STUDY OF FIRE CHARACTERISTICS OF INDUSTRIAL DUST

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Abstract

The article deals with the determination of fire characteristics of industrial dust samples. Particle size granulometry and determination of explosion parameters according to EN 14034 (Lower Explosion Limit LEL, P_{max} , K_{st}) are presented. The minimum ignition temperatures of the dust layer and dispersed dust from the hot surface according to EN ISO / IEC 80079-20-2: 2016 were measured. It was found that LEL is 60 g.m^{-3} , P_{max} is 8.61 bar, and K_{st} is $89 \text{ bar.s}^{-1} \text{ m}$. The minimum ignition temperature (MIT) of dust layer is 280°C and the minimum ignition temperature of dispersed dust is 400°C .

Key words

Dust layer, dust explosion, minimum ignition temperature, dust cloud

INTRODUCTION

In almost all industrial plants where mechanical processes such as cutting, grinding, milling, slicing etc. of solids are being carried out, dust starts accumulating. Its presence gives rise to a hazard, as the appropriate ignition sources can cause fire or explosion of dust, which may as a consequence lead to death or body harm. Moreover, those phenomena can cause considerable property losses. In the event of a fire, the most frequent cause of death or injury and loss of property is thermal radiation and toxic products of combustion as well as thermal decomposition. In case of explosion, this comprises a pressure wave and fragments of materials. [1] Many scientific papers ([2, 3, 4, 5, 6, 7]) are concerned with investigating the fire characteristics of industrial dust.

Sample preparation

A sample of industrial dust arising from the sanding of wood veneer was supplied in a powder form. The sample did not require any particle size preparation (milling). The sample was subjected to sieving to obtain the fractions needed to determine MIT and to determine the weight fractions of the individual fractions.

Determination of explosion characteristics

For measurement of explosion characteristics, a modified chamber KV 150-M2 was used. Dust clouds in this unit are carried out mechanically. From the tank of the volume 5.5 litres, compressed air is transmitted by fast opening of an electromagnetic valve to inner space of the chamber of 291 litre volume. The sample is located on a plate and spread by the compressed air at the pressure of 9.5 bar. The compressed air is directed to the sample through the metal profiled sheeting. The sample is ignited by a chamber nitrocellulose igniter after the spreading the sample. The igniter works with a fuse head. Immediate ignition of nitrocellulose is achieved by the power source with parameters 60 V DC and 5.5 A, which is supplied to the fuse head and results in an immediate burning. Ignition energy of the nitrocellulose used in the initiator is 2x5 kJ.

Ignition of the dust and dispersion of the dust is timed using a solid state timing relay. The relay is set to a fixed time interval between opening the fast opening valve and with the connecting power to the clamps of initiator. Time delay was set on 240 ms. The pressure changes inside the chamber are recorded through pressure transducer of the voltage output (0 - 10 V) and the maximum measurable overpressure value of 20 bar. The pressure transducer is powered by a stabilized 24 V DC source. Response time of pressure transducer is 0.5 ms and the current value is recorded through the datalogger. The measured sample was industrial dust. Particle size of the sample is listed in Table 2. Measurement of parameters was carried out on the apparatus described above. The igniter was nitrocellulose of a weight from 1.25 g. The voltage in the circuit was measured by a high-speed data logger. The values were recorded at the rate of 10 000 values/second. Recording of the pressure changes during the explosion of dust clouds was measured within the concentrations range 60 - 1000 g/m³. [8]

Determination of the minimum ignition temperature of a dust cloud

Small quantities of dust were blown through a heated furnace and ignition was detected by visual inspection. The test material was dispersed in the furnace by an air blast and the dust quantity was from 0.1 and 0.2 g. The dust was dispersed by the air at the pressure of 10, 20 and 50 kPa. The first test was performed at the temperature 450 °C and pressure 50 kPa.

