Research paper

Tests on suitability of a new pyrotechnical igniter for the determination of explosion characteristics of dust clouds in 20-L-sphere and1-m³-vessel

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Abstract

Safety characteristics are essential for the design of preventive and protective explosion measures. According to international standards explosion characteristics of dust clouds are determined in 20-L-sphere and 1-m³-vessel.

The ignition of respective dust samples is realized with special pyrotechnical igniters with energy of 1 kJ or 5 kJ which are defined in the testing standards. However Sobbe in Germany is the only company at the moment which sells such igniters.

The paper presents results of a comparative study between the 5 kJ Sobbe igniter and a 5 kJ igniter manufactured by Simex in Czech Republic. The study has been conducted under participation of BAM Federal Institute for Materials Research and Testing, Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA), Berufsgenossenschaft Nahrungsmittel und Gastgewerbe (BGN) and Swiss Institute for Promotion of Safety and Security (Swissi).

For the study six dusts from different product groups with various explosion severities and ignitabilities were chosen. The tests were carried out in the 20-L-sphere as well as in the 1-m³-vessel. Maximum explosion overpressure P_{max}, dust explosion constant K_{St} and lower explosion limit LEL were determined. Furthermore tests with a high speed and a thermal imaging camera were carried out, in order to compare burning time and flame pattern of Sobbe and Simex igniter.

Keywords : explosion characteristics of dusts, 20-L-sphere, 1-m³-vessel, pyrotechnical igniter, dust explosion testing

1. Introduction

Explosion characteristics are indispensable for the design of preventive and protective explosion measures.

Maximum explosion overpressure (P_{max}) and K_{St}-value are, for example, the basis for the design of explosion protection measures such as explosion venting or explosion suppression. According to the European standards EN 14034-1[1], EN 14034-2[2], 14034-3[3] and EN 14034-4[4], the guideline VDI 2263-1[5] and the North American ASTM - E 1226 explosion characteristics of dust clouds and fibres are determined in the test equipment 20-L-sphere or 1-m³-vessel.

The ignition of dust samples is realized by means of special pyrotechnical igniters with ignition energy of 10 kJ (two igniters of 5 kJ each) or 2 kJ (two igniters of 1 kJ each). Since the composition of the igniters may have an influence on the determined explosion characteristics, defined igniters are used which, in respect to their mass, consist of 40% Zirconium metal, 30% Barium nitrate and 30% Barium peroxide. The composition of the igniters is described in EN 140341-4[1)−4)]. However Sobbe in Germany is the only company at the moment which sells such igniters.

Unfortunately the igniters currently used contain the harmful compounds barium nitrate and barium peroxide and small amounts of toxic heavy metals like barium and lead. In consideration of the upcoming REACH directive (Registration, Evaluation, Authorization and Restriction

