Fire safety of buildings in terms of hazards caused by selected food dusts

Bezpieczeństwo pożarowe budynków w aspekcie zagrożeń spowodowanych wybranymi pyłami spożywczymi

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Streszczenie

Celem artykułu była analiza porównawcza parametrów zapalności, palności wybranych rodzajów pyłów herbat pobranych z obiektu przemysłowo-magazynowego. Stwierdzono, że pył z herbaty zielonej aromatyzowanej z pośród przebadanych pyłów stanowi największe zagrożenie pożarowe. Posiada najniższe temperatury zapłonu i największe wartości ciepła spalania, a dopuszczalna temperatura powierzchni urządzeń pracujących w obecności tego pyłu dla warstwy o grubości 5 mm, nie może przekroczyć 215℃.

Abstract

The aim of the article was a comparative analysis of the ignitability and flammability parameters of selected types of tea dusts collected from an industrial and warehouse facility. It was found that among the tested dusts, the dust of flavoured green tea poses the greatest fire hazard. It has the lowest ignition temperature and the highest combustion heat values, and the permissible surface temperature of devices operating in the presence of this dust for a layer with a thickness of 5 mm cannot exceed 215℃.

Słowa kluczowe: bezpieczeństwo pożarowe budynków, zapalność pyłów palnych

Key words: fire safety of buildings, ignitability of combustible dust

Introduction

The fire safety of buildings ranks second among the basic requirements to be met by buildings in use following structural safety (load-bearing capacity and stability). Civil structures, including production and storage facilities as a whole and their individual parts, must be fit for their intended use, taking particular account of the health and safety requirements for persons who come into contact with them throughout their life cycle [1]. Industrial activities are inherently associated with fire and explosion hazards and combustible dust explosions can occur in a variety of industries where bulk substances are present [2-6], which may happen during processing, storage and warehousing. The explosion hazard of food dusts, including tea dusts, is a particular issue, not only because of the loss of property, but it can be of critical importance in the continuity of the product supply [7]. A major concern in terms of the risk of fire or explosion in manufacturing plants is keeping the area clear of airborne dust in the vicinity of working machinery where dust is transferred, transported, treated and dried. Dust ignition can occur inside the equipment, with the consequences of damaging the production line and endangering the health or lives of those working on it. A dust explosion that involves spaces outside the working equipment is considered to be the most hazardous. Dust deposited on all surfaces such as machine housings, floors or horizontal structural elements of a building creates a fire risk and, as a result of atomisation in the air, also an explosion risk. Hazards from combustible settled dusts mainly relate to smouldering, glowing or ignition from flames or a hot surface where the fire hazard of the material is not usually due to the presence of the burning material itself, while the smouldering or glowing point may be a source of ignition for other combustible materials present in the vicinity and may cause self-sustaining flame combustion. Another type of hazard posed by already burning dusts is that, under favourable heat and flow conditions, they may burn producing a flame and also be a source of ignition for nearby combustible materials.

Tea dusts released from working environments in a facility are solid particles characterised by different physical and chemical properties, as a result of which the level of fire risk posed by them is not the same. The main factors influencing the ignitability of dust from a heated surface include the chemical composition of the dust particles, size, moisture content of the dust cloud formation, dust concentration, oxygen concentration and presence of inert gas [6-8]. Tea dust, if not completely removed during the production process, e.g. by vacuuming or cleaning, unfortunately settles on the tissue sealing equipment of the bags in which the tea is placed. The surfaces of the tea packaging equipment must generate a temperature of around 280℃ to bond the bags. Such a high temperature on the surface of the machine is necessary to seal the tea filter paper properly, so that this paper does not become unstuck when the tea is brewed, but at the same time can become an effective ignition stimulus when layers of dust are left behind. In tea packing lines, if there is no protection of the dust extraction system, e.g. in the form of spark extinguishing, accumulated dust on plant components may start smouldering or glow. If this phenomenon is not detected in a timely manner by plant personnel, the glowing dust can become 'entrained' into the central dust extraction system and lead to ignition or potentially to a dust explosion in the facility. Particular attention should be paid to the temperature of internal spaces in production equipment in which combustible dust is generated, transported, treated or dried, as well as outside such equipment, covering spaces and surfaces where it may settle to form layers of the so-called settled dust. The protection of technical installations is achieved through the design and installation, suitable for the type of hazard envisaged, of safety equipment and systems, which should form an integral part of the fire and explosion protected storage area for flammable bulk materials.

