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Comparative Study on Standardized Ignition Sources: Exploration of the Initial Igniting Volume of Standardized Ignition Sources for the Determination of Explosion Characteristics

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There are several standardized ignition sources in use for the determination of explosion characteristics of gases, vapors and dusts. In the standards the ignition source is stated, but they vary in stating other characteristics like burning duration, energy or burning volume. Since heat is not visible under normal circumstances a Schlieren-Technique was used to make the full heating volume and not just the flames visible. While an earlier paper of the authors focused on the ignition energy and burning duration of four standardized ignition sources, this paper focuses on the initial igniting volume, the ratio between initial igniting volume and the test-vessel size and other phenomena that were observed with the Schlieren-Technique.

1. Introduction

It is known that the type of the ignition source and the test vessel-size have an influence on the safety characteristics: Hertzberg et. al. investigated the lower and higher explosible limit of methane in a 120L and a 20L chamber (Hertzberg (1986)). In the 20L-sphere the explosible region widened from 5 % and 16 % to 4,5 % and 21,5 % by increasing the ignition energy from a 2 J spark to a 2500 J pyrotechnical igniter, whereas no change was observed for the 120L chamber.

Besides the mixture preparation the ignition source is the main difference in the standards for the determination of safety characteristics of dusts (EN 14034 and ASTM 1226) compared to the ones of gases and vapors (EN 1839, EN 15967 and ASTM 918). It is known that the minimum ignition energy alone is not a suitable characteristic for the choice of ignition source for standard tests. The burning duration (Glor and Schwenzfeuer (2005)) and the shape and volume of the initial ignition also play a key role, some of them in a non-intuitive way: in 1986 Hertzberg et. al. stated “Surprisingly, however, for the near-stoichiometric mixtures [of methane], both the pressure ratio [absolute explosion pressure / initial pressure] and KG are somewhat higher for the [induction] spark source than for the more energetic chemical ignitors.” Hertzberg et. al. (1986) further give an explanation, that this is “…an artifact of the differences in the source geometries: the spark is a point-source, whereas the chemical ignitor is a line source. The spark generates a spherical wave front that contacts the wall almost simultaneously everywhere along the flame front surface at the instant combustion is complete.” The authors do agree with the induction spark being a point-source but could show, that the chemical igniters are closer to a doubled sphere than to a line source. Other statements about the shape of the ignition source or the volume where not found in the literature.

For the development of a new standard for hybrid dust/gas-mixtures all the features of ignition sources should be investigated or at least be stated, what has not been done so far (see Table 1).

The burning duration can be estimated visually, but the only ignition sources with an online measurement or control for the burning duration are the exploding wire and the induction spark (Spitzer et. al. (2021)). The initial igniting volume of the ignition source is hard to measure because any optical measurement depends on the distance of the camera from the object, the aperture, the exposure time and threshold for the algorithm used,

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only to name a few parameters. Thus, the measurement of the “white space” (visible flame) in a picture is a first approach to a two-dimensional approximation of the burning volume but represents for most cases a lower limit of the real volume. To demonstrate this phenomenon, a tealight candle was lit and after measuring the width and height of the flame a match was placed outside the visible flame and caught fire (see Figure 1).

Table 1: Ignition sources and features (n.i.: not investigated)

Ignition Source	Burning Duration [ms] defined / adjustable	Initial igniting volume [m³]	Power [W] and power density [W/m³]	Affected by pressure	Found in
Exploding Wire	No / Yes	n. i.	n. i. / n. i.	No	EN 1839 B, ASTM E918, EN ISO 10156
Chemical Igniter	No / No	n. i.	n. i. / n. i.	No	EN 14034 series ASTM 1226 ASTM 1515
Induction Spark	Yes / Yes	n. i.	known / n. i.	Yes	EN 1839, ASTM E681, EN 15967
Surface-gap spark	No / No	n. i.	n. i. / n. i.	No	ASTM 2079

