of minimum electric spark ignition energies and quenching distances for clouds of maize starch in air showing very close agreement with the corresponding Lewis/von Elbe correlation for gases. From Proust (2006).

3 A new apparatus for determination of MIE below 1 mJ

3.1 Principle of operation

A new spark generator described more extensively by Randeberg, Olsen and Eckhoff (2006), capable of producing synchronized capacitive sparks of energies down to about 0.03 mJ was used for determining the MIEs of clouds in air of a selection of ignition-sensitive powders. The main electrical circuit is shown in Figure 2. The actual spark energies were computed from simultaneous measurements of spark current and voltage across spark gap as functions of time. The computed energies were generally only slightly lower than the theoretical ½CU^2.

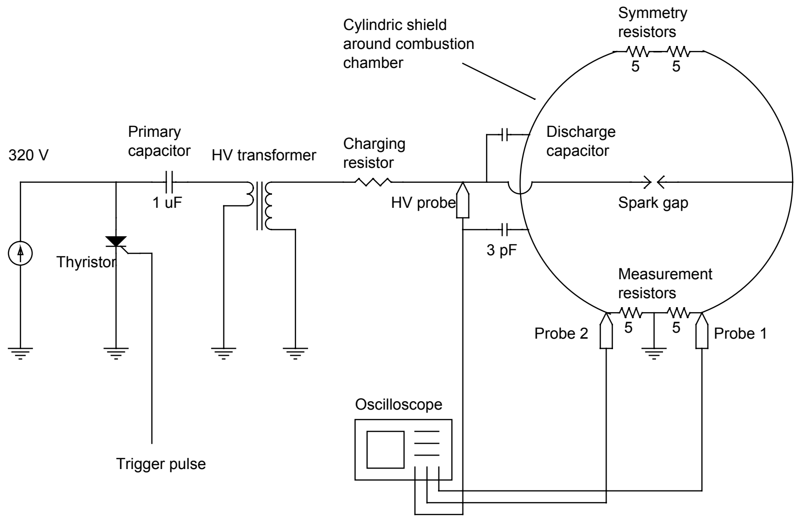

Figure 2. Schematic layout of new spark discharge circuit with spark energy measurement system. By triggering of the thyristor, sparks synchronised with dust dispersion can be generated. Further details of the generator are given by Randeberg et al. (2006).

3.2 *Validation of spark generator*

It was decided to validate the spark generator against one gas mixture and one dust/air cloud of known MIEs. The results for propane/air are given in Figure 3, which shows that the MIE found was of the order of 0.1 mJ, which is somewhat lower than the classical Lewis and von Elbe value of 0.25 mJ. However, as can be seen the present result is in agreement with two more recent investigations (Parker, 1985 and Kono *et al.*,1976).

The result for clouds in air of "CaRo 03", together with the range of results for the same dust obtained by a number of other laboratories in an extensive "Round Robin" test series, is given in Figure 4. As can be seen the present result approximately coincides with the lower limit of the acceptable band of values established in the "Round Robin" tests.

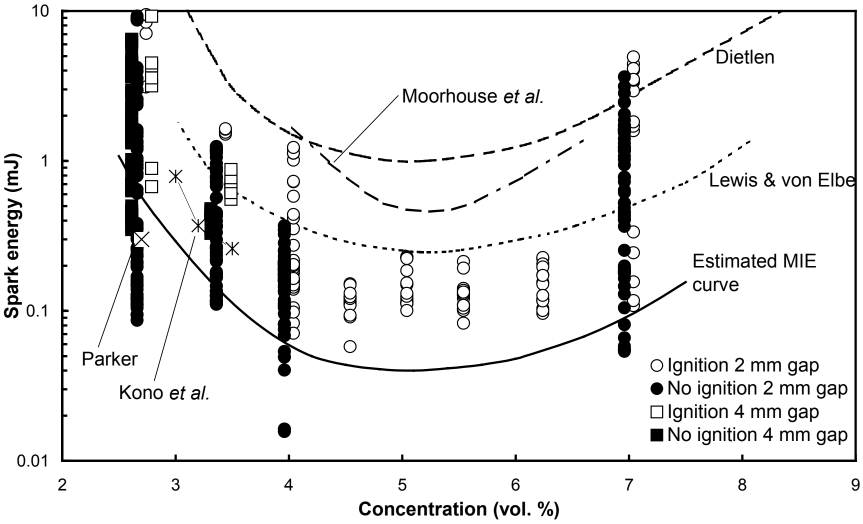

Figure 3. Minimum ignition energies for propane/air mixtures as a function of propane concentration. The white data points indicate ignition and the black no ignition, with 2 mm electrode gap represented as circles and 4 mm gap as squares. The solid line is an estimated MIE. Main data from Randeberg and Eckhoff (2006). Literature values added (Moorhouse et al., 1974; Dietlen, 1976; Kono et al., 1976; Parker, 1985; Lewis and von Elbe, 1987).