It is clear that familiarity with fire properties of tea dusts will therefore allow assuring appropriate safeguards and setting out the maximum permissible temperatures for the surfaces of equipment exposed to work in the presence of these types of dusts, which should be to be determined to such an extent as to reduce the risk of hazardous incidents in production and storage buildings.

Experimental part

Description of tested dusts

For needs of the testing five types of tea dusts with the physicochemical parameters shown in Table 1 have been selected. The tested dusts were taken from the processing line of a food processing plant. Samples of each tea for ignitability testing were passed through a steel sieve with a nominal mesh size of 200 µm. The samples were homogeneous and representative of the dust tested.

Tab. 1. Parametry fizykochemiczne badanych pyłów

Table 1. Physicochemical parameters of the tested dusts

Parameter	Cherry-flavoured fruit tea dust	Green tea dust flavoured with raspberry aroma	Green tea dust	Black tea dust	Red tea dust
Bulk density	0.36	0.39	0.498	0.615	0.582

[g/dm^3]*					
Transient moisture content in dust [%wt.]*	6.27%	6.11%	4.966	6.748	7.594
Elemental analysis of basic elements [%wt.]*	%C 42.42 %H 5.79	%C 46.40 %H 5.71	%C 43.45 %H 5.90	%C 45.40 %H 5.79	%C 44.41 %H 6.01

* arithmetic means of three measurements

Characteristics of research methods

To determine the flammability and ignitability of the flour dust samples tested, tests were carried out to:

- determine the minimum ignition temperature of dust from a heated surface forming a layer (method A) and dust-air cloud (method B) according to the standard PN-EN ISO/IEC 80079-20-2 [9],

- determine the heat of combustion according to PN-EN ISO 1716:2018 [10].

Method A involves the testing of a dust layer on a fixed temperature plate and the determination of the minimum ignition temperature of a dust layer (MITL), i.e. the lowest oven surface temperature at which ignition of a dust layer of a given thickness occurs. MITLs of 5 mm, 12.5 mm and 12.5 mm were determined for the tea dusts tested. The choice of a layer thickness of 5 mm was based on the recommendations contained in the standard [9], which is harmonised with the Atex Directive, while a layer thickness of 12.5 mm is recommended by the American standard ASTM E2021 [11]. According to procedure [9], ignition of the dust layer shall be considered to have occurred if: a) glowing or burning is observed or, b) the measured temperature has reached 450°C or, c) the measured temperature has exceeded the temperature of the hotplate by 250°C. In relation to (b) and (c), ignition shall be considered not to have occurred if it can be demonstrated that the reaction does not proceed to glowing or burning. Incandescence is the undisputed and most common sign of ignition of an organic dust layer. In order to determine the minimum ignition temperature of a dust layer of a certain thickness, a series of tests should be carried out, using a new dust sample in each test. The temperature of the slab should be varied accordingly, until a layer ignition temperature is found that is no more than 10℃ higher than the temperature that did not ignite the layer. The highest surface temperature of the hotplate where ignition did not occur should be confirmed by continuing the test long enough to be able to conclude that a reduction has taken place in the rate of self-heating; i.e. the temperature at the point of measurement in the layer drops to a fixed value, lower than the temperature of the heated surface. Tests on the teas tested were carried out in duplicate at the last determinations of MITL. According to [9], the lowest furnace temperature at which layer ignition was observed and the highest furnace temperature at which layer ignition was not observed with a maximum difference in furnace temperature of 10℃ must be recorded in a given series of measurements of the dust in question. In the second run, the observations made should be confirmed if layer ignition of the dust in question is recorded at a lower furnace temperature then this temperature is considered the final MITL. The testing shall be continued until either ignition of the layer is visible from observation of the dust or a temperature reading of the dust or self-ignition takes place without ignition, followed by cooling. If, after a period of 30 minutes, there is no self-heating of the dust or ignition of the dust, the test shall be stopped and repeated at a higher temperature. If at least one of the ignition criteria is found to be met, the test shall be repeated at a lower temperature, extending the test period beyond 30 minutes if necessary. The test shall be continued until the temperature of the heating surface causing ignition or self-heating of the layer has been determined to be no more than 10 ℃ higher than the non-ignition or self-heating temperature. The MITL should be the lowest furnace temperature, rounded to the nearest whole multiple of 10 ℃, at which ignition of dust piled in a layer of a given thickness occurs. A view of the test rig for determining the minimum ignition temperature of the dust layer is shown in Figure 1.