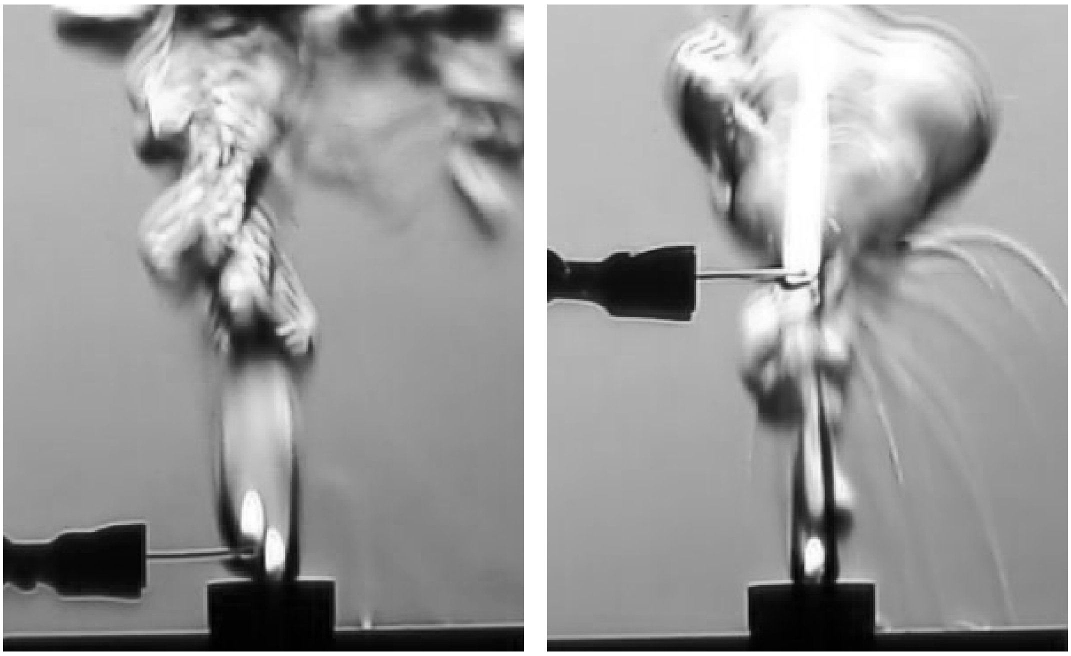

Figure 1: Tealight Candle with a (visible) flame-width of 6 mm and flame-height of 11 mm igniting matches 3 mm beside and 73 mm above the visible flame

This introducing experiment shows the need for a better conservative estimation of the initial igniting volume of an ignition source. It also shows, that an estimation from standard camera photos or videos alone is hardly possible, because of the directional property of heat due to convection. Schlieren-Imaging was used to gain an upper limit of the initial igniting volume for the four standardized ignition sources. On the borders of the areas displayed with the Schlieren-effect it is too cold to ignite but the initial igniting volume lies somewhere in between (see Figure 2).
Schlieren technique is a simple method for visualizing the flow based on the principle of refractive index change in environments of different densities. Schlieren could be observed in liquids, solids and gases and it has been used in studying fluid dynamics, particularly air convection. Instead of visibilities of temperature changes high speed flows, or the mixing of dissimilar materials occurred can also be observed (Merlin (2020)).