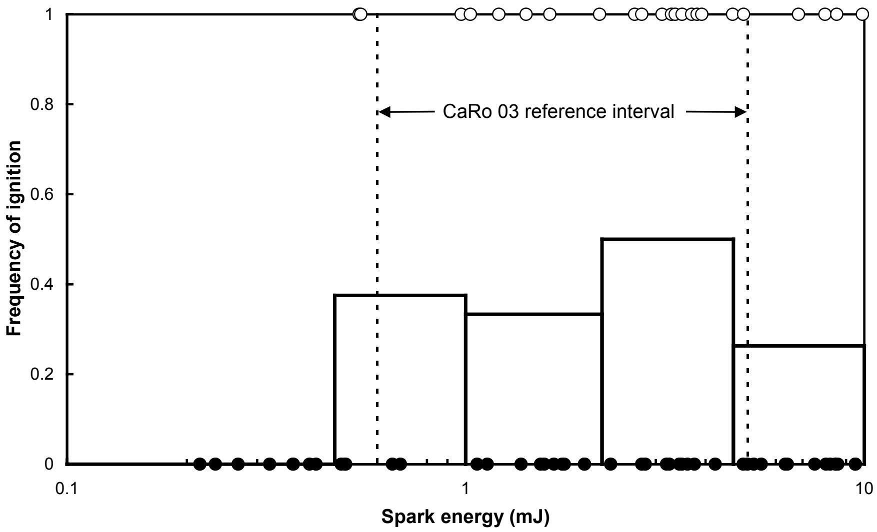

Figure 4. Frequency of ignition for niacin dust used in CaRo 03 calibration tests (Cesana, 2004). Ignition is indicated by white data points and no-ignition by black data points. Histograms are added, indicating the frequency of ignition within the energy levels.

4 Determination of MIEs of a range of very ignition sensitive powders

The spark ignition experiments with 8 different powders is reported in greater detail elsewhere by Randeberg and Eckhoff (2006). The powders were obtained somewhat arbitrarily from 3 different producers. The results are summarized in Figure 5, which shows that several of the materials tested were found to have MIEs 1-2 orders of magnitude lower than the lower energy limit (a few mJ) of current standard test apparatus.

It is seen that for three of the powders (Ti grade E, sulphur and Al flakes) the MIEs were well below 0.1 mJ. For ZrH_2 and SIBS-K32 it was about 0.1 mJ, whereas for CaRo 03 and Ti grade S it was in the range 0.1 - 1 mJ. In Table 2 these values are compared with published data for similar powders.

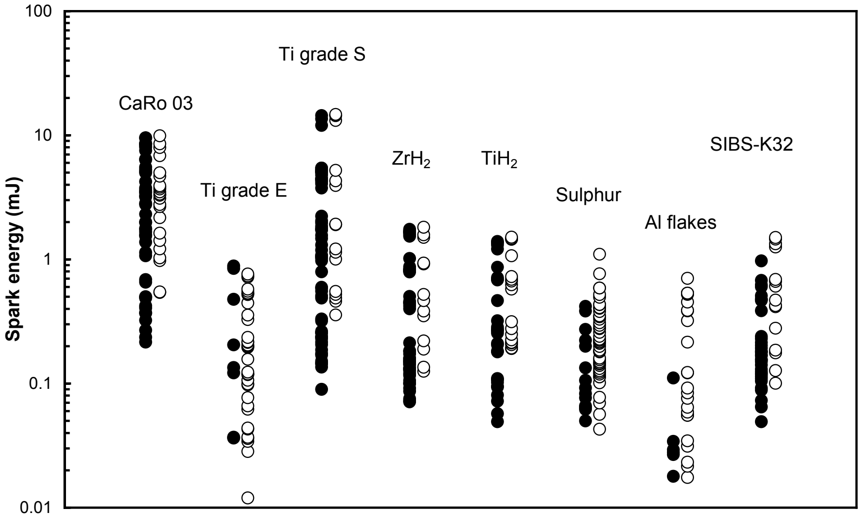

Figure 5. Spark ignition energies for various dusts in air, indicating the frequency of ignition as a function of spark energy. The white data points indicate ignition and the black no ignition. From Randeberg and Eckhoff (2006).