If a burst of flame was seen below the end of the furnace tube, it was considered as an ignition. The minimum ignition temperature was recorded as the lowest temperature of the furnace where ignition was obtained using the above-mentioned procedure minus 20 K for furnace temperatures above 300 °C and minus 10 K for furnace temperatures at or below 300 °C. The particle size of the sample was below 71 µm. [9]

Determination of the minimum ignition temperature of a dust layer

The apparatus consists of a heated plate and a dust ring. The heated surface consists of a circular metal plate and provides a working area of 200 mm in diameter and not less than 20 mm in thickness. The heated surface and its control device satisfy the following performance requirements:

- the heated surface is capable of attaining the maximum temperature of 400 °C,
- the temperature of the heated surface is constant within ± 5 K thorough the period of the test,
- a thermocouple is connected to a temperature recorder to record the temperature of the surface during the test.

The dust layer was formed without compressing the layer. The ring diameter was 100 mm and the depth of the ring was 5.0 mm $\pm$ 0.1 mm.

The dust layer temperature was measured within the layer at a height of 3 mm from the surface of the plate at the centre of the dust layer.

Ignition was considered to have occurred if:

- a visible glowing or flaming is observed; or
- a temperature of 450 °C is measured in the dust layer; or
- a temperature rise of 250 K above the temperature of the heated plate is measured in the dust layer.

If no further temperature increase was apparent after a period of 30 min. the test was terminated and repeated at a higher temperature. Testing was continued until the temperature was found to cause ignition in the layer. The particle size of sample was below 200 µm. [9]

RESULTS AND DISCUSSION ON RESULTS

Characterisation of sample

The sample was used as supplied. Tab. 1 shows the particle size distribution of the industrial dust sample with the median value and weighed average particle size.

Table 1 Particle size distribution of industrial dust sample (total mass of sample for sieving 228.32 g)		
Particle size	Weight of fraction [g]	Fraction [%]
> 500 µm	6.28	2.75
250 – 500 µm	3.51	1.54
200 - 250 µm	2.56	1.12
150 - 200 µm	3.91	1.71
90 - 150 µm	10.35	4.53
56 - 90 µm	8.20	3.59
56 – 71 µm	131.13	57.43
0 - 56 µm	62.38	27.32
median value:	50 µm	
average particle size	77.5 µm	

Explosion characteristics

The values of pressure depending on the time which were obtained by measurement are shown in Figures 1 and 2. From the results suggest that with increasing the concentration of the dust, the pressure value and the pressure rise value in the chamber also increase.

Fig. 1 Determination of the maximum explosion pressure P_{max} and Lower Explosion Limit (LEL) during explosion of industrial dust sample

Fig. 2 Determination of the maximum rate of pressure rise of industrial dust sample at concentration 750 g.m^{-3}

Table 2 shows explosion characteristics of industrial dust clouds at various concentrations.

Table 2 The explosion characteristics of sample		
Concentration (g/m³)	Sample 1	
	P_{max} (bar)	dP/dt (bar.s⁻¹)
60 (att. 1)	0.36	–
60 (att. 2)	0.33	–
60 (att. 3)	0.26	–
100	1.42	–
150	3.08	6.83
250	6.96	59.91
500	8.39	69.34
750	8.61	134.34
1000	8.49	113.32

$$K_{st} = dP/dt_{max} \times \sqrt[3]{V} = 134,34 \times \sqrt[3]{0,291} = 89,0 \text{ bar.s}^{-1}.\text{m} \quad (1)$$

The minimum ignition temperature of dispersed dust

Table 3 shows the results of determination of MIT of dispersed industrial dust sample of 02 g and air pressure of 20 and 50 kPa.

Table 3 Results of MIT of the dispersed industrial dust sample tests			
Furnace temperature [°C]	Sample weight [g]	Dispersing air pressure [kPa]	Test results
430	0.2	50	burning
430	0.2	20	burning
420	0.2	50	burning
420	0.2	20	without burning
410	0.2	50	without burning
410	0.2	20	without burning

The minimum ignition temperature of dust layer

Table 4 shows the results of determination of MIT of a 5 mm layer of the industrial dust sample. Figures 3 and 4 show the measured temperatures of a 5 mm industrial dust layer at 300 °C and 310 °C. Figure 5 shows decomposition of the industrial dust sample at 300 °C.

