FIRE CHARACTERISTICS OF POLYETHYLENE DUST

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Abstract

Dust is a product or by-product in many industries. To ensure effective measures of explosion prevention, it is necessary to know the fire properties of dispersed and settled dust. These parameters cannot be calculated, but can be determined on the base of measurements in standard equipment. The article deals with the measurement of fire properties of polyethylene. The values of the minimum ignition temperature of settled and dispersed dust (MIT) and the values of explosion characteristics of polyethylene dust cloud lower explosion limit (LEL), maximum pressure P_{max} and maximum rate of pressure rise $(dp/dt)_{max}$ were measured. The measurements were performed on the equipment according to the STN EN 80079-20-2: 2016 Standard Explosive atmospheres - Part 20-2: Material characteristics - Combustible dust test methods and according to the STN EN 14034 + A1: 2011 Standard Determination of explosion characteristics of dust clouds. The MIT of the settled dust was not determined (the sample melted), the MIT of the dispersed dust was 435 °C. The maximum explosion pressure P_{max} reached 7.0 bar, and the maximum rate of pressure rise dP/dt was 37.5 bar.s⁻¹.

Keywords

Fire characteristic, dust cloud, dust explosion, polyethylene

INTRODUCTION

Wherever flammable dust is present, there is a potential risk of fire or explosion. With the help of high-pressure technology, low-density polyethylene is produced in the LDPE 4 production unit in Slovnaft a.s. (Slovakia). During its production, the generated explosive dust can cause a fire or explosion. To prevent damage, it is necessary to know the fire and explosion parameters of such polyethylene. Based on the fire characteristics, it is possible to prevent material damage and take effective explosion prevention measures.

Dust

Dust occurs in two states: settled dust (airgel) and dispersed dust (aerosol). Dust consists of particles up to 500 μm in size [1] that are formed in industrial practice mostly by mechanical means. As the particle size decreases, the explosiveness increases and the minimum ignition temperature (MIT) decreases. Particles smaller than 100 μm are generally considered hazardous. Above 100 μm , the flammability and explosiveness of dust decreases rapidly [2].

Combustion and explosion of dust

The burning of polymers is a complex chemical chain reaction. The polymer decomposes at high surface temperatures and diffuses to the flame front where it completely decomposes into a monomer. At the top of the flame, the gases react exothermically with oxygen, forming a flame. During gas formation, the oxidation of the polymer surface has a significant effect on the combustion mechanism of the polymer [3].

A dust explosion requires five factors (Figure 1):

- fuel - dust,
- an oxidising agent,
- a source of ignition,
- mixing - swirling to form a dispersion,
- and an enclosed space [4].

Figure 1 Explosion pentagon [5]

Fire characteristics of dust

Knowledge of fire characteristics is important for assessing the fire hazard of a material or product. Fire characteristics are numerical values that describe the behaviour of substances or materials during the formation and course of combustion until its termination [6]. In the experiment described in this article, selected characteristics of polyethylene dust were determined. The measurement results are shown in Tables 3 and 4.

Table 1 Fire characteristics of settled and dispersed dust [7]	
Settled dust	Dispersed dust
Minimum ignition temperature of settled dust [°C]	Minimum ignition temperature of dispersed dust [°C]
Flame rate [mm.s ⁻¹]	Maximum explosion pressure [bar]
Critical heat flux [W.m ⁻²]	Maximum rate of pressure rise [bar.s ⁻¹]
Critical degradation temperature [°C]	Lower explosion limit [g m ⁻³]
Heat of combustion [MJ.kg ⁻¹]	Limiting oxygen concentration [Vol. % O ₂]
Oxygen number [Vol. % O ₂]	Minimum initiation energy [mJ]

MATERIALS AND METHODS

A sample of low-density polyethylene dust came from the LDPE4 production unit of SLOVNAFT a.s. A dust sample was obtained from the silo which was cleaned by water during rinsing. The moisture content of the low-density polyethylene was 1 wt. %. The melting point of LDPE is 100-120 °C. The sample was dried in a laboratory oven at 80 °C for two weeks.