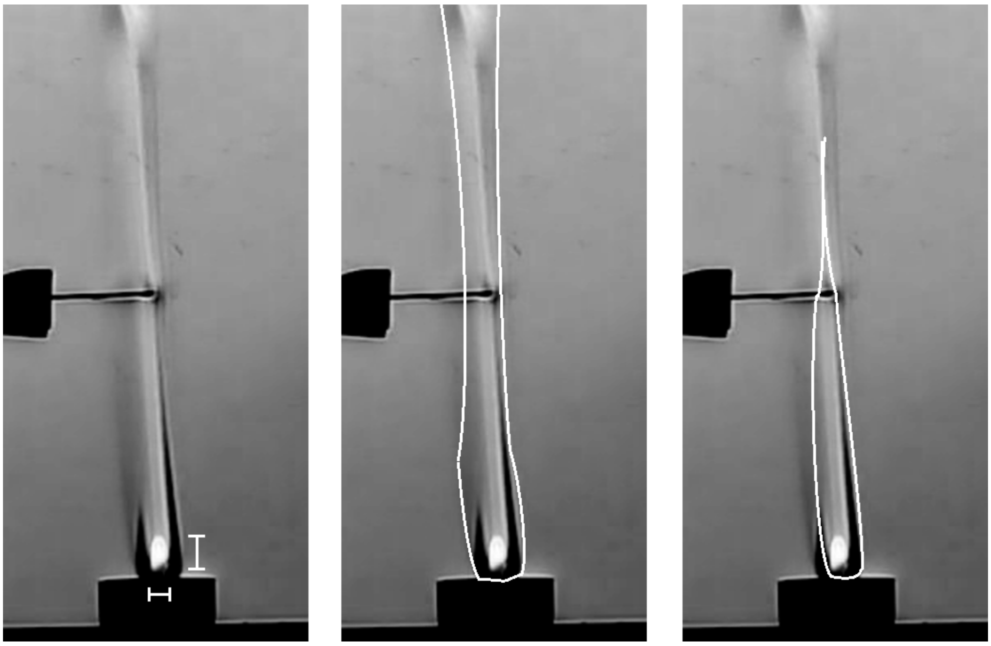

Figure 2: Burning Volume - Optical Approach on the left (too small) - Schlieren-Imaging Approach (displays any area over 20 °C and is therefor too big) – initial igniting volume (somewhere between the other two)

2. Methods and Materials

There are different methods to visualize density differences that are called schlieren (Bunjong (2018)). For this study a set-up with one parabolic mirror was used. For this technique it is necessary to have a parabolic or a spherical mirror, (for this technique both work!) a knife-edge, or some other type of cut-off of the refracted light (e.g. razor blade), and a point source of light. The smaller and brighter the source of light, the better results could be seen. For this reason, an LED light was used in the experiments. In addition, a device (e.g. a camera) is needed to record and store the individual images or a video during the execution of an experiment. The schematic of these individual components is shown in the following Figure 4, for replications and optimization of the components see Bunjong (2018).

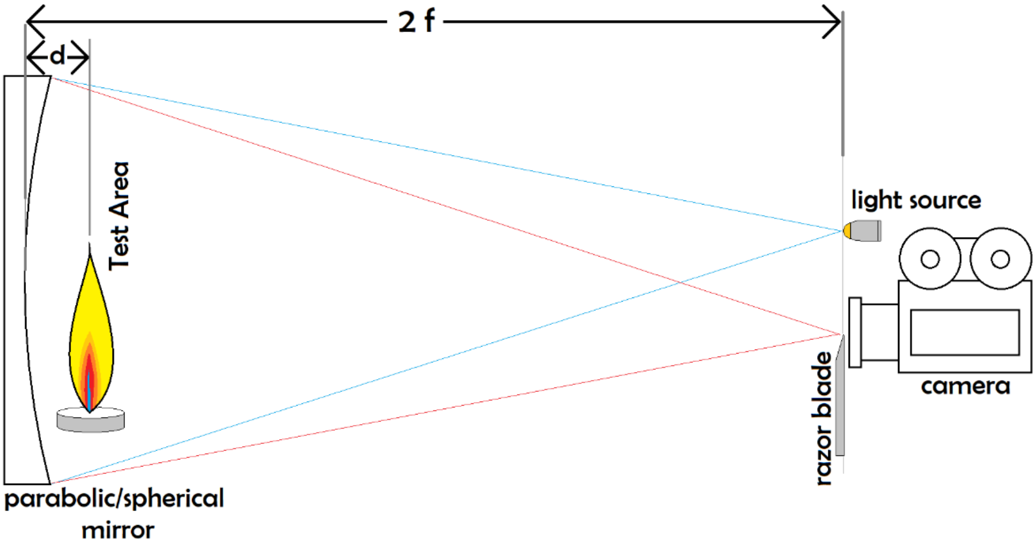

Figure 3: Optical setup for the Schlieren-imaging tests

In this series of experiments the light source was positioned at a defined distance (2f) away from the parabolic mirror. The camera and the razor blade were placed right next to the light source. The light is focused on the double focal length (f) of the parabolic mirror ("radius of curvature (r)", that means the distance from the pole to the focal point. The authors are aware of the fact, that a parabola has no radius and a spherical mirror has no focal point. For this set-up both types of mirrors work. For such a small part, a sphere and a parabola are pretty similar and the equation works as well). This is given by Eq 1:

$$f \approx r/2 \tag{1}$$

At the end the camera should be placed in the path of the light, behind the radius, respectively behind the razor blade. The razor blade then shields some of the reflected light from the mirror. If more light is blocked the schlieren-effect is more visible but the image gets darker. The testing area should be as close as possible to the mirror otherwise the image gets blurry. The basic theory of schlieren depends mostly on geometrical optics with additional consideration of diffraction affects. There is a simple relationship for the air and other gases between the refractive index n and the gas density ρ of a fluid, see Eq 2:

