

ANALYSIS OF THE NORMATIVE REQUIREMENTS FOR ENSURING THE SAFETY OF POWDER COATING BOOTHS IN TERMS OF THE RISK OF EXPLOSION

Eva VELIČKOVÁ¹, Petr ŠTROCH², Richard VELIČKA³

Review article

Abstract: During the process of electrostatic powder coating in coating booths, there is a probability of the risk of explosion. Compliance with the normative requirements referred to in the legislation in force minimize the hazards associated with the risk of explosion. This article focuses on the analysis of the current security level of coating booths in terms of the risk of explosion in relation to the lower explosive limit of the selected powder paints.

Keywords: A powder coating booth, the normative requirement, explosive atmosphere, the lower explosive limit, fire-technical characteristics.

Introduction

With the continuous development of science and technology, newer and more modern technologies and materials emerge. These materials are being developed for the purpose of improved properties of the finished articles. Many materials may have different characteristics from those previously used, and during their processing, they may also affect the safety of the technological process. This paper focuses on the properties of powder paints used in coating booths in electrostatic application with regard to their explosiveness. These properties are expressed by fire-technical characteristics. The current situation in practice is that in many establishments, fire-technical characteristics are not available at all, or identical values are given for the full range of products, sometimes even in a relatively wide range. These values are taken from professional literature for “a kind of general” paint, or even based on measurement, but only of “some” of the produced paints. In any case, these values are not the same for the different paints, and especially for newly manufactured paints; they may have different values than those measured in the past and then presented.

Materials and methods

Fire-technical characteristics mean the properties of a substance expressed in quantifiable value or determined on the basis of measurable values of more partial properties or phenomena that describe the behaviour of the substance in the process of combustion, or related to it. (*Decree, 2001*)

The basic fire-technical characteristics of powder materials include:

- Lower explosive limit;
- Ignition temperature of settled dust;
- Ignition temperature of dust clouds;
- The maximum explosion pressure;
- The maximum rate of pressure rise (brisance);
- Explosion Constant;
- Minimum ignition energy;
- Susceptibility to spontaneous combustion.

Furthermore, explosiveness of combustible dust is also influenced by its fineness, the concentration of combustible dust, the oxygen concentration in space, the pressure and temperature at the time of initiation, dust humidity, inert solid impurities, the state of movement of the mixture, the size and shape of the container, the arrangement of the containers, forming a hybrid mixture, and ventilation. (*Burian, 2008*)

¹ VŠB - Technical University of Ostrava, Faculty of Safety Engineering, Ostrava, Czech Republic, eva.velickova@vsb.cz

² VŠB - Technical University of Ostrava, Faculty of Safety Engineering, Ostrava, Czech Republic, petr.stroch@vsb.cz

³ VŠB - Technical University of Ostrava, Faculty of Electrical Engineering and Computer Science, Ostrava, Czech Republic, richard.velicka@vsb.cz

Powder coatings are a mixture of synthetic resins or a mixture polymers, pigments, fillers, and additives. Based on their physical and chemical properties, they belong to colloidal and dispersion systems, and they are not diluted for application, not dissolved in any liquid. The most widely used powder coatings are epoxy, epoxy-polyester and polyester coatings.

The principle of the powder coating is application to the surface of the product, which is preheated, and subsequently, the paint is hardened in an oven. The process of electrostatic powder coating is based on the physical principle that oppositely charged particles attract each other, it means that an electric field is formed between the powder paint and coated object, and the particles easily adhere to the colour of the grounded coated object. Powder coatings are conveyed from powder centres to spray guns. The powder particles are charged into the powder spray gun and applied in the form of the cloud on the grounded-coated object. Overspray that has not adhered is sucked, and according to the type of the separation system, it is either discharged to a separator or cyclone.