Rysunek 1. Widok stanowiska do oznaczania MTZW pyłów (metoda A).

Figure 1. View of the stand for of MITL determination of dusts (method A).

The appearance of glowing embers in the layers of the teas tested was the criterion by which ignition was considered to have occurred, according to [9]. A view of the glowing dust is shown in Figure 2.

Rysunek 2. Widok żarzącego się pyłu.

Figure 2. View of glowing dust

Method B specifies the test for ignition of a dust cloud in a constant-temperature furnace and the determination of the minimum ignition temperature of cloud dust (MTCD). Ignition of the dust cloud should be considered to have occurred if there is a visible flame projection beyond the lower end of the furnace tube. A certain slight delay in ignition is acceptable. Sparks without a flame do not constitute ignition of the dust-air cloud. The minimum ignition temperature of the dust cloud is to be taken as the lowest temperature of the furnace at which ignition has been recognised using a procedure according to [9] method B, reduced by 20℃ at a furnace temperature above 300℃ and by 10℃ at a furnace temperature of 300℃ or below. Determination of MTCD of the tested teas was carried out in ten iterations with the last determinations of MTCD values.

A view of the test bench for the determination of MTCD is shown in Figure 3.

Rysunek 3. Widok stanowiska do oznaczania MTZO pyłów (metoda B)

Figure 3. View of the stand for determination of MTCD of dust (method B).

Where hot surface hazards are identified in buildings in which combustible dusts are handled, the maximum allowable surface temperature of the device (MASTD) operating at the presence of these bulk substances should be determined. The method of determining the MASTD based on PN-EN 60079-14:2014-06 [12] for 5 and 12.5 mm dust layers and dust-air clouds is given in Table 2.

Tab. 2. Sposób obliczenia maksymalnej dopuszczalnej temperatury powierzchni urządzeń [12].

Tab. 2. The method of calculating the maximum allowable surface temperature of devices [12].

Dust form	Calculation method of MASTD
Dust-air cloud	MASTD = 2/3* MTCD
5 mm dust layer	MASTD = $MITL_{5mm}$ – 75°C
12.5 mm dust layer	MASTD = $MITL_{12,5mm}$ – 25°C

The final MD MASTD (T_{max}) value to be displayed on the nameplates of equipment operating in the presence of combustible dust is the smallest MASTD value calculated in accordance with Table 2 based only on the of $MITL_{5mm}$ and MTCD.

The heat of combustion values of the tested dusts were established in accordance with EN ISO 1716. According to [10] in the received in the validation of the test, the difference in on the PCS values of three repeated up to 5%.. In the fire protection regulations for buildings, knowledge of these values is necessary to determine the amount of heat emitted during a fire, which affects the calculation of e.g. the combustion temperature, the pressure generated during an explosion, the rate of flame spread and especially the determination of the fire load density.

