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Tests on Suitability of the Ignition Source “Exploding Wire” for the Determination of Explosion Characteristics of Combustible Dusts in the 20-L-Sphere

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According to international standards several safety characteristics of dusts are determined in the 20-L-sphere (also known as SIWEK Chamber). Dust cloud ignition is carried out using pyrotechnical igniters. Due to various disadvantages of such igniters the need for alternative ignition sources arises again and again. An alternative ignition source could be the so called “exploding wire” or “fuse wire". The paper presents test results of a comparative study between both ignition sources for the determination of the safety characteristics Maximum Explosion Pressure and Maximum Explosion Pressure Rise of five selected dusts in the 20-L-sphere. In addition to that the ignition mechanisms of both ignition sources were analysed by high speed camera recordings and the ignition energy was determined with electric and calorimetric recordings.

1. Introduction

Safety characteristics are essential for the determination of explosion hazards during handling of combustible dusts and for the design of safety measures. The safety characteristics Maximum Explosion Pressure p_{max}, Maximum Explosion Pressure Rise $(dp/dt)_{max}$ and Lower Explosion Limit LEL are determined in closed vessels such as the 20-L-sphere (also known as SIWEK-Chamber). Tests are preformed according to international standards, for example the EN 14034 series (2011) or ASTM E1226 (2012). In order to determine the safety characteristics the dust samples are dispersed in air and ignited using two pyrotechnical igniters with energy contents of 1 kJ or 5 kJ. Since the igniters could have an influence on the test results they are defined in the standards.

Due to various disadvantages of the pyrotechnical igniters such as high costs, legal requirements concerning its storage and use as well as high energy input in comparison to most ignition sources in practice, the need for alternative ignition sources arises again and again. Such an ignition source should be less expensive, readily available and the operator should be able to use it without a certificate of competence. In addition to that, the ignition energy should be adjustable over a wide range and if possible allow energy amounts less than 1000 J. Compared to the ignition energies described in the standards such energy amounts are more realistic for ignition sources found in practice, such as electrostatic discharges, mechanical sparks or hot surfaces.

An alternative ignition source which fulfils these requirements is the so called “exploding wire” or “fuse wire”. This type of ignition source is used for the determination of explosion limits of gases and is described in the standard EN 1839 (2003).

This paper presents first test results of a comparative study in order to find out, if the exploding wire is in principle suitable as an alternative ignition source for the determination of explosion characteristics of dusts and if it makes sense to start validation tests. For the study maximum explosion pressure and maximum explosion pressure rise values from 5 different dusts were determined with both ignition sources

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in the range of 100 J to 1 kJ. The dusts were selected such that different combustion mechanisms were considered. In addition to that high speed recordings allowed comparison of flame front and electrical arc generated from the igniters. Calorimetric and electric measurements obtained information on the ignition energy of the igniters.

2. Test assembly and test settings

2.1 20-L-sphere

Main component of the test assembly was the 20-L-sphere (Cesana and Siwek, 2012; EN 14034 1-2, 2011). In order to reach almost homogeneous dust dispersion into the test chamber the so called "rebound nozzle" was used.

The tests with the pyrotechnical igniters as an ignition source were performed using the standard control unit of the 20-L-sphere. For tests with the exploding wire an external ignition unit was necessary. Depending on the ignition energy two different ignition units were used. One uses an isolating transformer, the other one uses capacitors. An isolation amplifier allowed the determination of the ignition energy by measuring current and voltage.

2.2 Ignition source

One of the fundamental differences of the two ignition sources pyrotechnical igniter and exploding wire is the ignition mechanism. While for the exploding wire an electric arc is generated the pyrotechnical igniter emits flames and burning solids.

The ignition source was placed in the middle of the vessel and connected to the lid of the vessel, such as it is described in the test standards. According to the European standards for the determination of the explosion characteristics maximum explosion pressure and maximum explosion pressure rise two pyrotechnical igniters with energy of 5 kJ shall be used, firing horizontally in opposite directions (EN 14034 1-2, 2011).