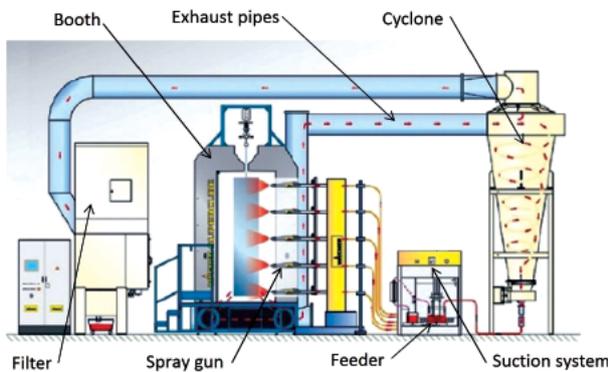


Fig. 1 Circulation of powder paint in the coating booth with a closed system of separation (Watech, 2014)

In a closed system, this overspray is sucked and removed through the suction pipe into the cyclone. In the cyclone, air is separated from the powder through a high rotation. The recycled powder is delivered back into the container in the powder centre. The output air is purified from any residual powder in the terminal filter (Fig. 1). In the case of an open system, overspray is sucked into the separator, which consists of filter cartridges placed directly in the powder coating booth. The separated powder is gradually removed from the filter cartridges by compressed air and falls to the bottom of the filter chamber, where the powder paint is collected and continuously conveyed back into

the powder container. Air from the space behind the filter cartridges is conveyed through the terminal filter to the production hall (Fig. 2).

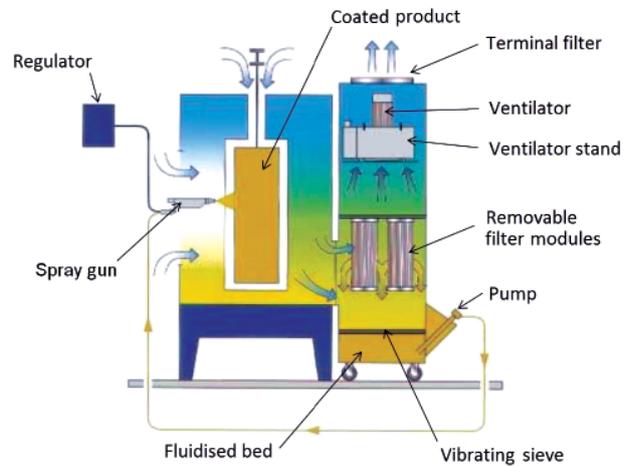


Fig. 2 Circulation of powder paint in the coating booth with an open system of separation (Nordson, 2013)

Powder coating booths can be operated inside or outside the booth, with stands for automatic spraying equipment outside the booth, or with an operator and stands for automatic spraying equipment outside or inside the booth. (ČSN [Czech National Standard] EN 12981 + A1, 2009, EN 12981 + A1, 2009)

The explosion of dust-air mixtures results from the combination of the following conditions:

- the presence of flammable substances in concentration explosion limits,
- the presence of an oxidizing agent in sufficient quantity,
- the presence of an effective ignition source,
- combustible dust must be sufficiently dispersed in the mixture with the oxidant,
- combustible dust must be dispersed in an enclosed or partially enclosed space. (*The concept of explosion prevention solutions in terms of industrial plants, 2012*)

According to Directive 1999/92/EC, which was implemented in the Czech Republic in Government Decree no. 406/2004 Coll. "On detailed requirements for ensuring safety and health at work in potentially explosive atmospheres", in assessing the risk of explosion, it is important to determine whether, under the circumstances, hazardous explosive atmosphere may occur, and whether this explosive atmosphere can be ignited. If a flammable substance is dispersed in the air and its concentration is within the explosion limits, it results in a hazardous explosive

atmosphere. If it is not possible to completely eliminate its formation, measures must be taken to exclude the presence of effective ignition sources. In the event that a dangerous explosive atmosphere and effective ignition sources occur simultaneously, further measures to limit explosive effect must be taken in conjunction with organizational measures. Places with a hazardous explosive atmosphere are classified as hazardous areas. These hazardous areas are classified into zones according to the likelihood of hazardous explosive atmosphere occurrence:

