Flow Conditions During the Formation of Hybrid Mixtures in the 20L-Sphere

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In previous works the flow conditions in the standard 20L-Sphere were investigated with different methods (e.g. schlieren technique, PIV) to validate the optimal ignition delay time, which is specified in the standard for measuring the safety characteristics of dusts. For measuring safety characteristics of hybrid mixtures from dust and vapors, a standardized method is currently being developed by the authors in working group NA-095-02-09-01-AK and transferred to CEN TC 305 WG1.

This work is focused on the investigation of streamlines and the distribution of the dust cloud for hybrid mixtures with vapors in a 20L-Sphere. Therefore, particle image velocimetry (PIV) is applied using a highspeed camera and tracer particles illuminated by an additional light source. A camera system takes pictures every 2 ms and a Python script with OpenPIV evaluates the distributions of the dust concentrations and the flow conditions. For various initial dust and vapor concentrations, the pictures were analysed to evaluate the testing procedure for hybrid mixtures. It was found that the required ignition delay time for pure dusts is also very well suited to hybrid mixtures with vapors.

Keywords: 20L-Sphere, hybrid mixtures, safety characteristics, fluid dynamics, highspeed camera system, PIV

1 Introduction

A hybrid explosive mixture is a multi-phase system consisting of combustible dusts and gases or vapors with air. Such mixtures are encountered regularly in industry, for example in the pharmaceuticals sector [1]. The 20L-Sphere is used as a standard operating experimental set-up for the laboratory-scale determination of safety characteristics, including explosion pressure and pressure rise rate, and is especially employed for pure dusts.

When measuring the explosion safety characteristics of well-defined hybrid mixtures, dust should be in suspension around the igniter, and the vapor well evaporated inside the Sphere. This is because hybrid dust/vapor/air mixtures, like pure dust/air mixtures, in the standard 20L-Sphere need to be ignited in a turbulent atmosphere that keeps the dust in suspension. For this reason, the ignition delay time is defined in order to specify the best moment of ignition after activation of the dust injection [7].

It is well known that the explosion pressure and in particular the pressure rise rate depend on the state of turbulence at the moment of ignition [8]. Investigations are therefore needed to obtain an understanding of the flow conditions in the original standard testing vessel shortly before ignition. Studies aimed at understanding the properties and reproducibility of dust clouds inside a sphere have been conducted by some researchers [2,3,4]. Of note is the work by Du et al. [5], who visualized the dispersion process in a transparent 20L-Sphere. They divided dust dispersion into three stages: a fast injection, a stabilization state, and a sedation state. El-Zahlanieh [9] investigated droplets of mists via PIV in a 20L-Sphere.

In this work the tracer particles were added to the testing mixture (corn starch and acetone) for the investigation of side effects like agglomerations or condensations of the vapor phase. Therefore, the experiments were placed in the original 20L-Sphere, which is also used for measuring safety characteristics of explosion protection for dusts and hybrid mixtures.

2 Methods

2.1 Explosion testing in the 20L-Sphere

A standard 20L-Sphere was used throughout the testing of the different explosive mixtures (

Fig *1*). It is described in [7] as the standard equipment for measuring the explosion safety characteristics of dust. Also installed was a syringe injection port for measuring the same safety characteristics of hybrid mixtures with vapors, plus an additional highspeed camera system for determining the flow conditions. The highspeed camera was located at the front of the sphere, where a sight glass was mounted. The video records were made with a frequency of 500 fps and an exposure time of nearly 2 ms. A piezoresistive pressure sensor was added to determine the start conditions for the experiments. The combustible dust sample was turbulently dispersed by a rebound nozzle after being introduced by a pressure blast initiated by a pneumatically actuated valve. Instead of the standard electrode stands, a high efficiency lighting source was located at the top of the sphere. The lighting source consisted of two high power LEDs (12 V and 700 mA) with a luminous intensity of 970 lm each. The sphere was tempered with a cryostat to 20 °C. During the experiment most of the components of the set-up were controlled remotely [3].