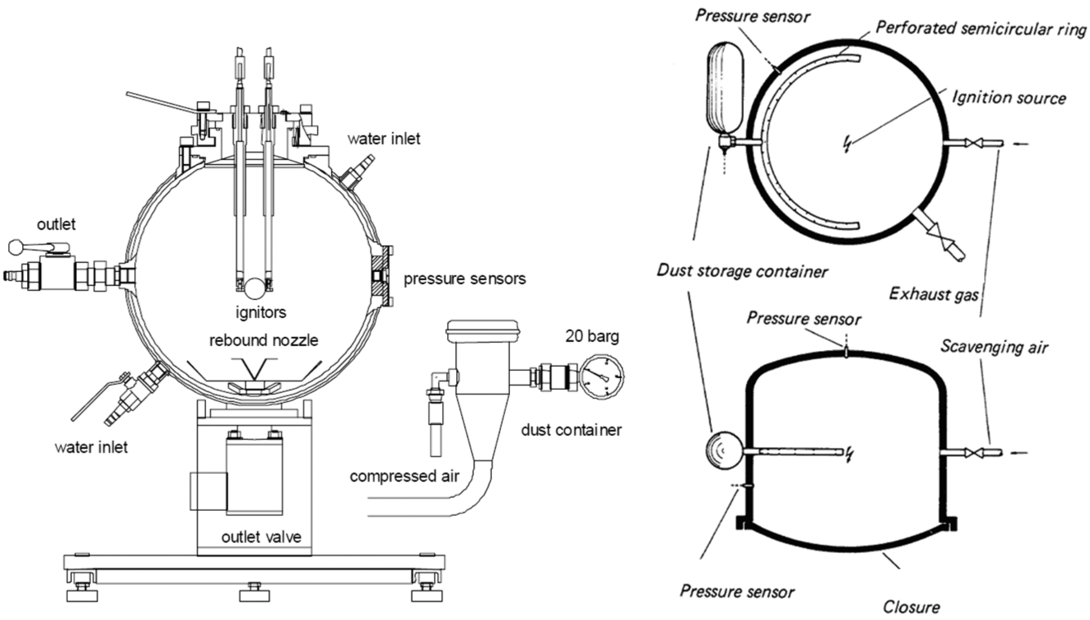

Fig. 1 Schematic of standard 20-L-sphere (left side) and front view (upper right side) and top view (lower right side) of 1-m^3-vessel (VDI 2263-1[5]).

for Chemicals), it is recommended to reduce toxic materials for indoor use. As a consequence the composition of the igniters has been deleted in the European standards. At the moment the igniters are only characterised by means of ignition energy and delay between triggering point and start of pressure increase in the vessel.

Consequently, alternatives to the existing igniters should be approved. An apparently promising option is a new igniter manufactured by Simex Control in the Czech Republic. The first testing series and validation by Swissi with lycopodium and aluminium powder with 5 kJ igniters in the 20-L-sphere indicated compatible values. For final validation a comparative study between the so far used igniters manufactured by Sobbe in Germany and the Simex ones has to be conducted. For this purpose a round robin test in 4 different test houses was initiated. This paper reveals the results of the study.

2. Experimental

The tests were carried out in the 20-L-sphere. This is the test vessel which is commonly used in practice. Since according to the European guidelines the 1-m^3-vessel is still the standard test vessel and because the effect of the igniters on the explosion characteristics may be stronger in a larger vessel, for some dusts additional testing in the 1-m^3-vessel was done.

Four test houses were involved in the tests, BAM Federal Institute for Materials Research and Testing (20-L-sphere), Institute for Occupational Safety and Health of the German Social Accident Insurance (20-L-sphere and 1-m^3-vessel), Berufsgenossenschaft Nahrungsmittel und Gastgewerbe (20-L-sphere and 1-m^3-vessel) and Swiss Institute for Promotion of Safety and Security (20-L-sphere).

2.1 Experimental setup

The 20-L-sphere (Fig. 1) consists of a hollow sphere made of stainless steel. The test chamber can be controlled thermostatically by a water jacket, in order to prevent heating in case of high testing frequency. For testing, a dust sample was placed in the storage chamber and dispersed into the sphere via the outlet valve and the rebound nozzle.

The 1-m^3-vessel also consists of a hollow sphere, with a front side which can be opened. The testing procedure is similar to the 20-L-sphere.

In the 1-m^3vessel the semicircular ring or the rebound nozzle was used for dispersion of the dust.

During each test the explosion pressure was measured and recorded with two piezoelectric sensors. The pyrotechnical igniters were located in the centre of the sphere.

The exact procedure to determine respective characteristics is described in EN 14034-1 to 14034-4[1)−4)].

For the tests in the 20-L-sphere 3 test series were carried out. In the 1-m^3-vessel only one test series was carried out, but the maximum values for explosion pressure and pressure rise were repeated including the values of the next higher and lower concentrations.

2.2 Dust samples

For the round robin tests 6 dusts in total from various product groups (organic, metals etc.) with different explosion severities and ignitabilities were chosen. These dusts shall represent the range of dusts tested in practice regarding ignitability, explosion characteristics and combustion mechanism. Table 1 lists the chosen dusts and their approximated explosion characteristics (GESTIS-DUST-EX[6)]).