Deviant from this description instead of two pyrotechnical igniters or exploding wires only one ignition source was used, producing a flame or electrical arc downwards, see Figure 1. The tests were performed with ignition sources with energy contents of approximately 100 J, 500 J and 1000 J.

Figure 1: Exploding wire with electrodes (left side) and pyrotechnical igniter (right side)

Pyrotechnical igniter

The pyrotechnical igniters used for this work have the same composition as the standard igniters used for determination of explosion characteristics in the 20-L-sphere. They contained 40 % by weight zirconium metal, 30 % by weight barium nitrate and 30 % by weight barium peroxide.

Exploding wire

The principle of the exploding wire is the evaporation and ionization of metal particles from a wire due to a sufficient current flow within milliseconds. During that process a metal vapour is created in which an electric arc is generated between the electrodes because of the electrical conductivity of the plasma.

For all tests a nickeline wire with a diameter of 0.12 mm was used. The wire was tensed between the ends of the two electrodes and connected with two springs, see Figure 1. For tests with energy content of 100 J the electrodes material was stainless steel, for higher energies tungsten was used.

Ignition unit with isolating transformer

For tests with ignition energy of 100 J the electrical power which is needed for melting the wire and generating the arc was supplied by an isolating transformer similar to that used for the determination of explosion characteristics of gases and vapors according to EN 1839 (2003). The power rate was adjusted

using a phase control technique which allowed the positive half-wave of the AC wave from the transformers secondary windings energizing the wire.
Main disadvantage of this ignition unit is that the accurate moment of ignition is not reproducible. Figure 2 demonstrates the reasons for this. It shows the AC waveform and the moment when the trigger signal from the control unit of the 20-L-sphere arrives (arrow). Since the energizing of the wire will not start before zero- crossing of the AC wave, the moment of ignition could differ up to 20 ms. This effect is not negligible because the ignition delay should not vary more than 5 ms according to the standards EN 14034 1-2 (2011). Larger deviations could have a significant influence on the test results due to changes of the turbulence in the test vessel. Hence, all tests in which the time delay between triggering of the ignition source and onset of pressure increase was too long had to be repeated.

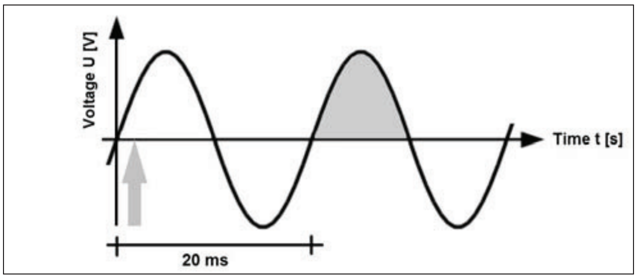

Figure 2: Additional ignition delay due to phase control technique for maximum power rate

Ignition unit with capacitors
In tests with ignition energies of 500 J and 1000 J an ignition unit with capacitors was used instead of the isolating transformer. The main advantages of this new ignition unit are the higher ignition energies which the unit can produce and that it is able to ensure an exact ignition delay. A choke enabled elongation of the electrical arc during each test.

2.3 Flame front recordings
A high speed camera which allowed recordings of 5000 pictures per second was used to film the flame propagation of both igniters. So it was possible to determine maximum flame volume and length as well as the time delay for activating the ignition source and its burning time.

2.4 Measurements of ignition energy
A combustion calorimeter working with the dry method allowed measurements of the ignition energy of both ignition sources. Dry method means, that the brass bomb of the calorimeter is covered with an insulating styrofoam and not with a water bath. This allows a more sensitive direct measurement of the temperature changes in the metal. Additionally an isolation amplifier was used to measure the burning current in the exploding wire as well as the voltage and enabled the determination of ignition energy generated in the electric arc during each test.

