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DETERMINATION OF THE MINIMUM IGNITION TEMPERATURE OF GROUND SWEET PEPPER PRODUCED BY THE FOOD INDUSTRY

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Research article

Abstract: The current article deals with the determination of fire parameters of ground sweet pepper (GSP) dust cloud. The minimum ignition temperature was determined in accordance with STN EN ISO/IEC 80079-20-2:2016 Standard Explosive atmospheres - Part 20-2, using a Godbert-Greenwald furnace apparatus with various dust concentrations, particle sizes, and dust-dispersion-air pressure (10 kPa, 30 kPa and 50 kPa). Three set of different particle size ranges of GSP powder were tested during the experiment, that is, 90 to<150 µm, 150 to<200 µm, 200 to<250 µm. The MIT depends on the particle size and varied by a maximum of 30 K, and values for the individual samples of GSP was in the range 550 - 610 °C. Minimum ignition temperature of the GSP powder was 550 °C (90 to<150 µm, 0.5 g and 50 kPa).

Keywords: Minimum Ignition Temperature, Ground Sweet Pepper, Dust Dispersion, Explosion, Fire Safety.

Introduction

The history of industrial development has been punctuated by several hazardous explosions, with a severity level and frequency increasing in proportion to the development of the process industry (Eckhoff, 1991). A few of them are still in the memory and undeniably played a part in the birth of safety engineering (Proust, 2006). They also related the danger of combustible dust explosions to the food and agricultural industry. The danger of igniting dust mixtures is very high in the vicinity of all equipment where combustible dust is handled. Adopting various technological, technical, and preventive solutions is necessary to prevent this possible danger. For this, it is necessary to know the fire-technical parameters of the given powders (Martinka and Rantuch, 2013). There has been an enormous increase in relevance and importance and is a major challenge to prevent dust explosions in industries dealing with combustible dust or powder (Eckhoff, 2003; Kuracina et al., 2018; Copelli et al., 2021).

Many industries face the threat of fires and dust explosions when dust layers and/or clouds form during technology processes, which are capable of ignition. Flammable dust can pose a fire hazard after sedimentation on the heated surface from which it absorbs heat (Blair, 2007; Polka et al., 2012).

Explosions can occur from agricultural products, food, metals, rubber, pharmaceuticals, wood, coal, and plastics. The conditions for a combustible dust explosion are very specific, not random processes (Amyotte and Khan, 2019). Five elements are required for the explosion of combustible dust, which is based on the three elements necessary for fire: fuel, heat, and oxidising agent. The dust fulfils the role of fuel. The ignition source is the catalyst for the explosion of the combustible dust, representing heat. Hot surfaces, embers, and electrostatic discharges all serve as ignition sources. For an explosion to occur, there must be an oxidising agent in the atmosphere, oxygen in the air being the most common oxidising agent. The next requirement is dust dispersion. An event must happen for

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the dust to be suspended in the air. The dispersed dust must reach a minimum explosive concentration in a dust cloud before it can ignite. The last element for dust explosions is an enclosed environment. In open space, explosion parameters do not reach their maximum values (McKee, 2016; Kuracina et al., 2021).

In conjunction with the conditions mentioned above, particle size and distribution, humidity, ventilation, ignition and dispersion locations of dust, and inert substances present in the dust may influence explosion parameters as well (Zhao et al., 2020; Kuracina et al., 2021).

The most reliable way to obtain information about the explosiveness and flammability of dust is a specific representative sampling of the dust sediment and experimental verification of the properties in the laboratory and subsequent description of the test results using fire-technical properties (Martinka and Rantuch, 2013).

The present study investigates the effects of three important parameters, namely, particle size, dust concentration, and dust-dispersion-air pressure on Minimum Ignition Temperature (MIT) using Godbert-Greenwald (G-G) furnace.

A combustible dust cloud's MIT or thermal ignition point may be defined as the minimum temperature needed to ignite the sample dust cloud so that the ignition is self-propagating (Addai et al., 2016; Mishra and Azam, 2018).

MIT is one of several key factors in designing dust explosion prevention measures. Several different test furnaces can be used to determine this parameter, including the G-G furnace (with different lengths, one version is 216 mm long, while the other has double that length), the BAM-oven, a 1.2 L furnace, and a 6.8 L furnace (Chunmiao et al., 2012).