The proportion of dimensional fractions of the polyethylene sample is determined by sieve analysis. The analysis procedure was performed according to STN ISO 3310-1: 2007-03 (25 9610). The analysis was performed on Retsch AS 200, an automatic vibrating sieving machine. A set of stainless-steel sieves with the sieve openings described in Table 2 was used. The sieving time was 15 min. with an amplitude of 2 mm/G. The results of the sieve analysis of the LDPE sample are shown in Table 2. The median value of 145 µm was determined from the measured values.

Table 2 Proportion of particles sizes in the sample	
Particle size [µm]	Proportion of particles sizes in the sample [%]
all	100.000
0 – 500	95.120
0 – 250	72.877
0 – 200	58.494
0 – 150	42.820
0 – 90	21.868
0 – 71	12.787
0 – 56	6.969

MIT measurements of dispersed dust were performed on a standardized equipment, Godbert-Greenwald furnace, Figure 2. [8] Apparatus for MIT of dust layer consists of a heated plate and a dust ring 5 mm in height. The explosion parameters were determined in the KV 150M2 explosion chamber, Figure 3.

Figure 2 Godbert-Greenwald furnace for determination of minimal ignition temperature of settled dust [8]

Figure 3 KV 150M2 explosion chamber (1 - lid, 2 - air flow reverser, 3 - dispersing plate, 4 - stand, 5 - igniter, 6 - manometer, 7 - air pressure vessel, 8 - dispersing valve)

RESULTS AND DISCUSSION

The MIT of settled dust was measured according to the STN EN 80079-20-2:2016 Standard [9]. At 375, 388 and 400 °C, no decay and heating of the polyethylene sample was observed during the 30 minutes of measurement. The polyethylene sample melted at all temperatures.

Determination of MIT of dispersed dust was performed according to the STN EN 80079-20-2: 2016 Standard [9, 10]. Air pressures of 20 kPa and 50 kPa were used to disperse the sample. A sample of polyethylene dust was placed in the dust container. The MIT of the dispersed dust was measured at the furnace surface temperatures of 450, 455, 465 and 475 °C. The sample weight was calculated based on the highest value of the explosion pressure $P_{\max}$. The highest value of the explosion pressure was reached at a concentration of 150 g.m⁻³ and the optimal weight of the polyethylene sample was 0.04 g. A polyethylene fraction of less than 71 µm was used to determine the MIT of the dispersed dust. During the test, an explosion flame was observed at the lower end of the furnace tube.

The minimum ignition temperature was determined to be the lowest temperature of the furnace at which ignition occurred, reduced by 20 °C. The minimum ignition temperature of the dispersed dust was 435 °C.

A KV 150M2 explosion chamber was used to determine the lower explosive limit of the sample, the maximum overpressure and the maximum pressure rise. The determination of explosion characteristics was performed according to the STN EN 14034 + A1: 2011 Standard [10]. The measurement was performed at the dust concentrations of 60, 100, 125, 150, 200, 250 and 500 g.m⁻³, Figure 4, Table 3. The value of the lower explosive limit (LEL) of the polyethylene sample is 60 g.m⁻³. The maximum value of the pressure at the explosion of 7.00 bar was at a concentration of 150 g.m⁻³, Figure 5. The maximum value of the pressure rise during the explosion was 37.5 bar.s⁻¹. The explosion constant K_{st} has a value of 24.9 bar.m.s⁻¹. Based on the K_{st} value, the polyethylene sample was classified in class St 1.

Figure 4 Maximum pressure of LDPE dust at concentrations 60, 100, 125, 150, 200, 250 and 500 g.m⁻³

Figure 5 Maximum pressure rise rate and max. overpressure of LDPE dust at 150 g.m^{-3}

Table 3 Explosion parameters of LDPE measured in KV 150M2 chamber		
Concentration [g.m⁻³]	Overpressure P [bar]	Rate of pressure rise dP/dt [bar.s⁻¹]
60	0.51	< 1
100	1.65	3.60
125	3.12	6.68
150	7.00	37.50
200	4.90	24.05
250	6.59	27.58
500	6.18	27.66

The results obtained in the experimental determination of fire parameters of low-density polyethylene dust were compared with the table values in the IFA database [11] for low-density polyethylene dust (median 135, 150 μm), with the values given in MSDS Bralen and the values given in the explosion protection document for LDPE4 (Table 4).