Table 2. MIEs of clouds in air of 8 different powders determined by Randeberg and Eckhoff (2006) compared with previously reported MIE data for similar powders.

Dust	MIE in the present tests (mJ)	MIE reported in earlier work (mJ)	
CaRo 03	0.54	0.6-5.1	(Cesana 2004)
Titanium grade E	< 0.012	~10	(Jacobson *et al.* 1964)
Titanium grade S	0.36	< 200	(Hartmann *et al.* 1943)
Zirconium hydride	0.13		
Titanium hydride	0.19		
Sulphur	< 0.043	0.01 0.3	(Bartknecht 1993) (Eckhoff 1975)
Aluminium flakes	< 0.018	0.1 1	(Bartknecht 1993) (Eckhoff 1975)
SIBS-K32	0.10	< 1	(Glor 2005)

5 A possible realistic mechanism for synchronization of dust cloud and spark discharge in accidental ignition situations with comparatively slow electrostatic charging

The optimal electronic synchronization between dust cloud appearance and spark discharge used in MIE testing is likely to yield rather conservative MIEs compared with those relevant for accidental electrostatic spark ignition in an industrial plant.

In the case of very fast charging and sparking processes, as indicated in section 2 above, synchronization is automatically provided by the falling of an unearthed metal object into an explosive dust cloud towards a location where spark discharge can occur.

A possible synchronization mechanism applying to comparatively slow charging processes, would be as follows: First the voltage across the potential spark gap, in the absence of dust, is raised comparatively slowly to a level somewhat lower than the natural breakdown voltage in air, by tribo-electric charging. Then an explosive dust cloud enters the region of the gap accidentally, whereby the electrical field is distorted and a spark discharge occurs that may ignite the dust cloud.

In the present investigation, some additional experiments were conducted using this method of synchronizing spark discharge and appearance of dust cloud. A more extensive report of the findings is given by Randeberg and Eckhoff (2006a). The spark discharge circuit used is shown in Figure 6.

The results for clouds of lycopodium in air are given in Figure 7. These data show that the minimum ignition energy obtained by the dust cloud triggering method using a 0.7 mH inductance in the discharge circuit was about 12 mJ, which is about twice the value obtained using electronically synchronized sparks. In the study by Mathiesen (1976), special care was exercised to optimize the experimental conditions, and to ensure that these conditions prevailed in all the tests. This resulted in sharper transition from zero to 100 per cent probability of ignition than in the experiments with the same equipment by Eckhoff (1975). In the case of the triggering of the spark discharge by the dust cloud itself, the transition from zero to 100 per cent probability of ignition occurred over a substantially broader band of spark energies, most likely due to lack of reproducibility of the structure (concentration, velocity, turbulence) of the dust cloud breaking down the spark gap. Figure 7 also shows that the minimum ignition energy obtained without an added series inductance of 0.7 mH (about 30 mJ) was about twice the value obtained with this inductance in the circuit (about 13 mJ).

The results for more ignition sensitive powders from direct dust cloud triggering of the spark discharge showed that even with this triggering method MIEs of the order of 1 mJ were found. Some results for fine sulphur are given in Figure 8.

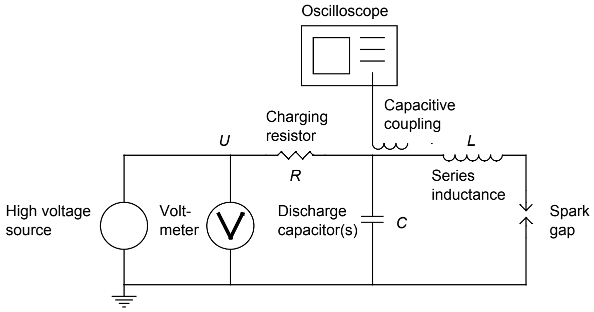

Figure 6. Spark discharge circuit used in experiments where the discharge was triggered by the appearance of the transient dust cloud in the spark gap. From Randeberg et al. (2006).