- **zone 20** - the area where an explosive atmosphere formed by a cloud of dispersing combustible dust in air is present continuously, for long periods or frequently (ČSN EN 12981+A1, 2009, EN 12981+A1, 2009, ČSN EN 1127-1, 2011, EN 1127-1, 2011, ČSN EN 50281-3 2, 2003, EN 50281-3, 2002);
- **zone 21** - the area where an explosive atmosphere consisting of a cloud of raised combustible dust in air can occasionally occur in normal operation (ČSN EN 12981+A1, 2009, EN 12981+A1, 2009, ČSN EN 1127-1, 2011, EN 1127-1, 2011, ČSN EN 50281-3 2, 2003, EN 50281-3, 2002);
- **zone 22** - the area where forming explosive atmosphere consisting of a cloud of raised combustible dust in the air in normal operation is not likely, and if it occurs, it is present only for a short period (ČSN EN 12981+A1, 2009, EN 12981+A1, 2009, ČSN EN 1127-1, 2011, EN 1127-1, 2011, ČSN EN 50281-3 2, 2003, EN 50281-3, 2002);
- for powder coating booths it applies that zone 20 is assigned the inner space of enclosed separating systems, and zone 22 the inner powder coating booths and open separating systems, as well as outer areas of the powder coating booths at a distance of 1 m from permanently open holes. (ČSN EN 12981+A1, 2009, EN 12981+A1, 2009)

To ensure safety in terms of the risk of explosion, a number of laws, government regulations and harmonized standards were issued in the Czech Republic, in which the individual requirements are specified in more detail. In the Government Decree 176/2008 Coll. "The technical requirements for machinery" it is stated that if the machinery fulfils the relevant provisions of the harmonized European standards which were referred to in the Official Journal of the European Union, or the harmonized Czech technical standards, or international technical standards in the member state of the European Union, which is related to the fundamental requirement, it is understood that a basic requirement to ensure the safety is met. (Decree, 2008, Directive, 2006)

Risk of explosion in the powder coating booth may arise if a cloud of powder coating material produced by spraying equipment ignites due to raising of settled material or otherwise. An explosion is likely if effective ignition sources are present and the powder paint concentration in the air exceeds the lower explosive limit (LEL).

In this case, an ignition source may be:

- electrostatic discharges;
- electric sparks;
- hot surfaces;
- sparks generated by mechanical energy;
- sources of thermal energy used in repair work;
- flames transferred due to forced ventilation to the system for separating the powder.

LEL may be approached or exceeded:

- if there is a malfunction of forced ventilation in the powder coating booth;
- if the settled powder coating material is raised in the powder coating booths in the system for the separation of powder during automatic self-cleaning of the filter. (ČSN EN 12981+A1, 2009, EN 12981+A1, 2009, ČSN EN 50177ed. 3, 2010, EN 50177ed. 3, 2010, ČSN EN 50050-2, 2010, EN 50050-2, 2009)

Range of protective measures by the zone type is listed in the following table.

Tab. 1 Range of protective measures in the various zones (COMMUNICATION FROM THE COMMISSION, 1999)

Zone	Sources of ignition must be reliably excluded
20	in normal operation (no fault) in case of expected faults in case of rare disorders
21	in normal operation (no fault) in case if expected faults
22	in normal operation (no fault)

In the above-mentioned zones, only equipment of the relevant category suitable for the particular zone may be used:

- in zone 20, category 1 equipment,
- in zone 21, category 1 or 2 equipment,
- in zone 22, category 1, 2 or 3. (Directive 1999, Decree 2004)

Results

To determine the environment according to ČSN 33 2000-1 ed. 2 and ČSN EN 60079-0 ed. 4, it is important to know the value of the LEL. The lower explosion limit represents the lowest concentration of combustible dust in air, at which the mixture is explosive. (ČSN EN 14034-3 + A1, 2011, EN 14034-3 + A1, 2011) Based on this quantity, protective measures against the danger of explosion at assessed facilities are implemented. If the performed test is positive, it is necessary to deal with explosion prevention for the particular facility.

