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DETERMINATION OF THE MAXIMUM EXPLOSION PRESSURE AND THE MAXIMUM RATE OF PRESSURE RISE DURING EXPLOSION OF WOOD DUST CLOUDS

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Abstract

The article deals with the measurement of maximum explosion pressure and the maximum rate of exposure pressure rise of wood dust cloud. The measurements were carried out according to STN EN 14034-1+A1:2011 Determination of explosion characteristics of dust clouds. Part 1: Determination of the maximum explosion pressure p_{max} *of dust clouds and the maximum rate of explosion pressure rise according to STN EN 14034-2+A1:2012 Determination of explosion characteristics of dust clouds - Part 2: Determination of the maximum rate of explosion pressure rise* $(dp/dt)_{max}$ *of dust clouds. The wood dust cloud in the chamber is achieved mechanically. The testing of explosions of wood dust clouds showed that the maximum value of the pressure was reached at the concentrations of 450 g / m*^{3} *and its value is 7.95 bar. The fastest increase of pressure was observed at the concentrations of 450 g / m*^{3} *and its value was 68 bar / s.*

Key words

wood dust clouds, explosion characteristics, maximum explosion pressure, maximum rate of explosion pressure rise

INTRODUCTION

The particle size of milled solid has a significant impact on fire hazard. A decreasing particle size reduces ignition temperature, and therefore the material in a compact state, which is non-flammable under normal conditions, becomes flammable and explosive when in the form of dust (1).

There are several definitions of dust. For example, the British standards define materials with particles smaller than 1000 micrometers as powders, and particles with a diameter of less than 76 micrometers as dust (BS 2955: 1993). According to The National Fire Protection

Association (NFPA), in the USA the term dust means any finely divided solid particles with a diameter of 420 micrometers or less (NFPA 68: 2002). Other literary sources classify also the particles with a diameter of more than 1000 micrometers as dust which is dangerous in terms of explosion (2).

In Slovakia, the existing harmonized standard defines dust as small solid particles in the atmosphere which settle by their own weight, but can also float in the air (3).

DETERMINATION OF EXPLOSION CHARACTERISTICS OF WOOD DUST CLOUDS

Burning is associated with the term of "fire triangle", while explosion with the term of "dust explosion pentagon". The principal elements of fire triangle is fuel to burn, oxygen and an ignition source. A dust explosion needs two additional elements: dispersion of dust in the oxidant and confinement of the dust cloud (4).

Figure 1 shows the dust explosion pentagon with different coexisting conditions that are necessary for dust explosion.

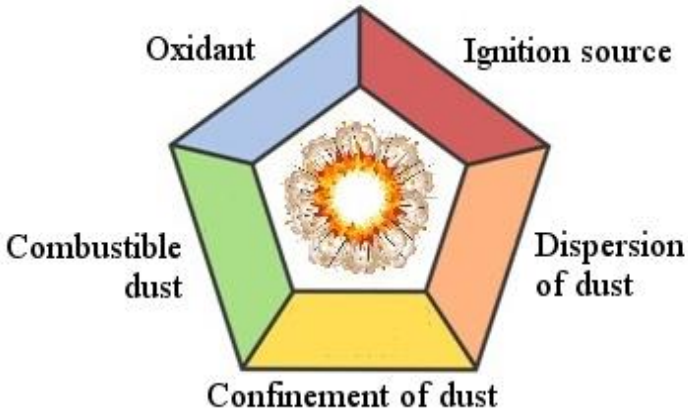

Fig. 1 *Dust explosion pentagon (8)*

A dust explosion is initiated by the rapid combustion of flammable airborne particles. Any solid material which is able to burn in the air under these conditions burns at a high speed. The burning rate increases with the increasing fineness of dust (4).

The extent and the rate of flame propagation in a cloud of dust depends on the factors such as character of dust, size of particles and properties of by-products formed during burning. Dust explosion is a complex phenomenon involving simultaneous momentum, energy and mass transfer in reactive zone of a multiphase system (5).