All dust samples were tested in as-received condition. Maize starch, niacin and powder coating were tested in both test equipment. Anthraquinone, carbon black and the

Table 1 Round robin test dusts and reference characteristics (GESTIS-DUST-EX[6]).

dust	P_{max} [10^5Pa]	K_{St} [10^5Pa ms^{-1}]	LEL [g m^3]	MIE [mJ]
Authraquinone	9	350	30	10 1 30
Carbon black	8.0	250	30	>10
Maize starch	8.5	190	60	10 1 30
Powder coating	9.0	200	30	3 1 10
Niacin	8.5	250	30	1 1 10
Blasting dust	4.5	100	60	10 1 100

P_{max} Maximum explosion pressure
K_{St} Dust explosion constant
LEL Lower explosion limit
MIE Minimum ignition energy

Table 2 Particle size (median) and moisture content of the tested dusts.

dust sample	median [μm]	moisture content [%]
Authraquinone	2.8	0.5
Carbon black	2.4	2
Maize starch	12.8	6.2
Niacin	13.2	0.4
Powder coating	17.1	0.6
Blasting dust	25.5	0.1

blasting dust were tested only in the 20-L-sphere.

For all dusts median value of the particle size and moisture content were determined, see Table 2.

2.3 Igniters

Due to product secrecy the composition of the Simex igniter is not known. The characteristics of both igniters are compared in Table 3. The table shows that the data for ignition energy and ballistics are the same. To avoid toxic or harmful products, according to the manufacturer barium and lead have been eliminated in the Simex igniter. In addition to that, tests at Swissi show that the safety current of the Simex igniter is higher than the safety current of the Sobbe igniter. Furthermore the Simex igniter is less friction sensitive.

Since 1 kJ igniters from Simex were not available when the tests started, only igniters with an energy of 5 kJ could be used.

3. Test results

3.1 Tests without dust

At first preliminary tests without dust were carried out in the 20-L-sphere to get information about the pressure generated from the igniters.

As can be seen in Fig. 2 the differences in pressure are rather small. The mean value of ten Simex-tests gave an overpressure of $1.03 \cdot 10^5$Pa, whereas ten Sobbe ignitions resulted in a slightly higher mean value of $1.09 \cdot 10^5$ Pa. The reason for that could be the influence of scattering due to the relatively small amount of tests. However, the scattering of pressure of the Simex igniters seems to be lower than the scattering of the Sobbe igniters.

In a second step the ignition of both igniters was filmed with a high speed camera (Redlake MotionPro X-4) with 5000 frames per second and with a thermal imaging camera (InfraTec VarioCAM®hr head) with 50 frames per second. The aim was to get information about flame shape, flame size and flame propagation of both igniters.

For these tests one of each igniter was fixed at a stand in a bunker. The igniters were aligned so that they showed in opposite direction.

Figure 3 shows photos filmed with the high speed camera at four different times. As can be seen the flame of the Simex igniter started to propagate and form a fireball a short period of time earlier than the Sobbe igniter. The marked circle shows the inner diameter of the 20-L-sphere. Due to overexposure of the photos the maximum size of the flame can only be estimated but assumed as minimum the size of the 20-L-sphere. Photos from the thermal imaging camera proof that assumption. They also show that the shape of both flames is comparable.

3.2 Tests with dust

The tests on maximum explosion overpressure showed

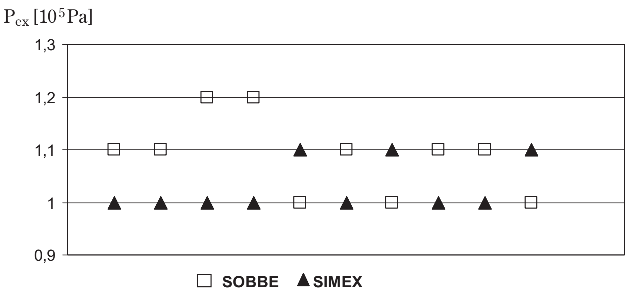

Fig. 2 Explosion overpressures of both igniters for tests without dust.