Lower Explosive Limit LEL was set in the explosive autoclave VA-20L from the Swiss company Kühner AG (see Fig. 3). It is an explosion proof hollow sphere having a volume of 20 l made of stainless steel. The water jacket serves to absorb heat from the explosion, so that the initial temperature T_i was 20°. In tests the dust is dispersed to the sphere from a pressurized container through the quick-opening valve and rebound nozzle jet. Quick-opening valve is opened pneumatically and closed by an auxiliary piston. The valve for the compressed air is activated electrically. The ignition source placed in the centre of the sphere are two chemical lighters, each with energy of 1 kJ. The system for pressure measurement has two pressure sensors, recording and control equipment. Before dispersing dust, the sphere must be partially evacuated to a pressure of 0.4 bar, so that after the injection of dust, the pressure in the sphere (the initial pressure p_i) was 1,013 mbar. Dispersion overpressure p_z is 20 bars and the initiation delay t_v is 60 ms. (ČSN EN 14034-1, 2, 2011, EN 14034-1, 2, 3, 2011)



Fig. 3 Explosion autoclave VA-20L

The required amount of dust is put in the feeder, and the feeder is then pressurized to 20 bar. Before starting the test, must measure and record the temperature inside the chamber. When dispersing

dust is initiated, the atmospheric pressure must be contained in the container. During initiation, the actual pressure (the initial pressure p_i) must be measured and recorded. The delay between the start of dispersing dust and the activation of the ignition source (delay in initiation t_v) must be (0.06 ± 0.01) s. The time course of pressure is recorded. From the curve of time versus pressure, explosion pressure p_{ex} is determined by calculating the arithmetic mean of the values measured with pressure sensors. Dust ignition occurred when the measured pressure (including the effects of chemical lighters) relative to the initial pressure $p_i \geq 0.5$ bar [$p_{ex} \geq (p_i + 0.5)$ bar].

The following equation for 20-l apparatus defines the relationship between explosion pressure p_{ex} and the corrected pressure p_m due to the volume of the pressure vessel. Correction respects especially surface to volume ratio and a cooling vessel. For correction of the explosion overpressure at $p_{ex} > 5.5$ bar:

$$P_m = 0.775 \cdot P_{ex}^{1.15}$$

Another parameter is the size of the explosion pressure p_{ex} , which affects the way of correction, because at less than 5.5 bar to show the influence of the chemical igniters as pressure p_{ci} . For correction of the explosion overpressure at $p_{ex} < 5.5$ bar:

$$P_m = 5.5 \cdot (P_{ex} - P_{ci}) / (5.5 - P_{ci}) \text{ bar}$$

where p_{ci} is pressure due to chemical igniters. (Manual, 2015)

When determining the lower explosive limit LEL, we start with a concentration of 500 g/m³ or other concentrations, at which the explosion occurs, and then the test is repeated to reduce the concentration in steps always to 50 % of the previous concentration in a row: ..., 1,000; 750; 500; 250; 125; 60; ... g/m³.

The highest concentrations of combustible dusts in which the explosion occurs in three consecutive tests, is taken as the lower explosive limit (LEL). (EN 14034-3, 2001)

To determine LEL, 7 samples of paints were selected, so that the most widely used paints, paints of different chemical composition, as well as paints with different grain size were represented. The test results are graphically presented in Fig. 4 - 10.