$$n-1=k\rho \tag{2}$$

This coefficient k is a constant for a given fluid. For air this coefficient is approximately 0.23 cm^3/g at standard atmospheric conditions, given visible illumination. Other gases may have a variety from 0.10 cm^3/g until 1.5 cm^3/g, but the refractive index varies only in the third or fourth decimal place for common gases (Settles (2001 and 2016)). Also, Eq 2 is not too deeply dependent upon ρ. The refractivity of a gas (n-1) depends upon gas composition, temperature, density and the wavelength of illumination. Simple perfect-gas state Eq 3 could be used in many cases when the temperature, density and pressure of gases is not too far from atmospheric conditions. In this equation, R is the specific gas constant.

$$p/\rho=R\,T \tag{3}$$

Due to temperature differences or high gas speeds velocities, flowing gases with variable density can arise. These possibilities lead to the fact, that gases are capable of refracting light. This refraction may be then visualized. In the schlieren image the gradients $\partial n/\partial x$ and $\partial n/\partial y$ are visible which are perpendicular to optical axis and the knife-edge orientation (Settles (2001 and 2016)).

All four ignition sources stated in Table 1 were put close (0,05 m < d < 0,15 m) to the parabolic mirror and several ignitions were filmed with a high-speed camera (Photron FASTCAM APX RS) with 10 000 frames per second. One should keep in mind, that the distance from the center of the standard autoclave (20L-sphere) for the determination of safety characteristics, to the wall is 17 cm and the diameter of the mirror is 33,5 cm, so the full images resemble a 2D-impression of the whole sphere.

3. Results and Discussion

Different types of phenomena were visible with the Schieren-Technique.

What surprised the authors at first, was the fact, that for the Chemical Ignitors and the Exploding Wire the visible burning volume (flame) was not smaller than the heating volume in the first 10 milliseconds in which most of the energy is released. This is caused by the short burning duration and, with that, no convection can take place. In Figure 4 it is displayed, when the exploding wire shows the first sign of ignition, after 5 ms, 10 ms, 15 ms and 50 ms.

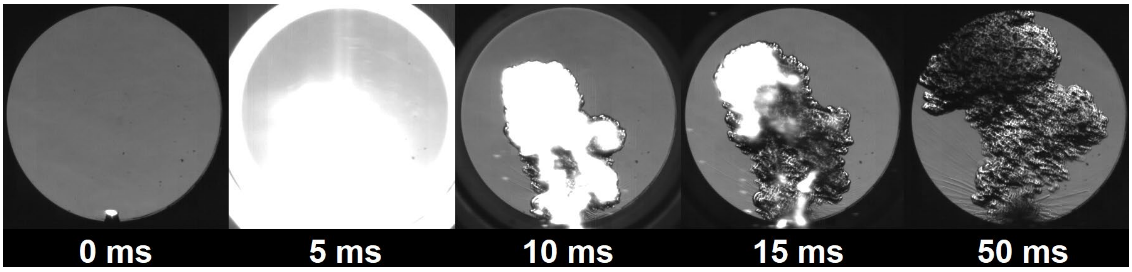

Figure 4: Exploding Wire filmed with the Schlieren-Setup, 1kJ of net energy (2,2 kJ electrical (gross) energy)

In Figure 5 it is displayed, when the chemical igniters show a first flame, when the shockwave front reaches the half diameter of the sphere, flame reaches half of the diameter of the sphere (normally it is placed in the middle), the full diameter and after 50 ms when the last sparks end to glow for one 1 kJ igniters and one 5 kJ igniter. One should keep in mind, that two ignition sources are used.