Table 3 Comparison of Sobbe and Simex igniter (Swissi[7] edited).

Parameter	Standard 5 kJ igniters (Sobbe)	NPI® 5 kJ igniters (Simex)
Calculated combustion temperature	3800±200℃	3800±200℃
Ignition energy	5 kJ	5 kJ
Ballistic output (20l t)	0.9 to 1.3 [10^5Pa]	0.9 to 1.3 [10^5Pa]
ESD sensitivity of igniter composition	10-20μJ	10-20 mJ
Friction sensitivity	200 g	4000 g
Safety current	0.18 Amps	0.40 Amps

Electro static discharge (ESD)

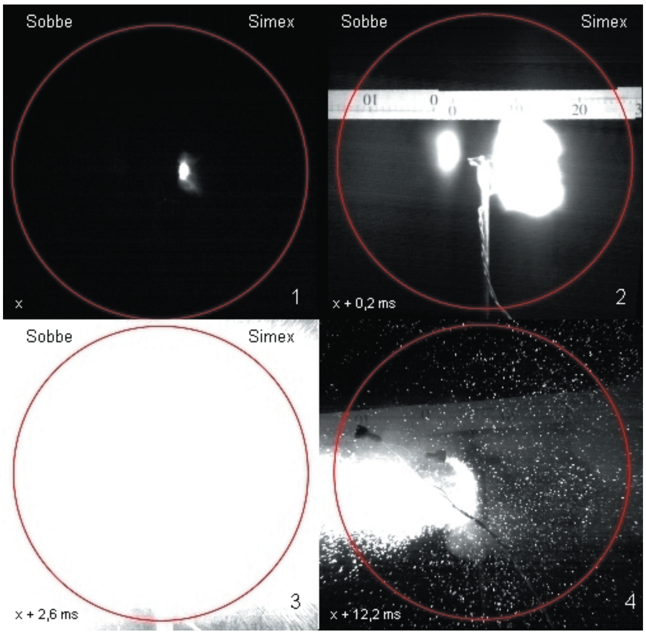

Fig. 3 Flame propagation of both igniters, photos filmed with high speed camera at time x, x + 0.2 ms, x + 2.6 ms and x + 12.2 ms.

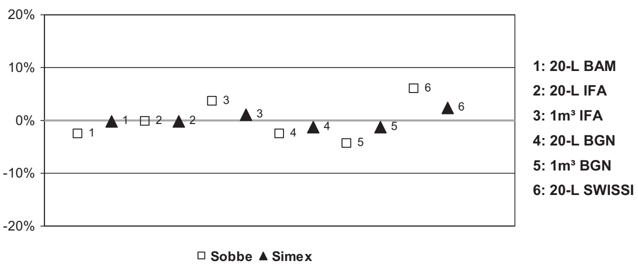

Fig. 4 Differences of P_{max} for tests with Niacin in 20-L-sphere and 1-m^3-vessel.

a good agreement between Sobbe and Simex igniter. Taking into account the accuracy of measurement and the differences which are typical for dust explosion testing, the results are identical.

Figure 4 illustrates the test results exemplary for Niacin. The figure shows that the differences between both igniters as well as the differences between the test houses and the test equipment are negligible. Comparable results were found for all tested dusts, see Table 4. The table gives an overview of the results for maximum explosion pressures determined in the 20-L-sphere.

The test results from the 1m^3-vessel are shown in Table 5.

Table 5 Test results for determination of P_{max} in 1-m^3-vessel.

Dust sample	P_{max}[10^5Pa]			
	IFA		BGN	
	Sobbe	Simex	Sobbe	Simex
Maize starch	9.2	9	8.4	8.4
Niacin	8.4	8.2	7.76	8
Powder coating	7.6	7.9	-	-

Table 6 LEL determined in 1-m^3-vessel.