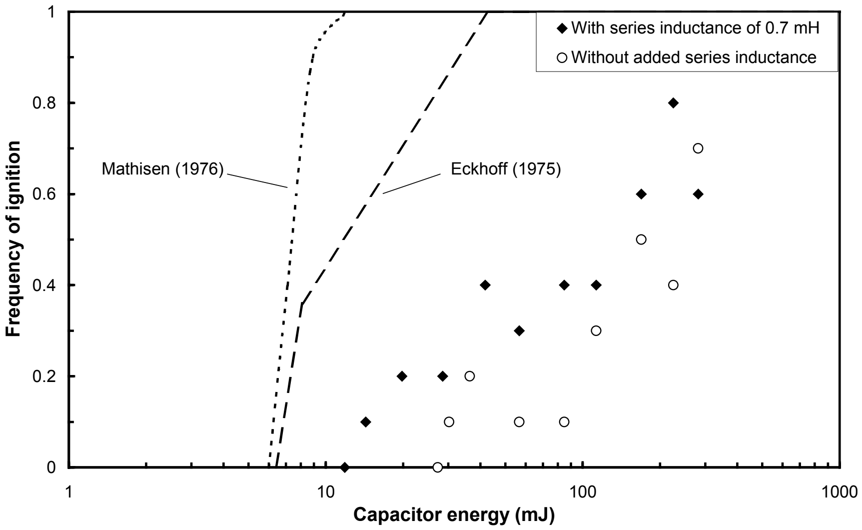

Figure 7. Frequency of ignition for transient clouds of Lycopodium in air as a function of capacitor energy for pure capacitive and prolonged sparks (added series inductance), from (Randeberg et al. 2006a). Each data point represents ten ignition trials when using the dust cloud itself to trigger the spark. Corresponding data from Eckhoff (1975) and Mathisen (1976) are added for comparison.

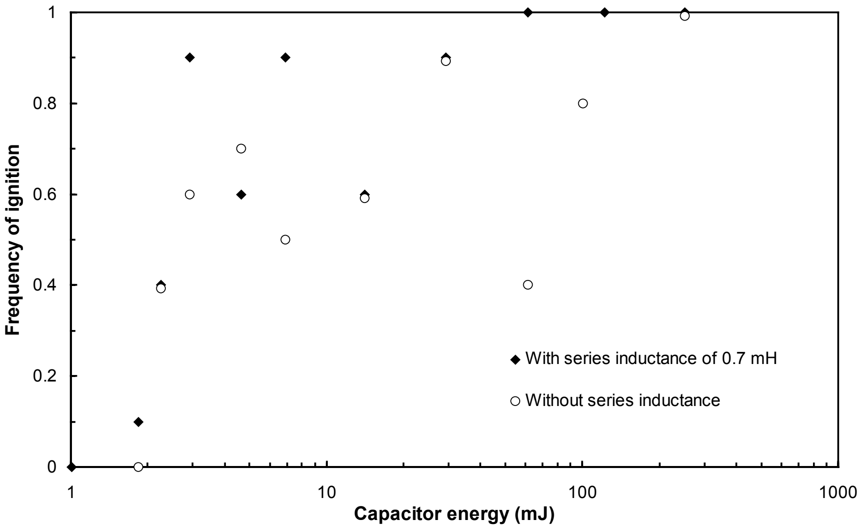

Figure 8. Frequency of ignition for transient clouds of sulphur in air as a function of stored capacitor energy for pure capacitive and prolonged sparks. Each point represents ten ignition trials. From Randeberg and Eckhoff (2006a).

6 Conclusions

- A new electric spark generator, capable of producing synchronized low-energy capacitive sparks down to about 0.03 mJ, has been developed. The generator was calibrated using premixed propane/air. It was found that with the most sensitive mixture ignition occurred even with spark energies of only 0.1 mJ. This is somewhat lower than the classical MIE value of 0.25 mJ (Lewis and von Elbe), but in line with some more recent data. The generator was also calibrated using a powder tested in an extensive "Round Robin" test comparison. The present result approximately coincides with the lower limit of the acceptable band of values established in the "Round Robin" tests.
- The spark generator was used for determining MIEs of a selection of very sensitive dusts, and several of the MIEs found were below 0.1 mJ, two even in the range of 0.01 mJ.
- The consequences of very low MIEs for the selection of practical safety measures for preventing accidental electrostatic spark ignition have been discussed. For example, spark discharges may result if a tramp metal object enters an earthed metal silo accidentally.
- Optimal synchronized sparks do not exist in accidental electrostatic spark ignition in practice. A series of experiments were therefore also conducted in which the spark gap, pre-charged to a voltage somewhat below its natural breakdown voltage, was broken down by the appearance of the transient explosive dust cloud itself. The MIEs obtained were somewhat higher than those obtained with electronically synchronized sparks, but even with this spark triggering method MIEs of the order of 1 mJ were obtained.
- It should be discussed whether there is a need for a new standard dust MIE test that covers the range below 1 mJ.

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