Results of the study

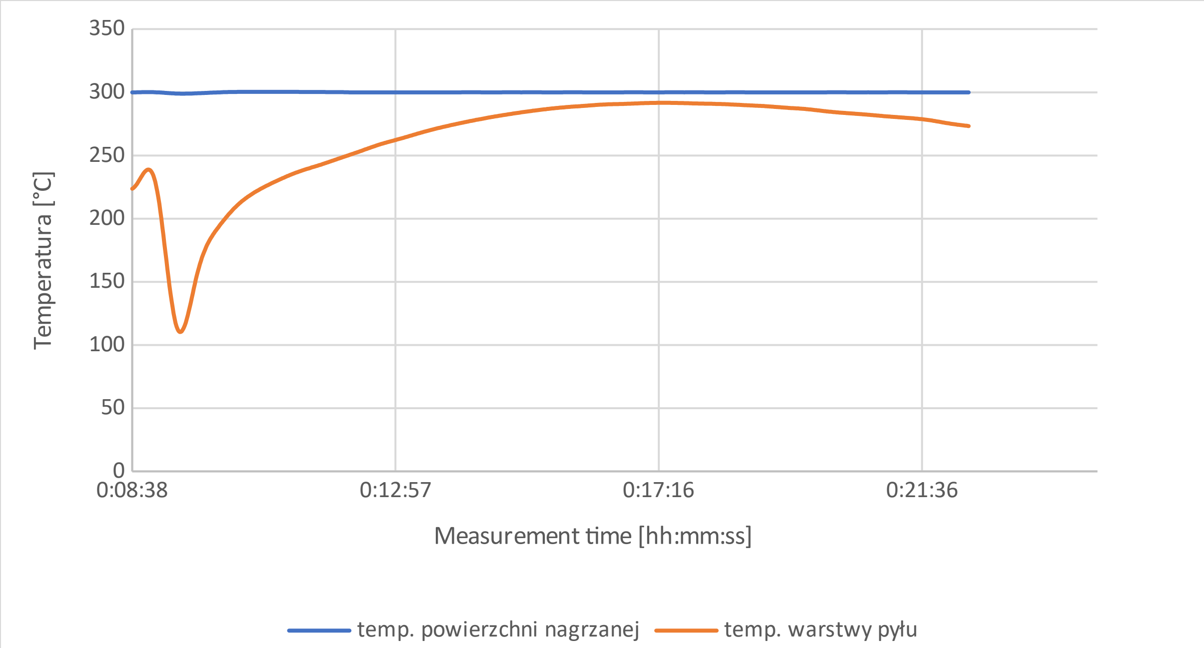
The results of MITL, MTCD and PCS determinations, together with the calculated MASTD, are shown in Table 3.

Tab.3. Sumaryczne wyniki oznaczeń MTZW, MTCD i PCS wraz z obliczonymi MASTD

Tab. 3. Summary results of MITL, MTCD and PCS and the calculated values of MASTD

Dust type	$MITL_{5mm}$ **[°C]**	MASTD **[°C]**	$MITL_{12,5mm}$ **[°C]**	MASTD **[°C]**	MTCD **[°C]**	MASTD **[°C]**	**PCS [MJ/kg]**
Cherry-flavoured fruit tea dust	300	**225**	270	**245**	440	**293**	14.357
Green tea dust flavoured with raspberry aroma	290	**215**	260	**235**	470	**313**	15.960
Green tea dust	300	**225**	270	**245**	460	**307**	15.532
Black tea dust	300	**225**	280	**255**	460	**307**	15.623
Red tea dust	300	**225**	270	**245**	480	**320**	15.892

An example of the temperature dependence of the dust layer as a function of time for testing black tea dust piled in a 5 mm thick layer at a heated surface temperature of 300°C is shown in Figure 4. Ignition of this dust layer in the form of its glow was achieved after 15 min.