Fig. 3 Measured temperatures of a 5 mm industrial dust layer at 300 °C

Fig. 4 Measured temperatures of a 5 mm industrial dust layer at 310 °C

a) Industrial dust layer sample at 300 °C, time 18 s

b) Industrial dust layer sample at 300 °C, time 2 min. 54 s

c) Industrial dust layer sample at 300 °C,
time 3 min. 51 s

d) Industrial dust layer sample at 300 °C,
time 3 min. 57s

e) Industrial dust layer sample at 300 °C,
time 4 min. 34 s

f) Industrial dust layer sample at 300 °C,
time 4 min. 59 s

Fig. 5 Decomposition of a 5 mm sample of industrial dust layer at 300 °C

Table 4 Results of MIT of 5 mm layer of an industrial dust sample tests	
Temperature of heated plate [°C]	Test Results
270	Without burning during 30 min. test
280	Without burning during 30 min. test
290	Burning after 10 min., $\Delta T = 100$ K
300	Burning after 5 min., $\Delta T = 190$ K
310	Burning after 3 min., $\Delta T = 215$ K

CONCLUSIONS

Testing the fire characteristics of an industrial dust sample revealed that the maximum value of the explosion pressure of the sample was attained at the concentration of 750 g / m^3 and its value was 8.61 bar.

Explosion constant K_{st} of the industrial dust sample was calculated for the concentration of 750 g/m^3 and its value was $89 \text{ bar.s}^{-1}.\text{m}$.

The MIT of the dispersed industrial dust sample was 400 °C and the MIT of the 5 mm layer of industrial dust sample was 280 °C.

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References

- [1] PÓŁKA, M., WOLIŃSKI, M., KUKFISZ, B., SALAMONOWICZ, Z. 2014. Analysis of susceptibility to ignition of dust layer and dust cloud of selected hardened unsaturated polyester resins, *Polimery*, **59**(11-12), 805-810. ISSN 0032-2725
- [2] TAVEAU, J. 2014. Application of dust explosion protection systems. *Procedia Engineering*. **84**, 297 – 305. ISSN 1877-7058
- [3] AMYOTTE, P. R., ECKHOFF, R.K. 2010. Dust explosion causation, prevention and mitigation: An overview. *Journal of Chemical Health & Safety*, **17**(1), 15 – 28. ISSN 1871-5532
- [4] EBADAT, V. 2010. Dust explosion hazard assessment. *Journal of Loss Prevention in the Process Industries*. **23**, 907 – 912, ISSN: 0950-4230
- [5] CHIN, Y. S., DARVELL, L. I., LEA-LANGTON, A. R., JONES, J. M., WILLIAMS, A. 2016. Ignition Risks of Biomass Dust on Hot Surfaces. *Energy and Fuels*, **30**(6), 4398-4404. ISSN 0887-0624
- [6] AJRASH, M. J., ZANGANEH J., MOGHADERI, B. 2016. Experimental investigation of the minimum auto-ignition temperature (MAIT) of the coal dust layer in a hot and humid environment. *Fire Safety Journal*, **82**, 12-22. ISSN 0379-7112
- [7] BO, M., CLERICO, M., POGNANT, F. 2015. Cone-calorimeter tests of rice dusts explosiveness. *Geoingegneria Ambientale e Mineraria*, **146**(3), 15-22. ISSN 1121-9041
- [8] EN 14034-3+A1:2012 *Determination of explosion characteristics of dust clouds. Part 3: Determination of the lower explosion limit LEL of dust clouds*
- [9] EN ISO/IEC 80079-20-2:2016 *Explosive Atmospheres - Part 20-2: Material characteristics - Combustible dust test methods*

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