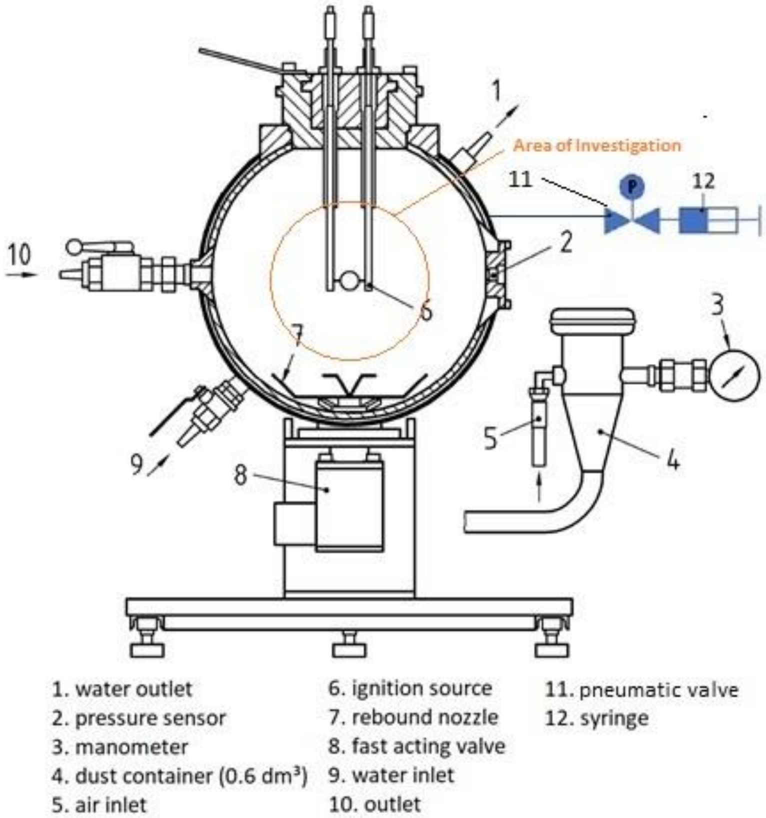

Fig 1: Schematic experimental setup

2.2 Measurement procedure

The corn starch dust, which was used throughout the entire standardisation project, was treated by a 1 % mass fraction of phosphorescence particles. At the beginning of each experiment, a defined mass of dust was placed in the dust chamber which was then pressurized to 21.2 bar. Then the sphere was evacuated to 0.020 bar. A defined mass of liquid was filled into the evacuated sphere, where it was allowed to evaporate. Then the sphere was filled with air to 0.4 bar (Fig 2). The fast-acting valve was opened, and the dust was blown into the sphere by the pressure blast, which resulted in a pressure of 1 bar inside the sphere. The highspeed camera system recorded the pressure blast and the particle trajectories inside the sphere. Each concentration was measured ten times for a statistical investigation. The video file of the camera system was chopped into frames and analysed with a python script. All experiments were performed at a temperature of 20°C ± 1°C.