A smaller particle size causes increase of the rate of reaction and explosive combustion. However, if the particles are too fine they tend to aggregate in larger units. If a dust cloud ignites in enclosed space, there is a rapid burning in the form termed "Flash Fire". If ignition of the dust cloud occurs in a limited space, combustion heat can result the rapid pressure rise with the flame spreading through the dust cloud. These processes lead to an explosion which is accompanied by the development of large amounts of heat and reaction products. The character of explosion depends on the particle size and the rate of energy release which is due to the combustion. It also depends on the range of heat generation and heat loss. In exceptional circumstances destructive explosion of dust cloud may occur also in limited space (6).

Properties of dust clouds and settled dust are characterized by Lower Explosive Limit (LEL), maximum explosion characteristics (maximum explosion pressure p_{max}, maximum rate of explosion pressure rise $(dp/dt)_{max}$), minimum *ignition* energy E_{min}, minimum ignition temperature of dust clouds t_{roz}, induction period for ignition τ_i and Limiting oxygen concentration (LOC) (7).

The article presents practical measurements of the maximum explosion pressure and maximum rate of the explosion pressure rise of wood dust clouds. The measurements were carried out in accordance with STN EN 14034-1+A1:2011 Determination of explosion characteristics of dust clouds. Part 1: Determination of the maximum explosion pressure p_{max} of dust clouds and the maximum rate of explosion pressure rise according to STN EN 14034-2+A1:2012 Determination of explosion characteristics of dust clouds - Part 2: Determination of the maximum rate of explosion pressure rise $(dp/dt)_{max}$ of dust clouds.

MATERIAL AND METHODS

A modified KV 150-M2 chamber was used to measure the monitored characteristics. Scheme of the chamber is shown in Figure 2. Dust clouds in this unit are carried out mechanically. The compressed air is transmitted from the tank of by fast opening of the valve to inner space of chamber. The chamber has a volume of 291 liters. The sample is located on a plate and spread by compressed air. This compressed air is directed to the sample through the metal profiled sheeting. The sample is initiated by a chamber nitrocellulose initiator after the spreading of this sample. The initiator works on a resistive principle. Immediate initiation of nitrocellulose is achieved by the voltage value which is supplied to the resistance wire and results into an immediate burning and interruption of wire. Ignition energy of nitrocellulose used in initiator is 5 kJ.

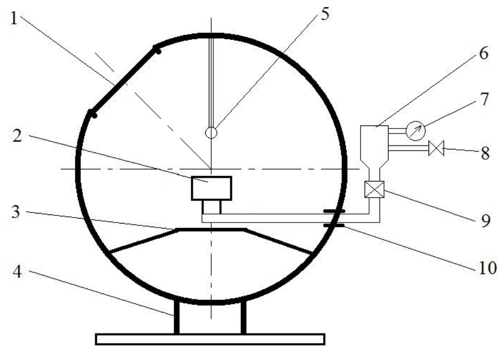

Fig. 2 *Scheme of a modified KV 150-M2 chamber (1- lid, 2- nozzle for spreading the sample, 3- desk, 4- base, 5- pyrotechnical igniter, 6- vessel, 7- manometer, 8- compressed air inlet valve, 9- fast opening valve, 10- window (9)*

Initiation of dust and its agitation is timed with dual digital timing relay. The relay has a fixed time interval set between opening of the fast opening valve and with connecting power to clamps of initiator. The pressure changes inside the chamber are recorded through an industrial pressure transducer with mA output and the maximum measurable overpressure value of 16 bar. The pressure transducer is powered by a stabilized DC source. Response time of the sensor is 1 ms and the current value is recorded through the datalogger. The measured sample was wood dust with a particle size of 500 μm; thus the distribution corresponded to the normal operation carpentry workshop. Characteristics of the sample (Table 1) were determined according to STN EN 15148 Solid biofuels. Determination of the content of volatile matter and STN EN 14775 Solid biofuels. Determination of ash content.

CHARACTERISTICS OF THE SAMPLE Table 1

Relative humidity	2,.7 % (105 °C/ 24 h)
Volatile matter	80.58 %
Ash	0.25 %
Fixed carbon	19.17 %

Measurement of parameters was carried out on the apparatus described above. The initiator was nitrocellulose with a weight from 1.19 to 1.22 g. As mentioned above, the weight of the nitrocellulose corresponded to the energy of initiator with the value of 5 kJ.