2.5 Tested Dusts
Dust explosions generally show complex reaction mechanism, which depend e.g. on the chemical composition of the dust, the dust concentrations and the flow conditions. Van der Wel (1993) differs between different reaction mechanisms depending on whether the reaction takes place in the gas phase due to evaporation or at the solid surface in form of gaseous products, solid or liquid material. The dusts used in this work were chosen such that they represent the different chemical classes and mechanisms as well as the dust explosion classes found in practice. As a result dusts from lignite, maize starch, niacin and anthraquinone were chosen. In addition to that a steel dust which was generated during a shot blasting process was tested.

3. Test results

3.1 Measurement of ignition energy
Measurements with the isolation amplifier lead to different test results depending on the boundary conditions of the measurements. Table 1 shows the test results for measurements of ignition energy outside the test vessel without dust and flow, inside the test vessel with flow but without dust and inside the test vessel with flow and with a dust concentration of approximately 1000 g/m³ - 1250 g/m³ maize starch. Ignition unit was the isolating transformer.

Table 1: Ignition energy of igniter determined with the isolation amplifier; ignition source isolating transformer; ignition energy 100 J

Experiment-No.	Determined ignition energies		
	Outside the apparatus [J]	Inside the apparatus without dust [J]	Inside the apparatus with dust [J]
1	93.61	98.42	98.88
2	86.84	94.19	84.14
3	90.92	89.27	88.24
4	89.80	101.59	48.85
5	91.62	82.96	94.13
6	84.46	98.58	83.89
7	90.40	94.74	100.63
8	94.41	91.37	74.36
Ø	**90.26**	**93.89**	**84.14**
SD	**3.30**	**5.97**	**16.67**

Table 1 shows that the ignition energy values for tests without dust inside and outside the test vessel are almost similar. As a trend as well the values with flow from inside the vessel as their standard deviation seem to be slightly higher. Tests with dust lead to slightly lower ignition energies and a significant higher standard deviation of the values. Most of the tests lead to ignition energies of more than 90 % of the adjusted value. However, some tests with dust lead to lower values. In one test less than 50 % of the adjusted value was measured. As a result the dust particles seem to influence the test results in some tests.

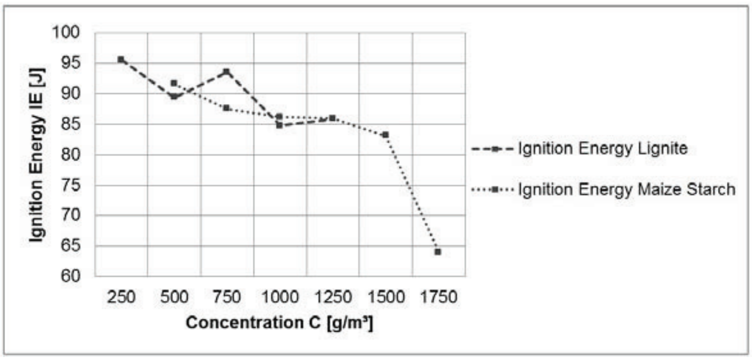

Figure 3: Arithmetic mean of ignition energy of igniter as function of dust cloud concentration for maize starch and lignite; adjusted ignition energy 100 J

Figure 3 shows the arithmetic mean of the determined ignition energies as a function of dust cloud concentration for maize starch and lignite for adjusted ignition energy of 100 J. From the course of the mean values follows, that there is only a minor influence of the concentration on the ignition energy up to concentrations of approximately 1250 g/m³. For higher concentrations the influence is significantly higher.
Comparable test results were determined for adjusted ignition energies of 500 J and 1000 J using the ignition unit with capacitors. But as a trend the influence of the dust cloud on the ignition energy seems to be lower. For all tests the determined ignition energy was at least 80 % of the adjusted value.

3.2 Ignition mechanism

High speed camera recordings of the flame propagation of both ignition sources for tests without dust and ignition energies of 100 J, 500 J and 1000 J showed that the flame of the pyrotechnical igniter propagates faster than the flame of the exploding wire and reaches a greater maximum volume. However, the determined effects seem to decrease with increasing ignition energy, see Figure 4.