Rysunek 4. Zależność temperatury warstwy pyłu w funkcji czasu badania pyłu herbaty czarnej usypanego w warstwie o grubości 5 mm przy temperaturze powierzchni nagrzanej wynoszącej 300°C [13]

Figure 4. Dependence of the temperature of the dust layer as a function of the test time of black tea dust in a 5 mm thick layer at the heated surface temperature of 300°C [13]

temp. powierzchni nagrzanej – temp. of heated surface
temp. warstwy pyłu – temp of dust layer
temperatura – temperature

Review of results

Considering the results from the tests for a layer thickness of 5 mm, it can be seen that the teas tested have similar MITL values and for most of the tea dusts tested, the $MITL_{5mm}$ is 300°C, only for the raspberry scented green tea this temperature was 10°C lower. Also for the same tea, the lowest $MITL_{12.5mm}$ value of 260°C was recorded for the 12.5mm layer. The ignitability of the dust-air cloud from the heated surface was found to be the greatest for cherry-flavoured fruit tea dust. Based on the results of conducted tests, the T_{max} of the surface of equipment operating in an explosive atmosphere was found to be 215°C. If all the teas tested are processed in a given premise, this temperature value should appear on the rating plate of the equipment operating in the presence of the tested tea dusts. The bulk density of the tested dusts, as well as their moisture content, did not have a significant effect on the MITL and MTCD values [13]. The values of these parameters were similar and did not determine the ignitability of the film. Also for raspberry scented green tea dust, a slightly higher but clearly the highest PCS value was obtained, hence for this type of tea stored in a room with a given surface area at the same weight of stored teas, the highest fire load density among the substances tested should be expected. The highest elemental carbon content of this particular tea and probably the essential oils or composition of the ingredients that alter the natural aroma of the teas increased its flammability from the heated surface and its heat capacity.

Conclusions

The experiments carried out prove that the tea dusts tested pose an explosion and fire hazard, both as dust layers that accumulate on the heating surface and as a dust cloud that creates an air-dust mixture. In production and storage facilities where tea is packaged and where it is not possible to reduce the temperature of the hot surface that seals the tea bags (the temperature of the equipment is 280℃, and the maximum permissible temperature of the equipment operating in the presence of the tested dusts is 215℃), spark extinguishing systems should be installed on the processing lines and/or temperature detectors should be fitted in production facilities where the dust accumulates on the hot surfaces of equipment.

References

[1] Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products.

[2] Yuan, Z.; Khakzad, N.; Khan, F.; Amyotte, P. Dust explosions: a threat to the process industries. Process Saf. Environ. 2015; https://doi.org/10.1016/j.psep.2015.06.008)

[3] Ramirez, A.; Garcia-Torrent, J.; Aguado, P.J. Determination Of Parameters Used To Prevent Ignition Of Stored Materials And To Protect Against Explosions In Food Industries. J. Hazard Mater. 2009; https://doi.org/10.1016/j.jhazmat.2009.02.013)

[4] Eckhoff, R.K. Understanding Dust Explosions. The Role of Power Science and Technology. J. Loss. Prevent. Proc. 2009; https://doi.org/10.1016/j.jlp.2008.07.006)

[5] Taveau, J. Dust Explosion Propagation and Isolation. J. Loss. Prevent. Proc. 2017, 48, pp. 320-330. (doi.org/10.1016/j.jlp.2017.04.019)

[6] Babrauskas V. Ignition handbook. Fire Science Publishers, Issaquah; 2003.

[7] Eckhoff R. K. Dust explosions in the process industries. Third edition. Burlington; 2003.

[8] Salamonowicz Z., Półka M., Woliński M., Sobolewski M. Badania eksperymentalne i modelowanie zapłonu warstwy pyłu na gorącej powierzchni. Przemysł Chemiczny. 2014;93:99-102.

[9] EN ISO/IEC 80079-20-2, Explosive atmospheres -- Part 20-2: Material properties -- Test methods for combustible dusts.

[10] EN ISO 1716:2018, Tests for reaction to fire of products. Determination of gross heat of combustion (calorific value).

[11] ASTM E2021-09, Standard Test Method for Hot-Surface Ignition Temperature of Dust Layers.

[12] EN 60079-14:2009, Explosive atmospheres. Part 14: Design, selection and installation of electrical installations.

[13] Krotowski T. Engineering thesis, MSFS, Analysis of ignitability from heated surface of selected tea dusts. 2022.