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THE EXPLOSION HAZARD RESEARCH OF THE POLYETHYLENE DUST

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Research article

Abstract: The aim of the article is to point out the dangers arising from the properties of plastic dust and what influence its properties have on the origin and course of the explosion. The present project analyzed the sample of polyethylene dust,by-product of granulate production and storage. The explosion tests were performed on containers of a similar shape to those found in a plants. By examining the properties of plastic dust and its behavior in the event of an explosion we have observed that the risk of explosion in technological equipment can not be underestimated. Knowledge about explosiveness of dust samples will be used in comprehensive safety solution of a particular technological node.

Keywords: Polyethylene dust, Maximum explosion pressure, Maximum rate of pressure rise, Constant for dusts, Flame volume.

Introduction

The dust consists of solid particles smaller than 0.5 mm. For fibers, the fiber length can be greater than 0.5 mm. Some atypical materials can behave like dusts even with larger particle sizes. The term dust thus includes ground solids referred to as powder, flour, fiber fragments and the like (Orlíková and Štroch, 1999).

Dust is considered explosive if, after ignition of a mixture of dust and air with a suitable source, the flame spreads in combination with an increase in pressure (Bartknecht, 2011).

The basic condition for the occurrence of an explosion is a substance with its properties, which represents the danger of an explosion. Factors responsible for the occurrence as well as for the spread of the explosion enter this condition. Relevant properties of dusts are given by fire-technical characteristics, are determined experimentally in laboratories and are not physical constants (Damec, 2005), therefore the given substance may not show the same values of fire-technical characteristics if it is produced and processed in different parts technological equipment and under different operating conditions.

In order to assess the danger of explosion of plastic dust, a part of the technology was selected, in which plastic granulate is transported and stored together with the dust. The subject of the investigation was dust, which is a by-product of the production and storage of granules.

The explosion hazard research was based on testing samples of polyethylene dust and thus obtain explosion characteristics of dust, their respective properties.

Combustible dust is only capable of explosion to a limited extent, given the lower (*LEL*) and upper (*UEL*) explosion limits. Explosion limits are the first to warn of an imminent danger. The lower explosion limit characterizes the degree of danger of explosive dusts in production processes (Orlíková and Štroch, 1999).

The maximum explosion pressure p_{max} represents the maximum value of the increased pressure generated in a closed container by the explosion of an explosive atmosphere under the specified test conditions and under normal atmospheric conditions. It is actually the maximum value of the explosion pressure p_{max} determined by tests in the range of explosion of dust concentration (STN EN 14034-1 + A1 (38 9684), 2011).

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The maximum rate of pressure rise $(dp/dt)_{max}$ is the maximum value of pressure increase per unit time during explosions of all explosive atmospheres in the range of explosion of flammable substance in a closed container under specified test conditions (STN EN 14034-2 + A1 (38 9684), 2011).

According to the values of the constant for dusts, combustible dusts are classified into three dust explosion classes:

- St 1 has K_{St} values 0 - 200 bar.m/s;
- St 2 has K_{St} values of 200 - 300 bar.m/s;
- St 3 has K_{St} values above 300 bar.m/s (Bartlová and Damec, 2002).

The reduced explosion pressure p_{red} is the pressure created by the explosion of an explosive atmosphere in a container protected either by the detonation of the explosion or by the suppression of the explosion (Damec, 2005).

The concentration of the explosive mixture affects the values of p_{max} and $(dp/dt)_{max}$. With increasing concentration, the maximum explosion pressure and the maximum rate of pressure rise increase (Eckhoff, 2003).

With decreasing particle size:

- the maximum explosion pressure increases (STN EN 14034-1 + A1 (38 9684), 2011),
- the limit oxygen concentration decreases (STN EN 14034-4 + A1 (38 9684), 2011; Pang et al., 2019),
- the maximum rate of pressure rise during an explosion increases (STN EN 14034-2 + A1 (38 9684), 2012).

The force and velocity of the explosion increases with increasing degree of fineness of the material. The reaction rate increases with temperature (Damec, 2005). Pressure reduction reduces maximum explosion parameters (Bartknecht, 2011). With increasing initiation energy, the maximum rate of pressure rise also increases (Damec, 2005).

With increasing container volume:

- the maximum explosion pressure does not change,
- the rate of pressure rise decreases.