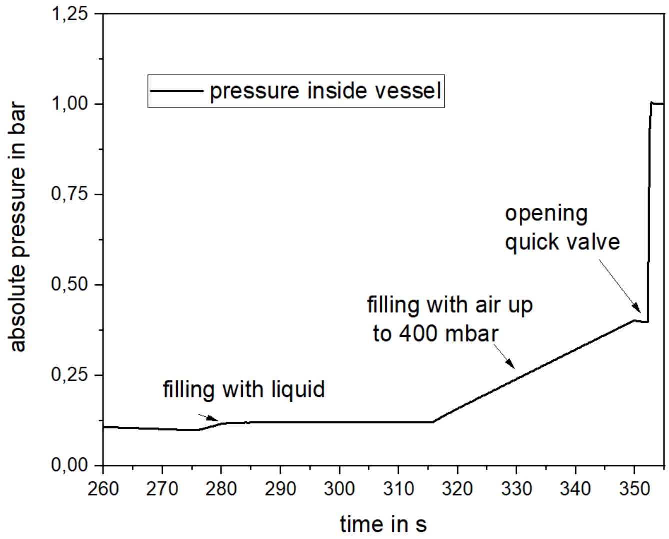

Fig 2: Absolute pressure during experiment in the 20L-Sphere

The test mixture consisted of 125 g/m³ corn starch and 2 vol% acetone. The median particle size distribution determined by means of a laser diffraction analyser was 20 µm. The humidity was found to be 7 % by mass fraction. Several checks were made to ensure that the humidity remained constant throughout the testing series.

3 Results and discussion

3.1 Brightness of the dust cloud

The test mixture of acetone, air, and corn starch containing titanium dioxide particles with a size of less than 5 µm was measured. The light from the top of the sphere was reflected by the particles [9] and detected by the camera system. Fig 3 shows selected frames from the dispersion process of the corn starch while surrounded by acetone vapor is around. The detected frames show the 10 cm x 10 cm area in which the igniters would be centred for an ignition experiment. During the first period (0 ms - 20 ms) after activation of the valve, the dust is introduced by the nozzle from the bottom to the top in a narrow stream. The analysis locates areas of high concentrations of tracer particles at the top of the picture. The dust cloud homogenizes between 30 ms and 80 ms. After 1500 ms nearly all of the dust has sedimented from the 10 cm by 10 cm area in the centre of the sphere.

In Fig 4 the number of pixels of a certain range of brightness for each frame (1024 pixels by 1024 pixels) is shown. Brighter pixels than 125 grayscale values were detected. The thresholds were set with the histograms of each frame of the investigated video. The highest number of bright pixels and hence the highest dust concentration around the igniter can be found around the ignition delay time given in the dust standards (60 ms – 70 ms) [7]. At the beginning of corn starch injection, the number of bright pixels is unsteady because of the irregular starch distribution of the dust. For this reason, Fig 4 shows a large scattering in the first period after the dust is injected. With higher additional steam contents, the dust also sinks to the ground more quickly.