Paint sample number 1011810: LEL = 60 g/m³

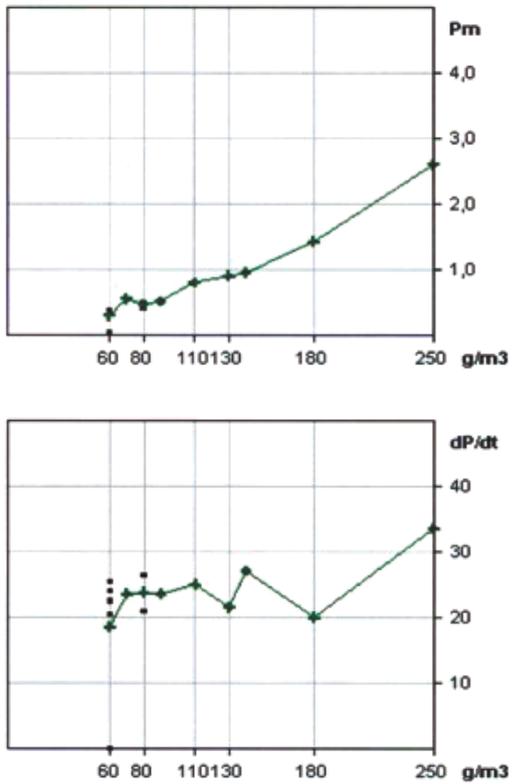


Fig. 4 Graphical representation of data for determining the LEL of paint sample 1011810

Paint sample number 1012616: LEL = 40 g/m³

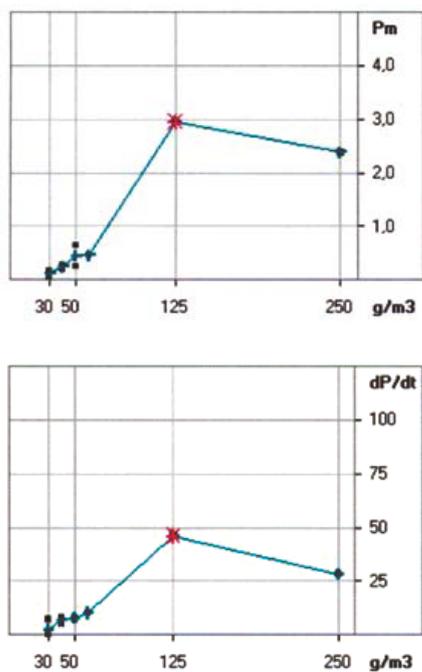


Fig. 5 Graphical representation of data for determining the LEL of paint sample 1012616

Colour sample number 1012521: LEL = 20 g/m³

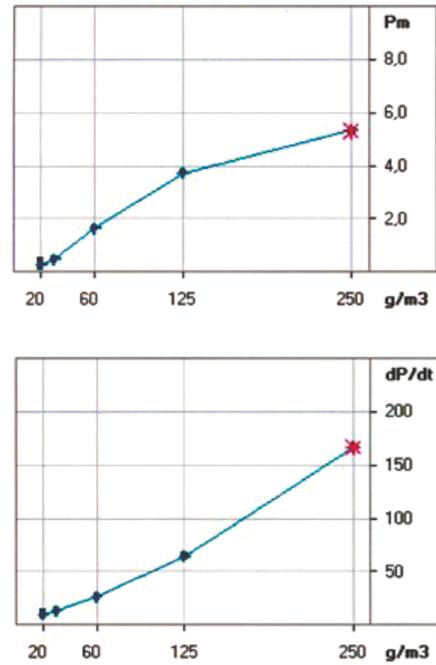


Fig. 6 Graphical representation of data for determining the LEL of paint sample 1012521

Paint sample number 1013367: LEL = 30 g/m³

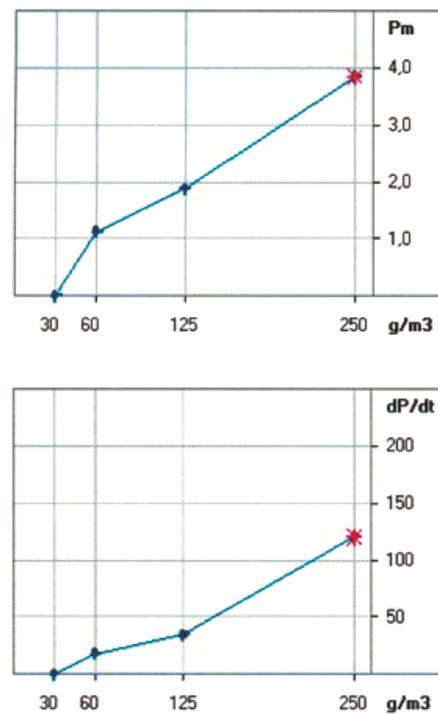


Fig. 7 Graphical representation of data for determining the LEL of paint sample 1013367