Table 4 Comparison of measured results with database values					
Fire technical parameter	Material safety data sheet - Bralen + , Slovnaft, a.s.	Explosion prevention document for LDPE4, Slovnaft, a.s.	IFA database, median 135 µm	IFA database, median 150 µm	Measured results, median 145 µm)
Ignition temperature of settled dust [°C]	350	melts	melts	melts	melts
Ignition temperature of dispersed dust [°C]	445	350	470	480	435
Maximum explosion pressure [MPa]	-	0.9	0.78	0.74	0.70
Maximum pressure rise rate [bar.s ⁻¹]	-	-	-	-	37.5
Explosion constant K _{st} [MPa.m.s ⁻¹]	-	15.6	56	54	24.85
Lower explosion limit [g.m ⁻³]	100	16	60	125	60
Explosion class	-	-	St1	St1	St1

CONCLUSION

Fire characteristics are important for the fire safety assessment. They are used for qualitative comparison of flammability and explosiveness of different dusts. Based on the fire characteristics, it is possible to propose effective measures to reduce the risk of explosion and fire.

By measuring fire characteristics of polyethylene sample we found that the MIT value of settled dust cannot be determined (polyethylene is melting), the MIT value of dispersed dust is 435 °C, maximum explosion pressure is 7.00 bar, lower explosion limit is 60 g.m⁻³ and explosion value K_{st} constant is 24.9 bar.m.s⁻¹.

Comparison of the results with the data in the database and the MSDS shows that the measured values in each database vary. The differences between the measured values are due to the different properties of the polyethylene samples, e.g. particle size, degree of polymerization, etc.

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References

- [1] LEES, F. 2005. *Loss Prevention in the Process Industries*, Vol. 2. Oxford, Elsevier, Butterworth-Heinemann. ISBN 978-0408106979.
- [2] DAMEC, J. 1998. *Protivýbuchová prevence (Explosion prevention)*. 1998. 1st edition SPBI SPEKTRUM 8. Ostrava: Sdružení požárního a bezpečnostního inženýrství (Association of fire and safety engineering), 288 p. ISBN 80-86111-21-0.
- [3] MIDDLEMAN, S. 1977. *Fundamentals of polymer processing*. New York: McGraw-Hill College.. ISBN 978-0070418516.
- [4] Eckhoff, Rolf, K. 2003. *Dust explosion in the process industries*. s.l. : Gulf Professional Publishing. ISBN: 0-7506-7602-7.
- [5] ŠIMONÍKOVÁ, I. 2014. *Způsoby ochrany před výbuchem – část 1 (Methods of explosion protection – part 1): Primární protivýbuchová ochrana (Primary explosion protection)*. [cit.2020-01-02]. Available at: <https://www.tzb-info.cz/pozarni-bezpecnost-staveb/10972-zpusoby-ochrany-pred-vybuchem-cast-1-primarni-protivybuchova-ochrana>.

- [6] MASŘÍK, I. 2003. *Plasty a jejich požární nebezpečí (Plastics and their fire prevention)*. OSTRAVA: Edice Spektrum SPBI. ISBN 80-86634-16-7.
- [7] TUREKOVÁ, I. 2008. Význam požiaro-technických vlastností potravinárskych prachov v praxi. (Significance of fire properties of food dusts in practice.) In: *Proc. Of VIII. Conference, Management of environment*). Žilina: Strix et VeV. ISBN 978-80-89281-34-3.
- [8] ECKHOFF R. K. 2019. *Origin and development of the Godbert-Greenwald furnace for measuring minimum ignition temperatures of dust clouds, Process Safety and Environmental Protection*, 129 p. 17–24.
- [9] STN EN 80079-20-2:2016 Explosive atmospheres - Part 20-2: Material characteristics - Combustible dust test methods
- [10] STN EN 14034+A1:2011 Determination of explosion characteristics of dust clouds.
- [11] BECK H., GLIENKE N., MOHLMANN C. 1997. *Combustion and explosion characteristics of dusts, Hauptverband der gewerblichen Berufsgenossenschaften*, pp. 471. ISBN 3-88383-469-6.

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