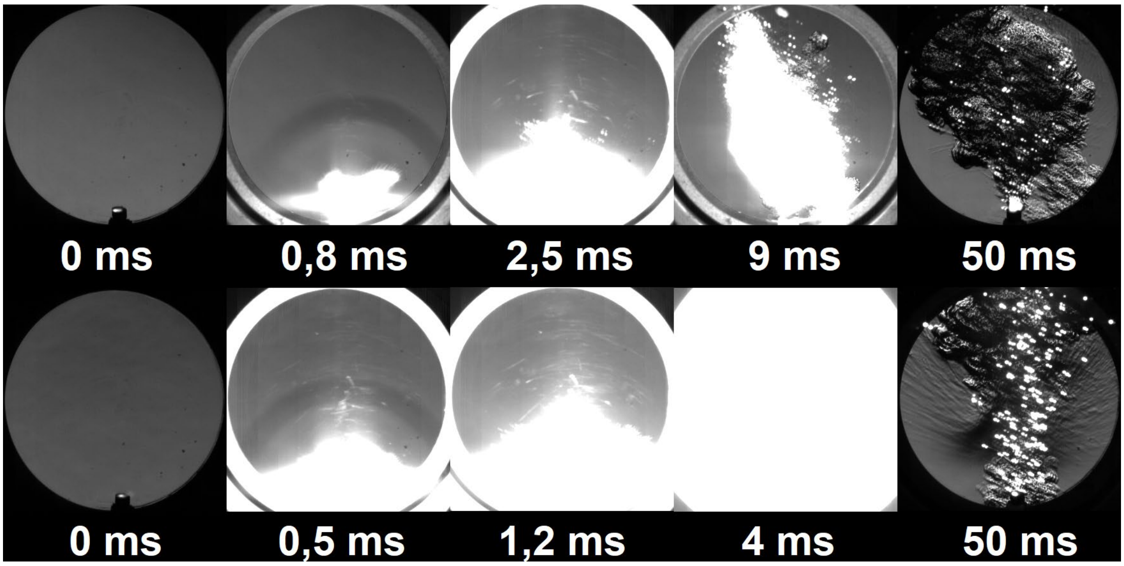

Figure 5: Pyrotechnical Igniters filmed with the Schlieren-Setup, 1kJ (upper row) and 5kJ (bottom row)

The Schlieren-Images of the Exploding Wire were similar to those of the Pyrotechnical Igniters: During the first 10 ms no difference could be observed between the visible flame and a surrounding heated atmosphere.
For the induction spark convection of the air within the two electrodes was observed (see Figure 6), that means the ignition energy does not stay in place but gets shifted away within 0,2 s and especially within 0,5 s. This is especially astonishing since in the European standard about the determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours it is allowed to increase the burning duration from 0,2 s to 0,5 s, if the mixture is not ignitable. If the energy is carried away because of convection from the electrodes, increasing the burning duration is increasing the number of sparks from 20 to 50 single sparks all having the same effect on the substance. A reason, why increasing the number of sparks donated to the mixture made a difference in the past may be an artefact of the gear used: Testing the induction spark of another laboratory it was observed, that the relay closing the circuit had an unwanted delay-time of about 30 ms when closing but none when opening. Some older gear might be even worse, so shifting the closing time of the relay from 0,2 s to 0,5 s might have resulted in an increase of the burning duration from some Milliseconds to at least over 0,3 s respectively from a few sparks to at least over 30, what leads to a real difference in probability of igniting the mixture.