The nitrocellulose was divided into two equal parts and placed into initiator. Each of these parts was placed into the chamber of initiator at a side of the resistance wire. The pressure value in the tank of compressed air before the swirling was 8 bar for each measurement. The time interval between opening of the fast opening valve and the connecting power of clamps of the initiator was 300 ms. Starting of the whole mechanism (swirling of the dust and the initiation) was carried out manually with a switch. The pressure transducer was powered by a stabilized DC voltage source with the value of 17.5 V and a current limiter set to 1 A. The current in the circuit was measured by a data logger. The values were recorded at the rate of 500 values / second. The pressure changes during the explosion of dust clouds were measured at the following concentrations: 150 g / m^3, 200 g / m^3, 250 g / m^3, 300 g / m^3, 350 g / m^3, 400 g / m^3 and 450 g / m^3.

RESULTS AND DISCUSSION

The values obtained by the measurement of pressure depending on the time are shown in Figure 3.

The individual concentrations are colour coded on the graphs. However, since the value of the current on a pressure transducer oscillates around the medium value, the curves were smoothed with a FFT smoothing filter. Curve smoothing is achieved by removal of the Fourier component with a frequency higher than the limit frequency determined by the formula:

$$F = \frac{1}{n.\Delta T}, \qquad [1]$$

where: n is the number of data points and Δ T is the distance between two adjacent data points. For the purpose of this measurement, chosen was the value of n = 15.

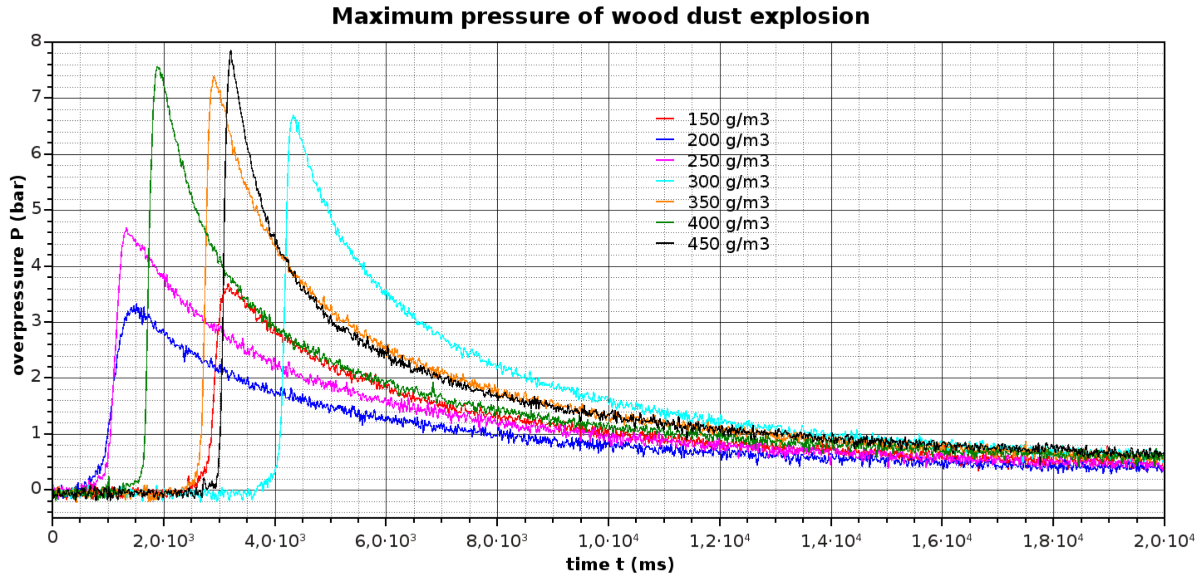

Fig. 3 *The maximum pressure obtained during the explosion of wood dust clouds depending on the concentration of dust*

The results allow us to conclude that the increasing concentration of the dust leads to the increase of the pressure value in the chamber. The increase of pressure is very low when the value of concentration is 350 g / m^3. It can be concluded that for the terms of the experiment (300 ms timing), the maximum pressure of 8 bar can be achieved.

From the measured results of time-pressure values measured in an explosion of wood dust clouds inside of the chamber, the rate of pressure rise can be further assessed. This value is also typical for the dust. This article presents the rate of pressure rise for the concentrations of 150 g / m^3, 250 g / m^3, 350 g / m^3 and 450 g / m^3. This value is also typical for the dust.