3.3 Explosion behavior

Figure 5 presents the explosion pressure for niacin determined with both ignition sources with ignition energy of 500 J as a function of the dust concentration. Both curves show a maximum of approximately 8.2 bar determined for a concentration of 500 g/m³. Also the course of the curves is quite similar. Deviations of the explosion pressure values are comparable for both ignition sources.
The determined pressure rise values as a function of the dust concentration are found in Figure 6.

All test results show a good conformity concerning maximum explosion pressure rise and concentration for which the maximum value was determined. Also the course of the curves is comparable. However, the reproducibility was not as good as for the explosion pressure. As a result the test values differed more for both ignition sources.

Comparable test results were found for all tested dusts and ignition energies. Table 2 gives an overview of the determined p_{max} and $(dp/dt)_{max}$ values as well as the K_{St} values which were calculated from the $(dp/dt)_{max}$ values. As a tendency most p_{max} and $(dp/dt)_{max}$ values determined with an exploding wire were slightly higher than the values determined with a pyrotechnical igniter with the same ignition energy.

Table 2 also includes test results which have been determined with two 5 kJ igniters. The test showed that the maximum explosion pressures values determined with ignition energies of 100 J, 500 J and 1000 J are less than 10 % lower than those with 10 kJ. For steel dust and niacin the values determined with 10 kJ were slightly lower than the values determined with the other ignition energies. The determined $(dp/dt)_{max}$ values and therefore the K_{St} values did not fit very well. The tests with 10 kJ lead to values which were up to 30 % higher than the values determined with the lower ignition energies.

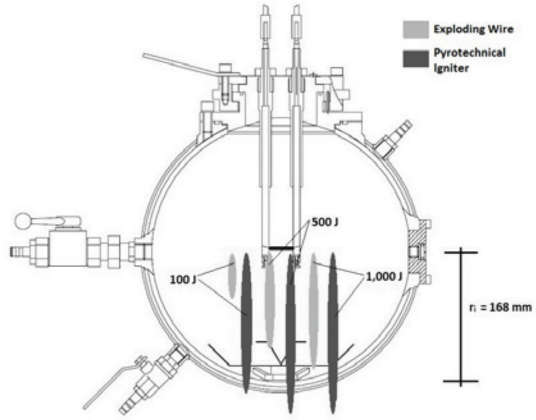

Figure 4: Flame propagation of exploding wire and pyrotechnical igniter for different ignition energies

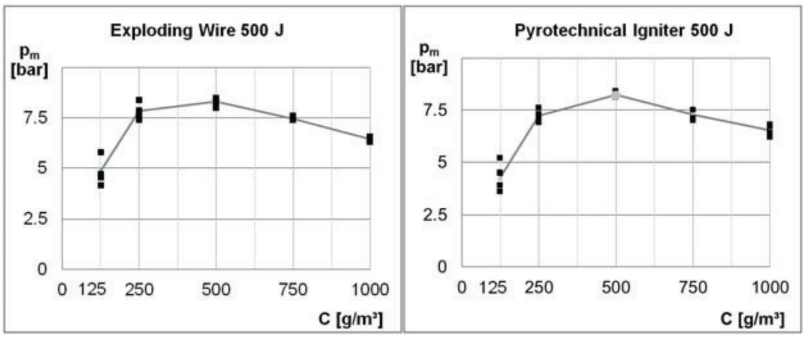

Figure 5: Explosion pressure of niacin as function of dust cloud concentration determined with pyrotechnical igniter and exploding wire with ignition energy of 500 J