However, this law applies to dust-air mixtures from 40 L. This law does not apply to oblong vessels and pipes. (Bartlová and Damec, 2002).

The maximum explosion pressure in closed, almost spherical vessels of sufficient size ($V \geq 20$ L) is independent of the volume. However, the maximum pressure increase depends on the volume. It decreases with increasing volume in accordance with cubic law. The K_{St} value resulting from this law is specific to the dust and test method, but is independent of the vessel size for volumes $V \geq 20$ L (Bartknecht, 2011).

Material and methods

The large-scale explosion tests was based on results of the laboratory measurements. The polyethylene dust samples were taken from bigbags, where dust from dedusting and storage silos of the polyethylene granulate is stored. Only 1 sample polyethylene dust was used for further measurements in big volume. The chosen sample had the highest explosion parameters in laboratory measurement.

Two test vessels with different volumes, a vessel of 1.35 m^3 ($N1$) and a vessel of 5.45 m^3 ($N2$), were used to test the dust of PE sample in large-scale explosion tests. The vessels were equipped with multipoint measurements of explosion pressure. The dust was weighed and poured into spreading tanks with a volume of 5.4 L a 12 L, which were pressurized to 20 bar with air, spreading nozzles were used for spreading. Due to clogging of the spreading nozzles, the method had to be modified during the tests and the nozzles had to be removed from the test vessels. After agitation, the mixture was initiated with energy from pyrotechnic initiators with an energy of 5 kJ each (Janků j and Bernatík, 2018). For testing, a venting area was installed on the upper flanges of the vessels, a venting area DN 250 was used on $N1$ and two dimensions were used on $N2$ - the venting area DN 585 or DN 775. The pipes with nominal diameter DN 150 and lengths of 3, 6 and 10 m were incorporated into the test set-up.

All tests were performed at ambient conditions, barometric pressure and ambient temperature. A pressure measuring set from Kistler was used, the storage of measured values was ensured by means of a Cronos FLEX data logger from IMC. The tests were recorded using two high-speed cameras.

Results

Sample of polyethylene dust was tested in large-scale explosion tests and trials. The basic fire-technical characteristics was obtained from the laboratory testing which are summarized in the tab. 1.

Tab. 1 Preview of explosion parametres PE sample in the laboratory measurements

Sample	**Medium size grain [mm]**	***LEL* ± 10% [g/m^3]**	**p_{max} ± 10% [bar]**	**K_{St} ± 20% [bar.m.s^{-1}]**	**$(dp/dt)_{max}$ ± 20% [bar/s]**	***E*1 < *MIE* < *E*2 [mJ]**	***Es* [mJ]**	***LOC* ± 1% [% obj.]**
PE sample 3	> 1	20.00	6.40	68.00	251	30 < 100	80	< 14.00

Large-scale explosion tests

The following types of large-scale explosion tests were performed for PE sample:

- maximum explosion pressure p_{max}, constant for dusts K_{max} and maximum rate of pressure rise in a closed vessel $(dp/dt)_{max}$,
- reduced explosion pressure, reduced rate of pressure rise $(dp/dt)_{red}$ and flame velocity in vessels with a venting area and with a pipeline connection.

Maximum explosion pressure and reduced explosion pressure

The aim was to determine the maximum explosion pressure and the maximum reduced explosion pressure on containers of a similar shape to those in the plant for the production of plastic granules and to compare them with the results obtained in laboratory testing. The intention was also to test and verify the effect of the installed anti-explosion measure on the vessel (venting area on the vessels) on the change of explosion pressure.

The measurements were performed at an optimal dust concentration of 750 g/m^3, which was based on the laboratory determination of p_{max}.

To determine the maximum explosion pressure and the constant for dusts PE sample, tests were performed in closed vessels (*N*1 and *N*2) with a volume of $N1 = 1.35$ m^3 and $N2 = 5.45$ m^3.

The reduced explosion pressure was measured on vessel *N*1 with a venting area DN 250, as well as on vessel *N*2 with a venting area DN 585 or DN 775 installed on the upper flanges of the vessels. An even lower reduced explosion pressure was achieved through the larger venting area. The aim was to get under the pressure resistance of the equipment in operation.

The results from the measurements of the large-scale PE tests are summarized in the tab. 2.