This article presents the rate of pressure rise for the concentrations of 150 g / m^3, 250 g / m^3, 350 g / m^3 and 450 g / m^3. Algorithm Fast Furier Transform - Low Pass Filter was used for the smoothing of curves. The frequency value was set at 10 Hz. Smoothed curves were subsequently derived, and the results are shown in Figures 4 – 7.

The value of explosion pressure rise per unit of time with increasing value of concentration increases, but this dependence is not linear. The highest value of explosion pressure rise is at the concentrations of 450 g / m^3 68 bar / s, and the lowest is at a concentration of 150 g / m^3 with increasing value of pressure rise 18 bar / s.

Table 2 shows the rate of exposure pressure rise of wood dust clouds for individual concentrations.

THE RATE OF EXPLOSION PRESSURE RISE EXPLOSION OF WOOD DUST CLOUDS AT A PARTICULAR CONCENTRATION

Table 2

Concentration (g/m3)	150	250	350	450
The rate of pressure increase (bar/s)	18	18	54	68

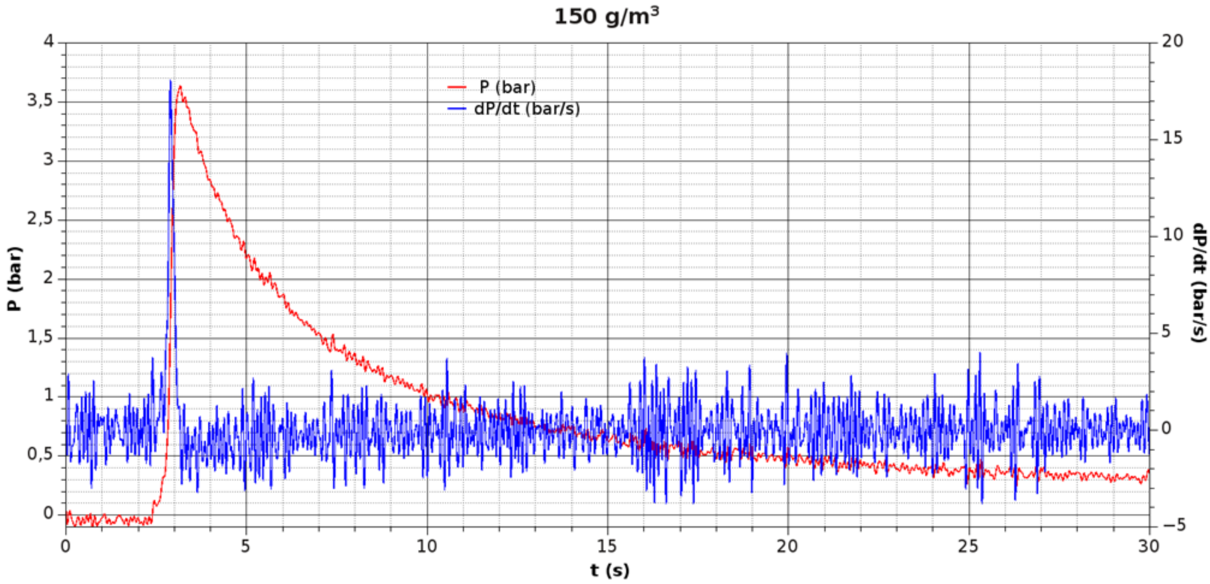

Fig. 4 *Dependence of explosion pressure of wood dust clouds in the concentration of 150 g / m*^{3} *and determination of explosion pressure rise*