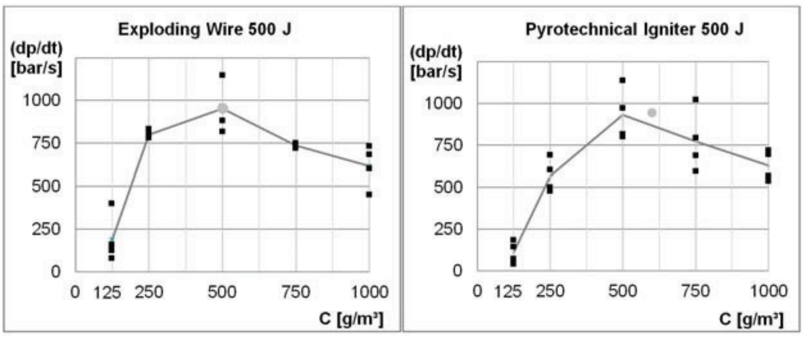

Figure 6: Explosion pressure rise of niacin as function of dust cloud concentration determined with pyrotechnical igniter and exploding wire with ignition energy of 500 J

Table 2: p_{max}, $(dp/dt)_{max}$ and K_{St} values for all tested dusts determined with exploding wire and pyrotechnical igniter with ignition energies of 100 J, 500 J, 1000 J and 10 kJ.

Dust		100 J		500 J		1000 J		10 kJ
		Ex. Wire	Pyro. Igniter	Ex. Wire	Pyro. Igniter	Ex. Wire	Pyro. Igniter	Pyro. Igniter
Lignite	p_{max}	8.4	8.1	8.1	7.6	7.9	7.7	8.4
	$(dp/dt)_{max}$	601	545	681	630	671	608	785
	K_{St}	163	148	185	171	182	165	213
Maize starch	p_{max}	8.4	8.5	8.4	8.6	8.2	8.4	8.7
	$(dp/dt)_{max}$	408	470	528	480	487	468	616
	K_{St}	111	127	143	130	132	127	167
Niacin	p_{max}	-	-	8.3	8.2	8.2	8.0	7.9
	$(dp/dt)_{max}$	-	-	953	942	920	874	1051
	K_{St}	-	-	259	256	250	237	285
Anthraquinone	p_{max}	-	-	-	-	8.1	8.0	8.4
	$(dp/dt)_{max}$	-	-	-	-	1113	999	1379
	K_{St}	-	-	-	-	307	271	374
Steel dust	p_{max}	-	-	-	-	4.1	4.1	3.8
	$(dp/dt)_{max}$	-	-	-	-	398	394	432
	K_{St}	-	-	-	-	108	107	117

4. Conclusions

Measurements of the ignition energy of the igniters using two different methods showed that the ignition energy generated with the exploding wire was reproducible. For ignition energies of 500 J and higher, the dust cloud did not influence the ignition energy significantly. However, some tests with ignition energy of 100 J and dust concentrations with more than 1000 g/m³ showed that the dust cloud was able to influence the ignition process such that the electric arc extinguished earlier. This resulted in lower ignition energy.

High speed recordings showed that the flame generated from the pyrotechnical igniter propagated faster as the flame generated from the exploding wire and reached a larger volume. As a result the igniter should have a significant influence on the determined p_{max} and $(dp/dt)_{max}$ values. However, such an effect was not determined during the measurements of p_{max} and $(dp/dt)_{max}$ of 5 different dusts. All tests resulted in comparable values of p_{max} and $(dp/dt)_{max}$ for both ignition sources.

The p_{max} values determined with ignition energies of 100 J, 500 J and 1000 J were less than 10 % lower than values determined according to the test standard with two igniters of 5 kJ. As a result the influence of the ignition energy of the igniter on the maximum explosion pressure seems to be almost negligible.

In contrast to that $(dp/dt)_{max}$ values determined according to the test standard led to 30 % higher values. The reason for that could not be solved totally. It is assumed that a combination of different effects has to be considered such as turbulence generated from the ignition source and the flame volume of the ignition source. However, the effect of the flame volume should result in different test results for exploding wire and pyrotechnical igniter which were not determined.

In a next step tests with two pyrotechnical igniters and two exploding wires are planned which allow ignition energies up to 10 kJ. Depending on the test results the validation of the exploding wire with a greater number of dusts is planned.

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