Currently, the G-G furnace is the most commonly used equipment for measuring the MIT of dust clouds in the laboratory (Eckhoff, 2019). Experimental results have shown that dust concentration and particle size distribution of dust clouds have significant effects on the MIT of dust clouds (Gao et al., 2013; Zhang et al., 2017; Deng et al., 2019). These factors are closely related to dust-dispersion-air pressure (Liu et al., 2019; Sun et al., 2020).

One of the essential features of the test sample selected for the explosion test is that it represents to the greatest extent, the substance exposed to danger in the plant and workplace. This also ensures that the values provided by the test stand reflect the processes taking place in the real world as much as possible. To ensure the best results, it is important that the size distribution of the test powder is similar to the finest sizes that occur during the production, processing, and transportation of the powder, and that the moisture content of the sample is as low as the driest material in the plant. It is also important to note that when classifying dust, we must pay attention to the conditions under which the dust will be handled (for example, temperature and pressure) (Barton, 2002; Kuracina et al., 2018).

Understanding the fundamentals of how dust ignites, and its distinct attributes is essential for the dust ignition process and has practical implications in furnace design, combustion control, and avoiding or reducing the destructive forces of dust explosions. The operation of the process is determined by the environment surrounding the fuel particle and the furnace combustion state, including pressure, temperature, oxygen content, and excess air. The fuel and oxidiser properties also play an important role. In turn, mutual interactions between the particles influence the heat and mass exchange processes in the particle's surroundings. A dust cloud's size and concentration can further influence the ignition process under these conditions (Rybak et al., 2019).

Materials and methods

The experimental determination of the minimum ignition temperature of food dust in a dispersed state by the test method according to STN EN ISO/IEC 80079-20-2:2016 Standard Explosive atmospheres - Part 20-2: Material characteristics - Combustible dust test methods. The measurement was carried out on a Godbert-Greenwald (G-G) furnace apparatus for determining the minimum ignition temperatures of dispersed dust (Figure 1).

Figure 1 Device for determining the minimum ignition temperature of dispersed dust

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Figure 2 shows the scheme of the heated furnace and the system for measuring the ignition temperature of dispersed dust according to STN EN ISO/IEC 80079-20-2:2016.

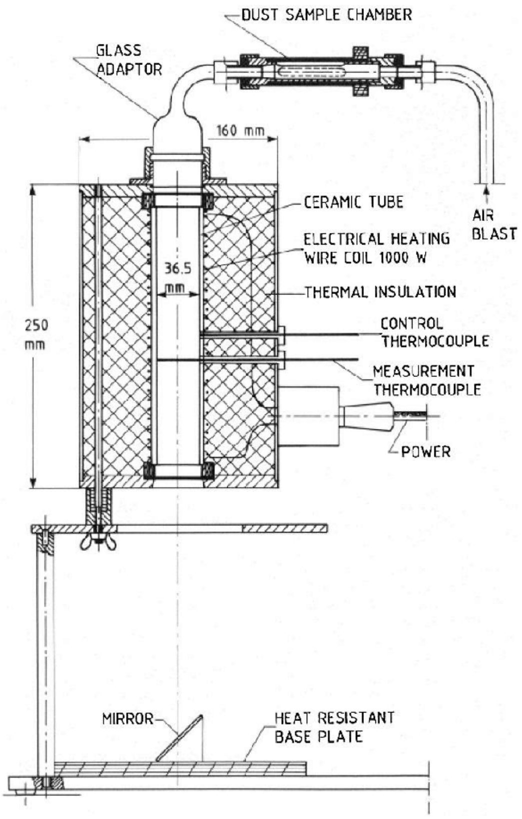

Figure 2 Cross-section of Godbert - Greenwald furnace (Eckhoff, 2003)
a - dust sample chamber, b - glass adaptor, c - ceramic tube, d - electrical heating wire coil 1000 W, e - thermal isolation, f -control thermocouple, g -measurement thermocouple, h -power, i - mirror, j - heat resistant base plate, k - air blast

Small quantities of dust are blown vertically downward through a heated furnace, and ignition is detected by visual inspection. At the lower open end of the heated furnace, we observe the ignition process. At the upper end, it connected the furnace via a glass adapter to the dust reservoir. The test material is dispersed in the furnace by an air blast, which is released from the reservoir by opening a solenoid valve. A thermocouple that is inserted into the oven measures the temperature on the inside of the oven. The test device is connected to the gas bomb through the compressed air supply N. The temperature of the inner edge of the furnace is regulated using a temperature controller (STN EN ISO/IEC 80079-20-2:2016).