By measuring the explosion pressures on large vessels *N*1 and *N*2, it was found that pmax and K_{St} on equipment of larger volumes reach higher values compared to equipment in the laboratory, from which it can be concluded that the explosion pressure in operation equipment is likely to reach higher values such as values obtained from laboratory measurements.

By installing venting area on the vessels, we have become convinced that explosion-proof measures in the form of venting area are important. In the event of an explosion and the opening of the venting area at the same time, the device will be less stressed by the explosion pressure. The proposed venting area can achieve explosion control and thus prevent damage to the device, taking into account the existing pressure resistance of the device.

Explosion tests with installed piping

The aim of these tests was to measure and to obtain of the values of the maximum reduced explosion pressure in the vessel, the pipes and the flame velocity v_{ex} and to verify the influence of the installed pipes on their change. Pipes DN 150 with lengths of 3, 6 and 10 m were installed on test vessels *N*1 and *N*2:

- the first type of tests was to determine the effect of the length of the installed piping system on p_{red} without installing a venting area on the vessel,
- in the second type of tests, a venting area was installed on top of the explosion vessel.

The performed measurements show that with the length of the installed pipeline, the explosion pressure increases slightly (at the same point, for example 3 m, but at different lengths of pipeline). From a practical point of view, this indicates the need to protect these parts of the technological equipment as well as the adverse effects of the explosion.

Explosion tests in connected vessels

The aim of the tests was to test the possible transmission of the explosion and to determine the flame velocity v_{ex} in the pipeline and the pressure values of the explosion. The tests were performed on vessels *N*1 and *N*2 with a venting area installed at the top of the vessel, interconnected by pipes with a diameter of DN 150 and a length of 3, 6, 10 m.

The dust-air mixture was formed in both vessels, with the initiation of the agitated dust taking place in only one of the vessels. The transmission of the explosion was solved in both directions.

Tab. 2 Explosion parametres PE sample measured in vessels *N*1, *N*2 with pipes of length 3, 6, 10 m

No.	Type of device	Pipe length [m]	Type of device	p_{max} [bar]	(*dp*/*dt*) [bar/s]	p_{red} in *N*1 [bar]	p_{red} in *N*2 [bar]	p_{red} in pipe [bar]			v_{ex} [m/s]
								in length 3 m	in length 6 m	in length 10 m	
1.	**VA 20 autoclave**	X		6.400	251.00	X					
2.	***N*1**	X		7.170	74.201	X					
3.	***N*1 DN 250**	X			108.587	0.440	X				
4.	***N*1**	3	X		90.490	2.185	X	0.275	-	-	71.5
		6				2.175		0.640	0.210	-	111.5
		10				2.470		-	1.150	0.620	207.0
5.	***N*1 DN 250**	3	X		99.548	0.340	X	0.020	-	-	57.3
		6				0.365		0.305	0.020	-	117.5
		10				0.396		-	0.396	0.080	144.0
6.	***N*1 DN 250 initiation**	3	***N*2 DN 775**	X	171.930 (*N*1) 229.133 (*N*2)	0.985	0.459	0.441	-	-	35.5
		6 →				0.528	0.281	-	0.263	-	38.0
		10				0.300	0.239	-	-	0.255	36.0
7.	***N*2**	X		7.140	75.620	X					
8.	***N*2 DN 585**	X			160.905	X	0.660	X			
9.	***N*2 DN 775**	X			138.731		0.190	X			
10.	***N*2**	3	X		65.385	X	4.525	1.385	-	-	262.0
		6					4.615	2.210	1.390	-	267.5
		10					4.805	-	1.790	1.185	267.5
11.	***N*2 DN 775**	3	X		135.320	X	0.185	0.013	-	-	205.0
		6					0.170	0.160	0.014	-	132.5
		10					0.150	-	0.140	0.013	116.5
12.	***N*1 DN 250**	3	***N*2 DN 775 initiation**	X	152.377(*N*2) 159.261(*N*1)	0.865	0.225	0.590	-	-	43.5
		← 6				1.002	0.205	-	0.855	-	44.5
		10				0.888	0.218	-	-	0.133	63.0

Legend for tab. 2:

🟧 p_{red} measured on *N*1 or *N*2;
🟦 p_{red} measured on pipe length 3 m;
🟨 p_{red} measured on pipe length 6 m;
🟩 p_{red} measured on pipe length 10 m;
➡ Designation of the vessel with the first initiation and the direction of the spread of the explosion.