Paint sample number 1028415: LEL = 30 g/m³

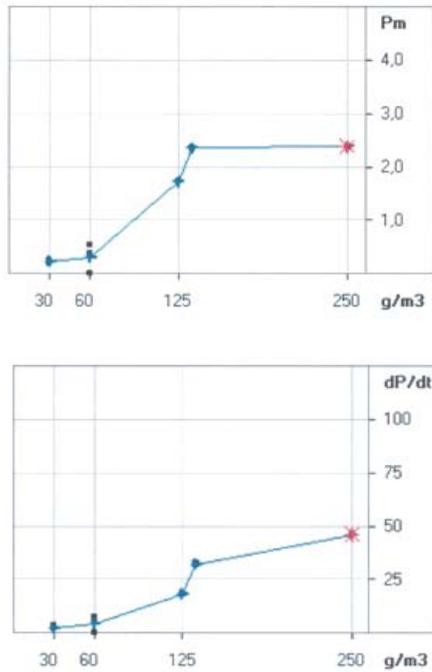


Fig. 8 Graphical representation of data for determining the LEL of paint sample 1028415

Paint sample number 1027230: LEL = 80 g/m³

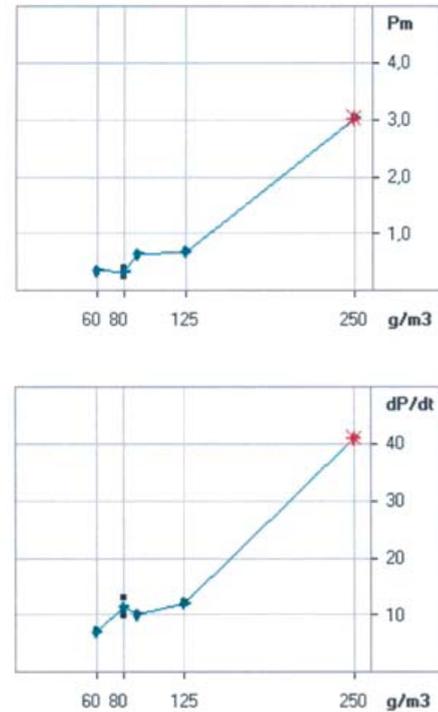


Fig. 10 Graphical representation of data for determining the LEL of paint sample 1027230

Paint sample number 1027056: LEL = 10 g/m³

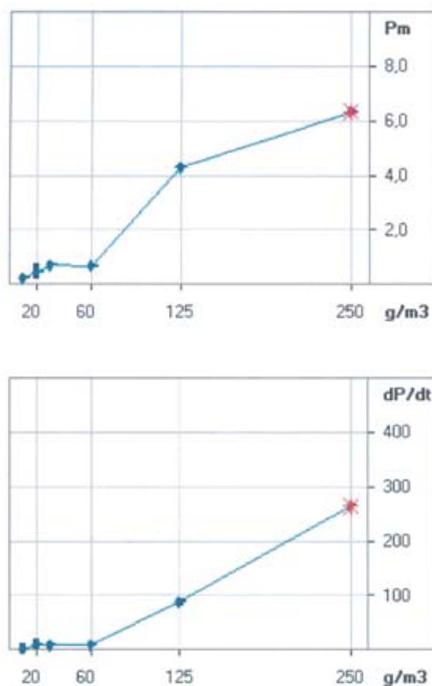


Fig. 9 Graphical representation of data for determining the LEL of paint sample 1027056

Dependencies displayed on Fig. 4 - 10 introduce the experimentally measured curve explosion selected samples of powder paints of different chemical composition and different granularity. They represent the dependence of pressure p_m on the concentration and rate of explosion pressure rise dp/dt on the concentration of powder paints.