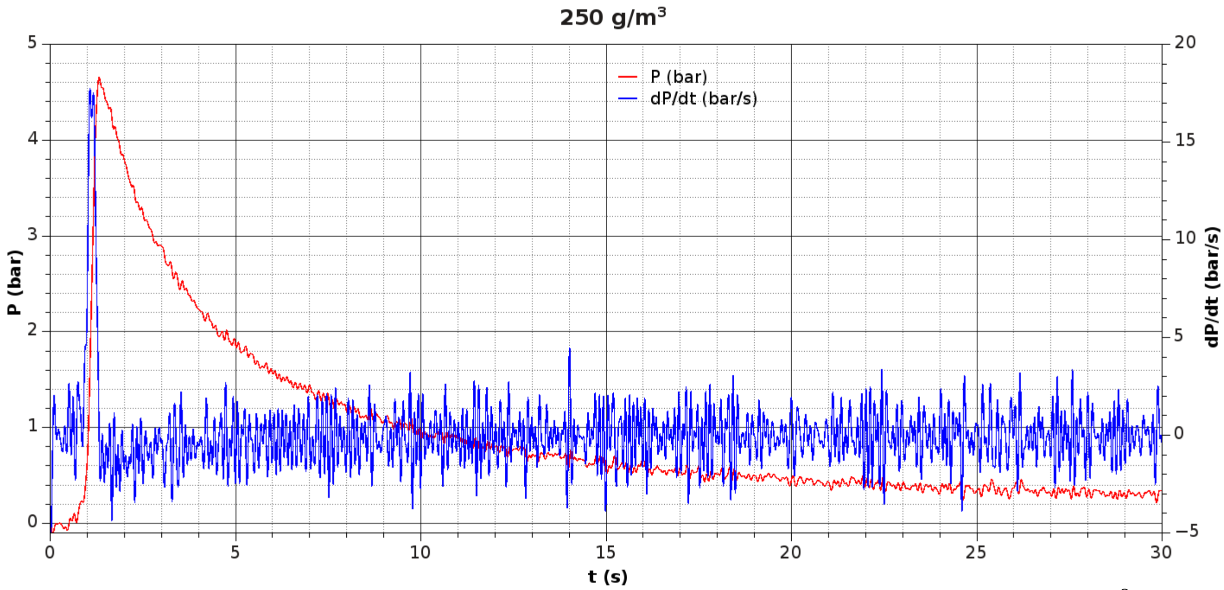

Fig. 5 *Dependence of explosion pressure of wood dust in the concentration of 250 g / m*^{3} *and determination of explosion pressure rise*

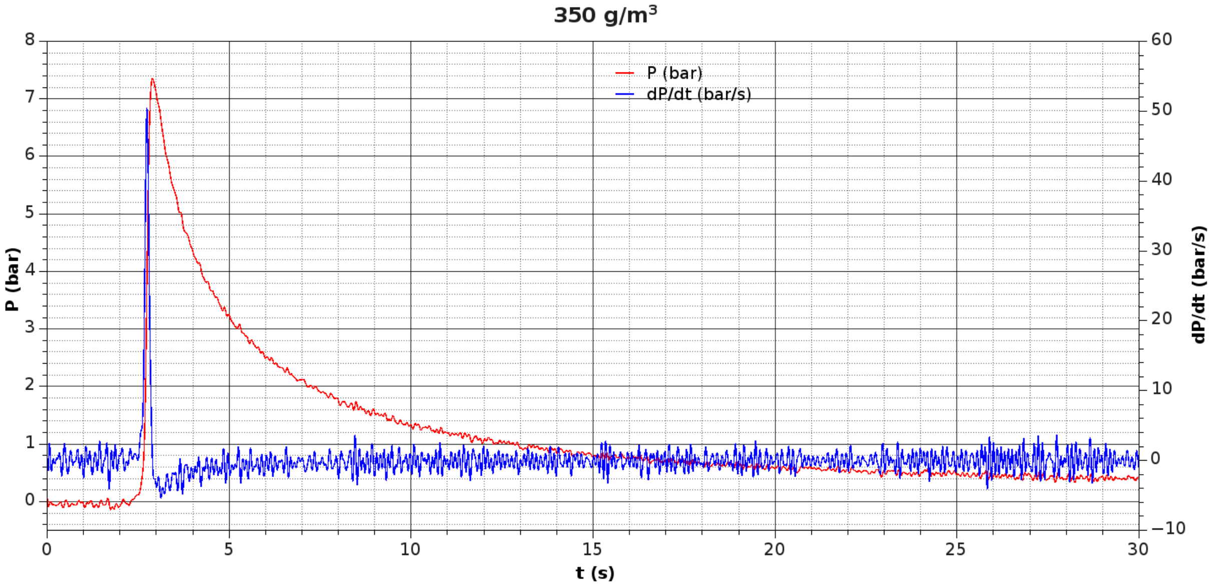

Fig. 6 *Dependence of explosion pressure of wood dust in the concentration of 350 g / m³ and determination of explosion pressure rise*