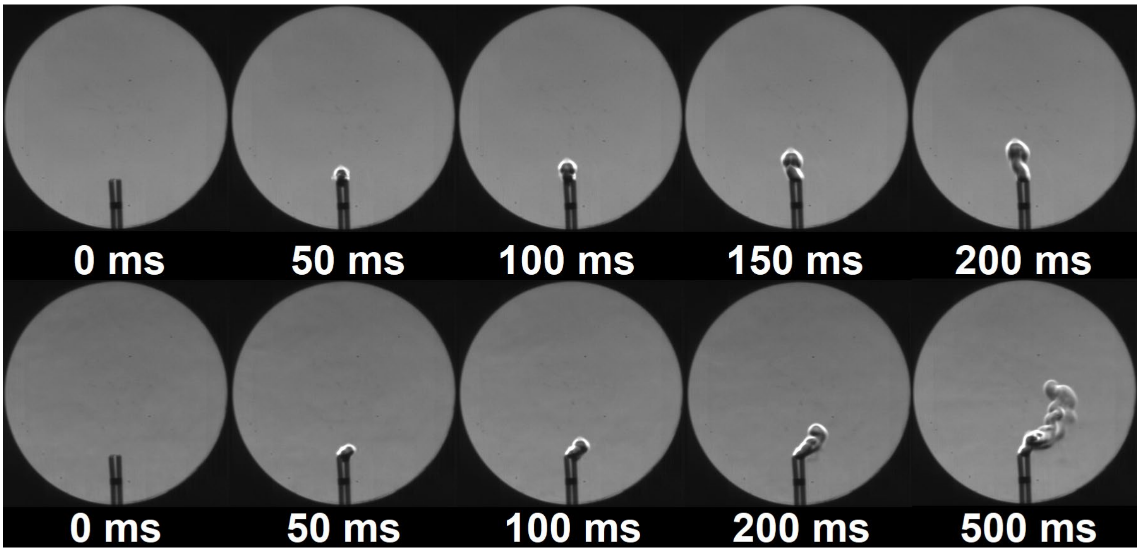

Figure 6: Induction spark filmed with the Schlieren-Setup, 0,2 s (200 ms) of ignition duration (top) and 0,5 s (500 ms) ignition duration (bottom)

The Schlieren Images of the Surface-Gap Spark showed a shockwave and an igniting volume about the same size of the induction spark. Both, the shockwave pushing the dust away and the comparably small igniting volume may be the reason, why the surface-gap spark is not used for dusts. Whether or not the dust really gets pushed away from this ignition source will be analyzed in the future.

4. Conclusions

It was shown, that for the fast-acting ignition sources, exploding wire and pyrotechnical igniter, there is no difference between the initial igniting volume and the visible flame. The visible flame however fills the whole testing apparatus in case of a 20L-sphere. For the slower-acting one, the induction spark, a flow of heat from the ignition point within the burning duration was observed. This is especially astonishing, since some standards allow to increase the burning duration from 0,2 s to 0,5 s if there is no ignition with 0,2 s. This leads to the conclusion, that not simply the ignition energy but also the ignition probability is the reason, why a difference can be observed between the two burning durations. The tests with the surface gap spark showed, that a shockwave is emerging from the pencil lead. This might be the reason, why this ignition source is not suitable for dusts.

In upcoming databases and literature-values and also in standards it should be considered to not only state the ignition energy, but also how it was measured, which one was taken, what shape it had and an estimation about the ignition time and power density to gain a robust fundamental knowledge on safety characteristics. The Initial igniting Volume to test-vessel ratio is also an approach to estimate the influence of the ignition source on the determined safety characteristics.

Acknowledgments

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References

ASTM 1226 – 12a - Standard Test Method for Explosibility of Dust Clouds, ASTM International, West Conshohocken

ASTM 681-09 - Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases), ASTM International, West Conshohocken

ASTM E1515 – 2007 - Standard Test Method for Minimum Explosible Concentration of Combustible Dusts, ASTM International, West Conshohocken

ASTM E 2079 - 2000 - Standard Test Methods for Limiting Oxygen (Oxidant) Concentration in Gases and Vapors, ASTM International, West Conshohocken

Bunjong D., Pussadee N., Wattanakasiwich, P., 2018, Optimized conditions of Schlieren photography, Journal of Physics: Conf. Series 1144

DIN EN 14034:2006 - Determination of explosion characteristics of dust clouds, Beuth-Verlag, Berlin

DIN EN 1839:2017 - Determination of the explosion limits for flammable gases and vapours, Beuth-Verlag, Berlin

DIN EN 15967:2011 - Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours, Beuth-Verlag, Berlin

DIN EN ISO 10156:2017 - Gas cylinders – Gases and gas mixtures – Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets, Beuth-Verlag, Berlin

Glor M., Schwenzfeuer K., 2005, Direct Ignition tests with brush discharges, Journal of Electrostatics, 63, 463-468

Hertzberg M., Cashdollar K. L., Zlochower I. A., 1986, Flammability Limit Measurements For Dusts And Gases: Ignition Energy Requirements And Pressure Dependencies, Twenty-First Symposium (International) On Combustion, 303-313

Merlin P., 2020, Schlieren Images Reveal Supersonic Shock Waves, https://www.nasa.gov/centers/armstrong/features/shock_and_awesome.html, accessed 08/02/2022

Settles G. S., 2001, Schlieren and Shadowgraph Techniques, Springer Verlag Berlin

Settles G. S., Hargather M.J., 2016, A review of recent developments in schlieren and shadowgraph techniques Measurement Science and Technology, 28, 042001

Spitzer S., Askar E., Schröder V., Krietsch A., 2021, Comparative study on standardized ignition sources used for explosion testing, Journal of Loss Prevention in the Process Industries, 71, 104516