LEL measurement results, including average grain size of paint types are summarized in Tab. 2.

Tab. 2 The resulting values LEL

Paint designation	Paint type (Chemical composition)	Average grain size measured [μm]	LEL [g/m^3]
1011810	epoxy-polyester	32.480	60
1012616	epoxy-polyester	28.864	40
1012521	epoxy	28.468	20
1013367	polyester facade	38.086	30
1028415	epoxy-polyester	34.083	30
1027056	polyester facade	32.046	10
1027230	epoxy-polyester	41.647	80

These measurements were made to compare LEL values for paints used with the normative requirement for ensuring safety in terms of the risk of explosion. A normative requirement means the specific technical requirement contained in the Czech technical standard; if it is met, the requirement of the relevant provision of the decree is considered fulfilled. (*Decree, 2001*)

In the examined samples, the resulting lower explosive limit ranged from 10 to 80 g/m³. According to ČSN EN 12981 + A1, the concentration of the powder paint must be kept below the LEL by forced ventilation. In the powder coating booths, the system of forced ventilation has to be ensured so that the average concentration of coating powder in the air does not exceed 50 % of LEL. If there are no reliable data on the value of LEL, the average concentration must not exceed 10 g/m³. For sample 1027056, which is a polyester paint, LEL is 10 g/m³, so in this case, the LEL value of 5 g/m³ should not be exceeded, which is the required value of 50 % LEL. If the value is not known, it is 10 g/m³, which is already the value at which the powder paint can explode, and it means that there is a real danger of explosion. This situation can easily occur because at most workplaces, LEL values are not available, as well as any other fire-technical characteristics.

For paint sample 1027056, this finding means that if fire-technical characteristics are not known, hazardous explosive atmosphere may be permanently present during the process of paint application, which would mean that according to the standard, the zone in the coating booth, is not zone 22, but 20 or 21.

References

- BURIAN, S. (2008).: *Explosivity of combustible dust* [cit. 10.4.2014]. Available at: <<http://www.tlakinfo.cz/t.py?t=2&i=1585&h=12010.10.2012>>. (in Czech)
- CESANA, Ch.; SIWEK, R.: *Manual 20-L-Apparatus* [cit. 10.9.2015]. Available at: <http://safety.kuhner.com/tl_files/kuhner/product/safety/PDF/B000_071.pdf>[online].
- Circulation of the powder paint during application* [cit. 10.3.2014]. Available at: <<https://www.watech.cz/wagner-group-produkty/wagner-produkty-praskovy-prumysl/praskova-technologie/obeh-praskove-barvy-pri-aplikaci.html>>. (in Czech)
- Collective of authors (2012).: *Concept of the solution of explosion prevention in the conditions of industrial operations*. In: Kolektiv autorů. Koncepce řešení protivýbuchové prevence v podmínkách průmyslových provozů, SPBI Ostrava, 1st edition, ISBN 978-80-7385-120-0. (in Czech)
- COMMUNICATION FROM THE COMMISSION concerning the non-binding guide of good practice for implementing Directive 1999/92/EC of the European Parliament and of the Council on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres. Available at: <https://osha.europa.eu/fop/czech-republic/cs/legislation/files/smernice1999_92_ec.pdf>[online].
- ČSN EN 1127-1:2011. Výbušná prostředí - Prevence a ochrana proti výbuchu - Část 1: Základní koncepce a metodika, Praha. (in Czech)

Conclusion

These measurements show that ignorance of fire-technical characteristics of the materials used in the technological process can lead to danger to life and health of workers and damage to property and the environment. Clear classification of areas with explosion hazard into zones serves as the basis for determining the extent of preventive measures in these areas. Incorrect classification of hazardous areas into zones may lead to an incorrect determination of the extent of protective measures and to use facility of other categories in these dangerous areas. On the basis of clear and correct information about the fire-technical characteristics, it is then necessary to choose an adequate level of elements of explosion protection for technologies of powder coating booths, so that even in the case of explosion, their operation was sufficiently secured, not only against material damage, but also against injury or loss on lives. On the basis of these observations, it would be worth considering whether normative requirement that the average concentration should not exceed 10 g/m³ should be used if fire-technical characteristics are not known, because there is a permanent occurrence of explosive atmosphere for the above-mentioned case.