The fractions we used for the measurement were selected based on their sufficient representation in the individual examined samples. For the comparability and correctness of the experimental determination of the minimum temperatures, it is necessary to know the nature of the examined sample. The results of the given characteristics can be influenced by the test conditions, the type of test method, and the examined material. The dimensions of the dust particles of the sample have a relatively significant influence on the measurement results. Before determining the temperature, the spice samples were not treated by drying in order to preserve the original properties of the investigated dust. High temperatures during drying could significantly affect the original properties of food dust.

Based on the information provided by the manufacturer, the sample contains carbohydrates, proteins, fat, water, dietary fiber, and may contain traces of other substances sold by the manufacturer, such as celery, mustard, sesame seeds, cereals, soy.

The behaviour of the sample during the experiments is probably most influenced by the organic components with higher representation, such as carbohydrates, fats (oils) or fiber. It appears that the minimum ignition temperature is not significantly affected by the humidity, but only delays the ignition time at higher moisture content (after evaporation) (Polka et al., 2012).

The sample shall be representative of the material as it appears in the entire process operated. It must not contain any additives. The measurement was carried out on a Retsch AS200 sieving machine to determine the particle size distribution of aggregates (Figure 3).

Figure 3 Test sieves of metal wire cloth

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The sample is obtained by sifting through a test sieve with a given mesh size, according to the required size of the sample particles. The mesh size of the test sieves is only available for the sieves with principal sizes because the standards ISO 3310-1/ASTM E11 used by the manufacturer's (Retsch) international comparison table for test sieves does not specify the mesh size for the sieves with only supplementary sizes. The mesh sizes of the test sieves are shown in Table 1.

Table 1 The sizes of the test sieves with the given mesh size (Retsch.com, 2023)

Principal sizes (µm)	Supplementary sizes (µm)	Tyler Screen Scale Mesh
500	500	**32**
250	250	**60**
-	200	**-**
150	150	**100**
90	90	**170**
-	71	**-**
63	63	**250**
45	45	**325**

Sample preparation, such as grinding and sieving or drying, can alter the material characteristics. All observed visible changes in dust properties during sample preparation must be noted in the test report (STN EN ISO/IEC 80079-20-2:2016).

Results and discussion

The moisture content of the sample was determined using RADWAG Wagi MA 50.R moisture analyzer. The moisture content of ground pepper was 5.982 %.

The measurement was carried out in laboratory conditions at a temperature of ± 25 °C and a humidity of 45 %. The standard STN EN ISO/IEC 80079-20-2:2016 does not define laboratory conditions. Also in foreign literature, such as (Arshad et al., 2021; Wang et al., 2019), the measurements were carried out at 25 °C ± 5 °C. Environmental factors are not given as much emphasis as measurement parameters.

Sieve analysis revealed that ground sweet pepper has the largest percentage (38.5 %) of dust particles in the 250 - 500 µm fraction, and under 90 µm has the smallest percentage (0.2 %).

The ignition temperatures of the dispersed dust were determined for individual fractions. Three different size ranges (90 to<150 µm, 150 to<200 µm, 200 to<250 µm) were selected for individual samples. The measurement was carried out with sample weights of 0.1 g, 0.3 g, and 0.5 g at dispersion pressures of 10 kPa, 30 kPa, and 50 kPa for each particle size. The initial temperature of the furnace was set at 400 °C and increased by 20 °C. Each measurement was repeated ten times at the determined ignition temperature. The test result was considered positive if at least one out of ten measurements ignited the sample from the hot surface. The ignition temperature was considered to be the temperature at which ignition occurred at least once, while at a temperature lower by 10 °C it did not occur even once in ten attempts.

The measured minimum ignition temperature for the sample at individual pressures and weights is shown in Table 1. According to the STN EN ISO/IEC 80079-20-2:2016 standard, the minimum ignition temperature of dispersed ground sweet pepper dust is recorded as the lowest temperature of the furnace at which ignition was obtained using the above procedure minus 20 K for furnace temperatures.

Table 2 shows the measured results of MIT. Figures 3 - 5 show a graphical comparison of the measured MIT under different conditions.