Initialization was first performed on vessel *N*1 and the explosion was transferred via pipeline to vessel *N*2, where a pressure drop was observed. Subsequently, the opposite possibility was tested, in which the initiation was performed on vessel *N*2 and the explosion was transferred via a pipeline to vessel *N*1, where an increase in pressure was observed. The flame velocity, the front of the flame was always measured from the vessel on which the first initiation was performed.

Explosion tests with connected vessels have shown that the propagation of an explosion from vessel *N*2 (larger volume) to vessel *N*1 (smaller volume) leads to a significant increase in reduced explosion pressure, despite the installed venting area on both vessels. The flame transfer in vessels connected by piping during explosion test is shown in fig. 1. In this testing, we have come to the conclusion that the installation of venting area, as a form of explosion protection, will not be quite sufficient and other elements will have to be used to ensure sufficient explosion protection.

Fig. 1 Example of flame transfer in vessels connected by piping during explosion tests

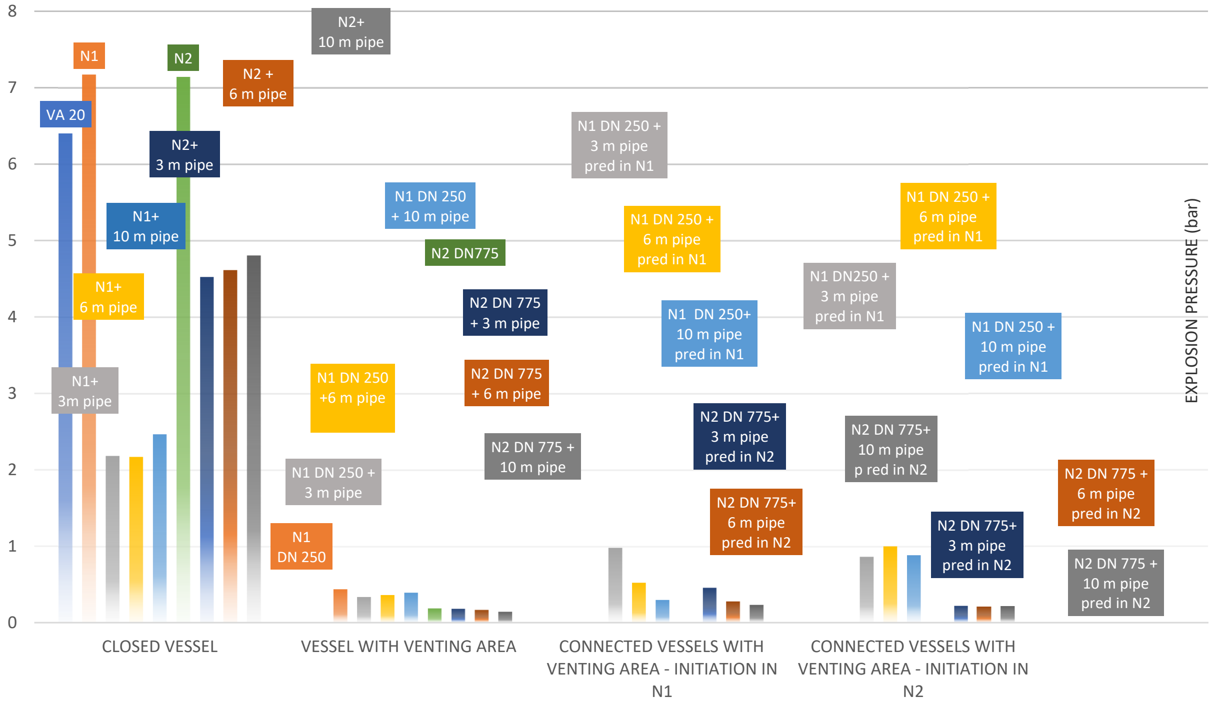

Fig. 2 Comparison of values of the explossion pressure (from tab. 2) in different vessels

Tab. 2 summarizes the results of the large-scale explosion tests, from which the differences in p_{max}, p_{red} and (dp/dt) values occurring in closed vessels and vessels with a venting area and with piping connected to the vessels can be easily seen. The v_{ex} flame velocity is for the connected pipe.