Acknowledgments

The article was elaborated with the support provided by the project SP2013/28 "Explosiveness of powder paints in coating booths".

- ČSN EN 12981+A1: 2009. Lakovny - Stříkací kabiny pro nanášení organických práškových nátěrových hmot - Bezpečnostní požadavky, Praha. (in Czech)
- ČSN EN 14034-1+A1: 2001. Stanovení výbuchových charakteristik rozvířeného prachu - Část 1: Stanovení maximálního výbuchového tlaku p_{max} rozvířeného prachu, Praha. (in Czech)
- ČSN EN 14034-2+A1: 2011. Stanovení výbuchových charakteristik rozvířeného prachu - Část 2: Stanovení maximální rychlosti nárůstu výbuchového tlaku $(dp/dt)_{max}$ rozvířeného prachu, Praha. (in Czech)
- ČSN EN 14034-3+A1: 2011. Stanovení výbuchových charakteristik rozvířeného prachu - Část 3: Stanovení dolní meze výbušnosti LEL rozvířeného prachu, Praha. (in Czech)
- ČSN EN 50050-2: 2010. Elektrostatické ruční stříkací zařízení - Bezpečnostní požadavky - Část 2: Ruční stříkací zařízení pro hořlavé práškové nátěrové hmoty, Praha. (in Czech)
- ČSN EN 50281-3: 2003. Elektrická zařízení pro prostory s hořlavým prachem - Část 3: Zařazování prostorů, kde jsou nebo mohou být hořlavé prachy, Praha. (in Czech)
- ČSN EN 50177ed. 3: 2010. Stabilní elektrostatické zařízení pro nanášení hořlavých práškových nátěrových hmot - Bezpečnostní požadavky, Praha. (in Czech)
- Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC. (recast)
- DIRECTIVE 1999/92/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (15th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC).
- Decree of the Ministry of Interior no. 246/2001 Coll. establishing fire safety conditions and state fire surveillance (Fire Prevention Decree) of 29 06th 2001. (in Czech)
- EN 1127-1: 2011. Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology.
- EN 12981+A1:2009. Coating plants - Spray booths for application of organic powder rating material - Safety requirements.
- EN 14034-1+A1: 2011, Determination of explosiv characteristics of dust clouds - Part 1: Determination of the maximum explosiv pressure p_{max} of dust clouds.
- EN 14034-2+A1: 2011, Determination of explosiv characteristics of dust clouds - Part 2: Determination of the maximum rate of explosiv pressurerise $(dp/dt)_{max}$ of dust clouds.
- EN 14034-3+A1: 2011, Determination of explosiv characteristics of dust clouds - Part 3: Determination of the lower explosion limit LEL of dust clouds.
- EN 50050-2: 2009. Electrostatic hand-held spraying equipment - Safety requirements - Part 2: Hand-held spraying equipment for ignitable rating powder.
- EN 50177 ed. 3: 2009. Stationary electrostatic application equipment for ignitable coating powders - Safety requirements.
- EN 50281-3: 2002: Equipment for use in the presence of combustible dust - Part 3: Classification of areas where combustible dusts are or may be present.
- Government Regulation 176/2008 Coll. of 21 April 2008 on technical requirements for machinery. (in Czech)
- Painting booth with an open system separation* [cit. 8.3.2013]. Available at: <http://www.nordson.cz/NR/rdonlyres/2CC9DAC6-E91F-4092-99F6-E15CB4C07937/0/CARTRIDGE_Booths_English.pdf>.