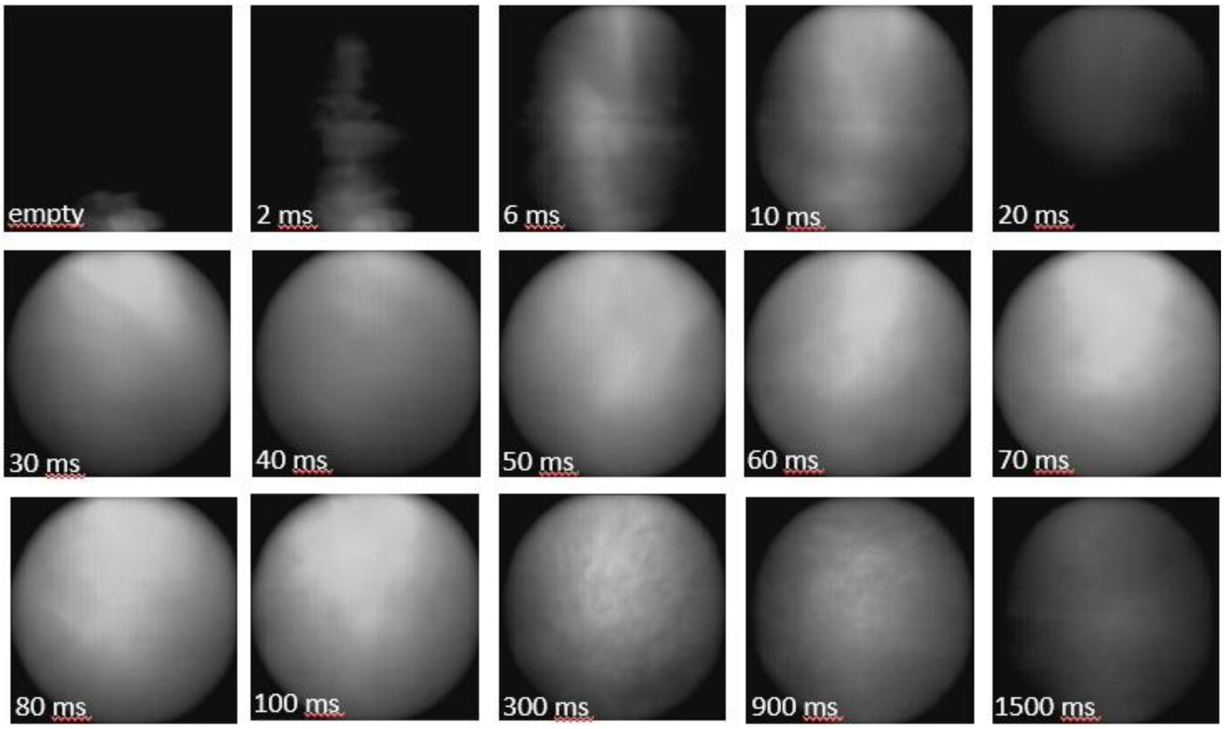

Fig 3: Selected frames showing hybrid dispersion with 2 vol% acetone and 125 g/m³ corn starch with 2 % titanium dioxide tracers

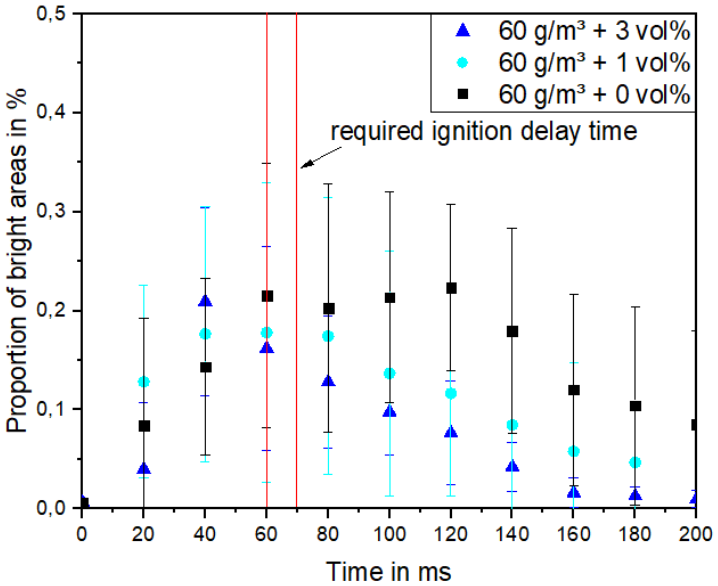

Fig 4: Bright pixel evolution of three measurements

3.1. Streamlines

To further investigate the streamlines and velocities of the pre-ignition turbulence phosphorescence particles with a mean particle size of 20 µm were used with the test mixture of corn starch and acetone. In Fig 5 selected frames of the hybrid dispersion between 10 ms and 80 ms are shown. The streamlines are plotted by vectors, while the velocities are indicated by the colors of the vectors. The streamlines at 10 ms show less homogeneity because of the dust injection. At 30 ms the corn starch was blown to the top of the sphere. This is evidenced by the streamlines pointing upwards in the flow direction. It is assumed that good dispersion of the dust occurs at 60 ms, given the higher velocities additionally seen in the unrelated streamlines. A rotation of the corn starch is seen after 80 ms in the original video, effected to the spherical geometry of the 20L-sphere. Hence it could be assumed that the streamlines demonstrate this rotational effect. The streamlines at the bottom corner of each picture are not part of the correlation calculations, due to the round original frame