- Row 1 also summarizes the properties from the laboratory instrument VA-20; when compared with large-scale explosion tests, it is possible to see differences in the values of explosion parameters.
- The values of p_{max} were determined for the closed containers (rows 1, 2, 7).
- The values of p_{red} were determined for the vessels with an installed venting area (rows 3, 8, 9).
- In the case of connecting the piping to the vessel (rows 4, 5, 10, 11) were measured p_{red} on the vessel itself as well as on the connected piping.
- In the case of both vessels with venting area and interconnected by pipes (rows 6, 12), the pressure on both vessels was measured. In the first case (row 6), the dust-air mixture was initiated in *N*1 and spread through the pipes to *N*2. In the second case (row 12), the mixture was initiated in *N*2 and spread in the direction of *N*1.

The graphical representation of the obtained explosion pressures on the VA-20, *N*1 and *N*2 is expressed in the fig. 2.

Flame volume

During the large-scale explosion tests, we also made estimates on the volume of the flame that occurs during the explosion in the *N*1 and *N*2 vessels.

The flame volume was tested on a vessel *N*1 with the venting area DN 250 and *N*2 with the venting area DN 775 and a pipe DN 150 with a length of 6 m.

The flame volume increases with increasing the vessel volume and the size of the venting area. The flame volume is always greater in the case of flame transfer from vessel to vessel than in the vessel itself. The largest flame volume was recorded on vessel *N*2, when transferred from vessel *N*1 to *N*2.

Tab. 3 The flame volume during explosion transmission

Type of device	**Flame volume [m^3]**
*N*1 with pipe	8.77
Connected vessels - initiation in *N*1	185.63
*N*2 with pipe	130.99
Connected vessels - initiation in *N*2	15.10

Conclusion and discussion

The fire-technical characteristics of substances, which represent their properties, can be drawn from the literature, but these values are mostly indicative, because they depend on several conditions such as moisture content, size, shape of dust particles, but through research we realized how their behavior varies depending on operating conditions. Underestimating this step can lead to incorrect determination of the danger of explosion and thus to underestimation of anti-explosion measures.

Through research, we have worked on the specific properties and behavior of PE dust not only in laboratory conditions, but also in large-scale tests. Large-scale tests simulated the real design of the given technological equipment, in which selected dust samples are located. Selected conditions for the course of the explosion, such as volume, shape, arrangement of vessels, turbulence, were investigated.

We found that:

- Some samples contained particles of different sizes. Even very small particles (less than 0.5 mm), but also particles larger than 1 mm and are rather atypical, fibrous materials and behave like dusts.
- The fire-technical characteristics of p_{max} and K_{St} on equipment of larger volumes reach higher values compared to equipment in the laboratory, the explosion pressure in the equipment of the plant is to reach higher values than the values obtained from laboratory measurements.
- Based on the constant for dusts, samples of PE dust can be classified in class St 1 with values up to 200 bar.m/s. The turbulence was evident in large-scale tests causing increases of the rate of pressure rise and it affects the values of maximum explosion parameters.
- The proposed venting area can be used to achieve explosion control and thus prevent damage to the equipment, taking into account the existing pressure resistance of the equipment.
- Piping systems connected to technological equipment must also be protected against the adverse effects of an explosion.
- When the explosion spreads from a larger volume vessel to a smaller volume vessel, there is a significant increase in the reduced explosion pressure, despite the installed opening on both vessels. In addition to the release openings, other elements must be used to ensure sufficient explosion protection.

We have come to the conclusion that PE dust generated in the technology of production and storage of PE granules is very explosive in a mixture with air, it cannot be underestimated in terms of creating an explosive atmosphere and the risk of explosion.

The risk of explosion occurs wherever it cannot be completely ruled out. Therefore, it is important to know the substances with their properties that are present in the technology, the technological processes that take place in the technology and the operating conditions under which the process takes place. These findings are important factors for performing a detailed analysis.

If the concentration of the mixture inside the technological equipment is below the value of the dangerous concentration and at the same time there is no settling and sticking of dust, then we can say that the technology is explosion-safe. Therefore, the next step, after assessing the properties of the dust, must be to determine the concentration of dust inside the technological equipment and to assess the possibility and effectiveness of initiation sources that may lead to the initiation of an explosive atmosphere.

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