Dust sample	LEL [gm^{-3}]	
	Sobbe	Simex
Maize starch	125	125
Niacin	30	30
Powder coating	60	60

For all tested dusts the differences between both igniters were smaller than between the different test houses and the different test equipment.

Figure 5 illustrates the determined K_{St}-values for Maize starch, for both igniters in 20-L-shpere and 1-m^3-vessel. As can be seen the differences between the igniters are much smaller than between the test houses and between 20-L-sphere and 1-m^3-vessel. Taking into account the accuracy of measurement and the differences which are typical for dust explosion testing, the differences are negligible and the results can be assumed as identical. Comparable test results were found for all 6 tested dusts.

The results of lower explosion limit tests in the 1-m^3-vessel are displayed in Table 6. As can be seen all tests led to identical values for the LEL.

4. Conclusions/outlook

Tests with six different dusts with a wide range of P_{max} and K_{St} in the 20-L-sphere and 1-m^3-vesel showed a good correlation between both igniters for the determined values P_{max}, K_{St} and LEL (only tested in the 1-m^3-vessel). Taking into account the typical differences for dust explosion testing, the results can be assumed as identical.

According to the validation results the new igniter is therefore an alternative to the standard igniter for the determination of P_{max} and K_{St} in both test equipment and for the determination of LEL in the 1-m^3-vessel.

Further validation tests for the determination of the limiting oxygen concentration (LOC) in the 1-m^3-vessel

Table 4 Test results for determination of P_{max} in 20-L-sphere.

Dust sample	P_{max}[10^5Pa]									
	BAM		IFA		BGN		SWSSI		θ	
	Sobbe	Simex	Sobbe	Simex	Sobbe	Simex	Sobbe	Simex	Sobbe	Simex
Authraquinone	8.4	8.5	8.5	8.4	8.5	9.1	8.2	8.6	8.4	8.65
Carbon black	8.1	8	8.1	7.7	8.2	8.2	8	7.9	8.1	7.95
Maize starch	8.2	8.3	8.4	8.3	8.6	8.2	8.7	8.3	8.48	8.28
Niacin	7.9	8.1	8.3	8.1	7.9	8	8.6	8.3	8.18	8.13
Powder coating	7.1	7.1	7.4	7.2	7.2	6.8	7.2	7.3	7.23	7.1
Blasting dust	3.9	3.8	4	3.9	3.7	3.7	3.7	3.6	3.83	3.75

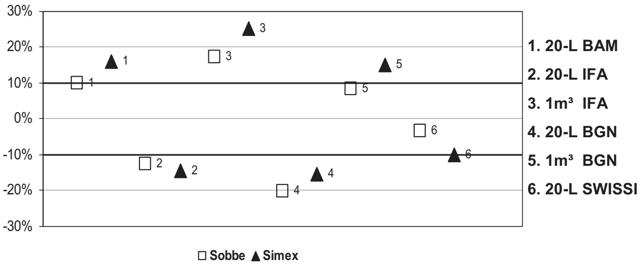

Fig. 5 Differences of K_{St}-values for tests with Maize starch in 20-L-sphere and 1-m^3-vessel.

should be performed, since it would be good to have an igniter that is applicable for all tests in 20-L-sphere and 1-m^3-vessel.

In a next step validation tests with an alternative 1 kJ igniter for the determination of explosibility, LEL and LOC in the 20-L-sphere should be conducted.

Since explosion overpressure and pressure rise generated from the igniter as well as flame shape and size most likely have an influence on the determined characteristics, it is furthermore beneficial to define these parameters in the testing standards within a respective tolerance level.

A comparison of the test results for some dusts showed, that differences in the maximum explosion pressure rise between 20-L-sphere and 1-m^3-vessel were much higher than estimated. This should be investigated more clearly during further testing.

Acknowledgments

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