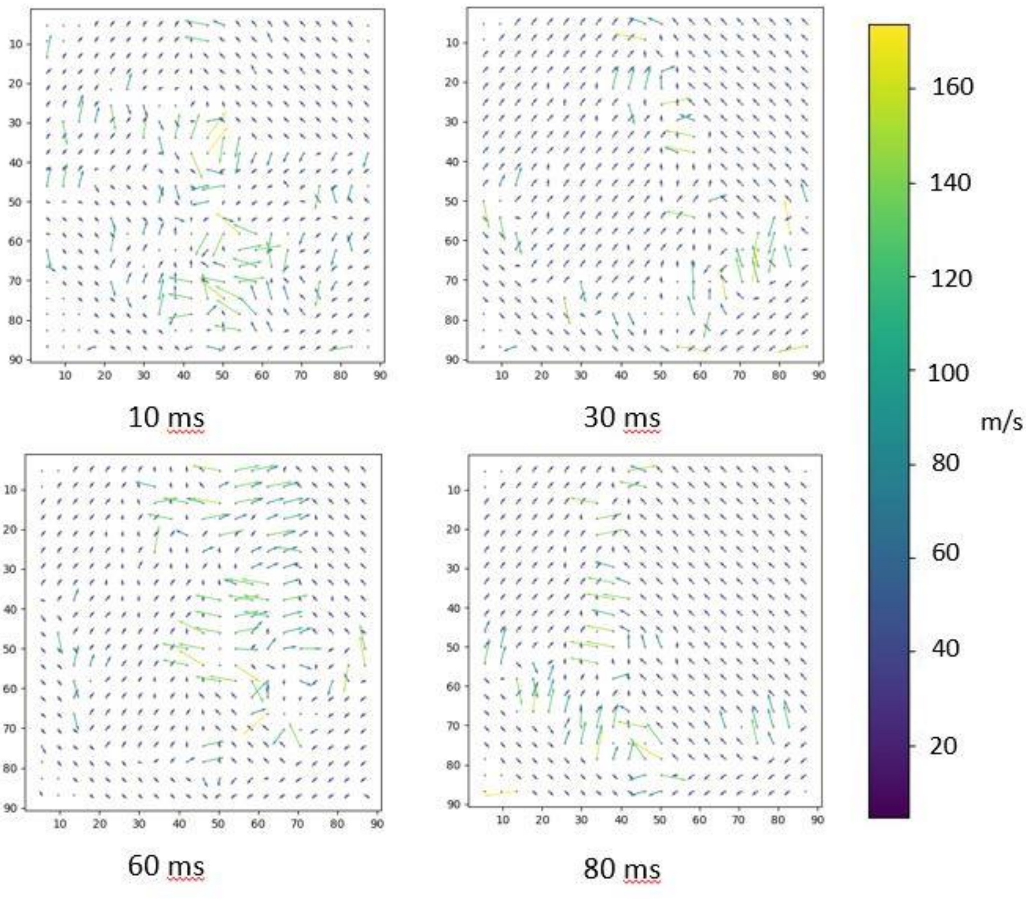

Fig 5: Selected frames of the dispersion within the test mixture with phosphorescence particles and their streamlines analysed with OpenPIV

4 Conclusion

The dispersion behaviour was investigated with the original testing sphere by using a high-speed camera system with two different sorts of tracer particles. Titanium dioxide particles were used to visualize the distribution of the dust cloud around the igniter. It was found that the highest concentration of dust occurred at 60 ms. Phosphorescence particles were used for the investigation of the streamlines via OpenPIV. This allows to conclude that the ignition delay time of 60 ms for dusts is also very well suited for hybrid mixtures. This thesis could be evaluated by conducting further cross correlation calculations using python, for example with a local correlation tracing instead of PIV. The local correlation tracing would lower the scattering of the results.

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