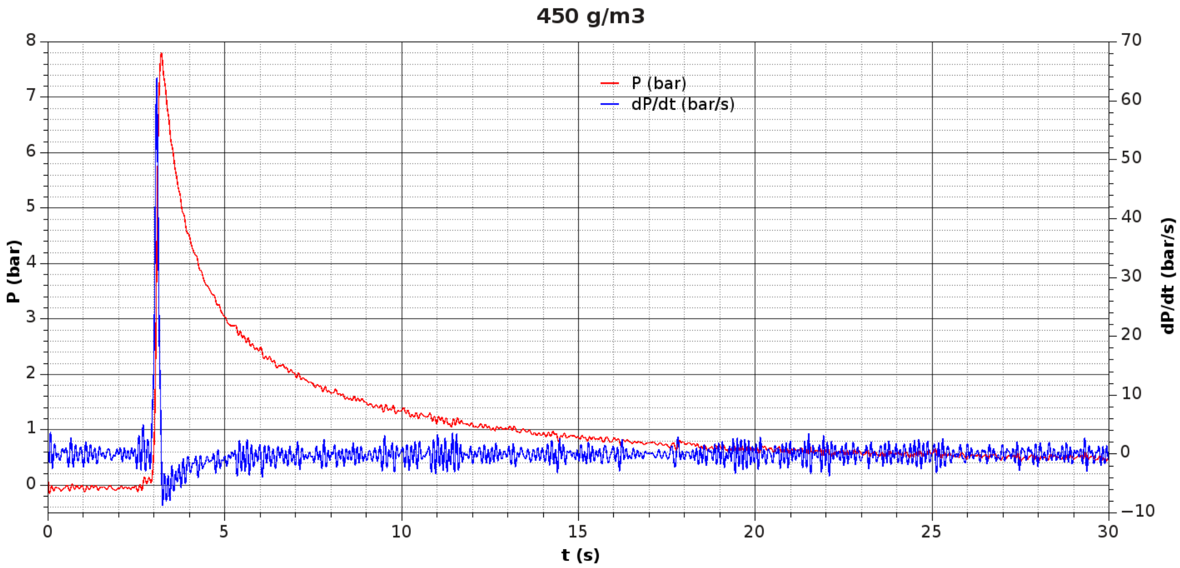

Fig. 7 *Dependence of explosion pressure of wood dust in the concentration of 450 g / m³ and determination of explosion pressure rise*

CONCLUSIONS

The testing of explosions of wood dust clouds by the device of the above-described parameters proved that the maximum value of the pressure was reached at the concentration of 450 g / m^3 and its value is 7.95 bar. The fastest increase of pressure was observed at the concentration of 450 g / m^3 and its value was 68 bar / s. Further research will focus on optimizing the system configuration with the aim of achieving the ideal conditions for the dust clouds and explosions, and also for the achievement of the maximum parameters of explosions.

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References:

1. KALOUSEK, J. 1999. *Principles of physical chemistry of combustion, explosion and fire fighting.* Ostrava: SPBI, 203 p. ISBN 80-86111-34-2
2. PALMER, K. N. 1993. *Dust Explosions and Fires*. Londýn: Chapman and Hall, 350 p. ISBN 978-0412354205
3. STN EN 14034-3+A1:2012 *Determination of explosion characteristics of dust clouds. Part 3: Determination of the lower explosion limit LEL of dust clouds*
4. ABBASI, S. A. 2007. Dust explosions – Cases, causes, consequences, and control. *Journal of Hazardous Materials*. Elsevier. ISSN: 0304-3894
5. LEES, F. P. 2005. *Loss Prevention in the Process Industries*.vols*, 2*. Oxford: Elsevier /Butterworth-Heinemann. ISBN 978-0408106979
6. CASHDOLLAR, K. L. 2000. Overview of dust explosibility characteristics. In: *Loss Prevent. Process Ind.*, 13, pp. 183–199. ISSN: 0950-4230
7. DAMEC, J. 1993. Risk of industrial dust explosions (Part 4). In: *150 Fire*, No. 6. ISSN 0682-8467
8. SIWEK, R. 1996. Determination of technical safety in dices and factors influencing hazard evaluation of dusts. In: *Loss Prevent. Process Ind.,* 9, pp. 21–31. ISSN: 0950-4230
9. PASTIER, M. 2014, *Study of flammability of combustible organic dusts.* [Dissertation Thesis]. Trnava: MTF STU, 104 p.

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