Table 2 Results of measured MIT of ground sweet pepper

m (g)	P (kPa)	Fraction (µm)					
		90 - 150		150 - 200		200 - 250	
		t (°C)	MIT (°C)	t (°C)	MIT (°C)	t (°C)	MIT (°C)
0.1	10	620	**600**	630	**610**	630	**610**
	30	620	**600**	620	**600**	620	**600**
	50	610	**590**	620	**600**	620	**600**
0.3	10	600	**580**	610	**590**	610	**590**
	30	590	**570**	600	**580**	610	**590**
	50	590	**570**	600	**580**	600	**580**
0.5	10	580	**560**	600	**580**	600	**580**
	30	580	**560**	590	**570**	600	**580**
	50	570	**550**	590	**570**	600	**580**

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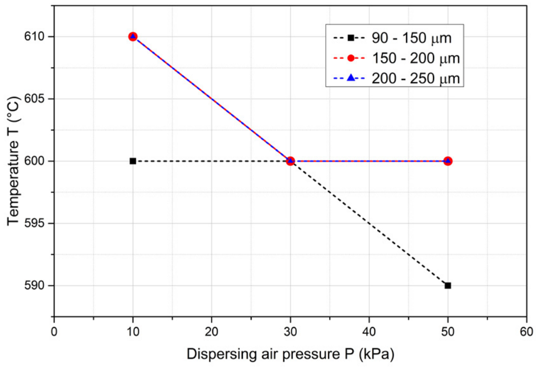

Figure 4 Dependence of MIT of ground sweet pepper on particle size and air dispersing pressure for a sample weight of 0.1 g

The influence of individual measurement conditions (dispersing air pressure and fraction size) with a sample weight of 0.1 g is shown in Figure 4. The results show that, at higher dispersion pressures, the minimum ignition temperature was lower. This observation is supported by several other research, such as (Liu et al., 2019; Sun et al., 2020), where the MIT continuously decreased up to 60 kPa, however thereafter it increased. In addition to this, it would be interesting for future research to investigate the effect of higher dispersion pressure on MIT in sweet pepper samples.

In this case, the lowest ignition temperatures were observed at the 90 - 150 µm fraction. The ignition temperature for a weight of 0.1 g was 590 °C at a pressure of 50 kPa, and 600 °C at pressures of 10 kPa and 30 kPa.

The sample with a fraction of 200 - 250 µm and the sample with a fraction of 150 - 200 µm had identical minimum ignition temperatures measured at the individual monitored pressures.

The minimum ignition temperature of the studied dust in accordance with STN EN 80079-20-2:2016 for the fraction 200 - 250 µm and the fraction 150 - 200 µm was 610 °C at a pressure of 10 kPa, and 590 °C at pressures of 30 kPa and 50 kPa.

The results show that a better distribution of the particles and also a decrease in the minimum ignition temperature occur if the sample enters the furnace under higher pressure.

As the dust particle size of the same sample mass decreases, the available surface area of the sample increases, providing more capacity for rapid reaction (Li et al., 2019).

Therefore, the explosiveness of dust increases with a decreasing particle size, and the smaller the particle size, the less energy is required to ignite the dust (Di Benedetto and Russo, 2007).

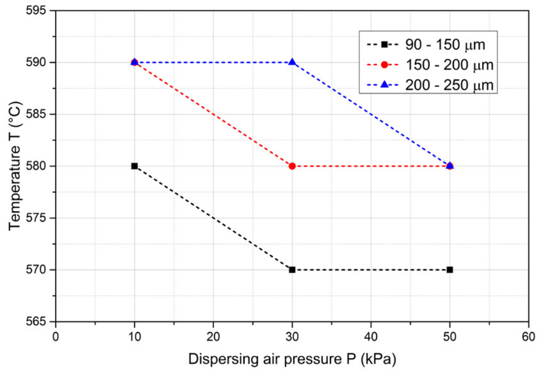

Figure 5 Dependence of MIT of ground sweet pepper on particle size and air dispersing pressure for a sample weight of 0.3 g

Figure 5 shows that the lowest ignition temperatures were observed for the 90 - 150 µm fraction. The minimum ignition temperature for a weight of 0.3 g was 570 °C at pressures of 30 kPa and 50 kPa.

For fractions 150 - 200 µm and 200 - 250 µm at 30 and 50 kPa the minimum ignition temperature of 580 °C was observed.

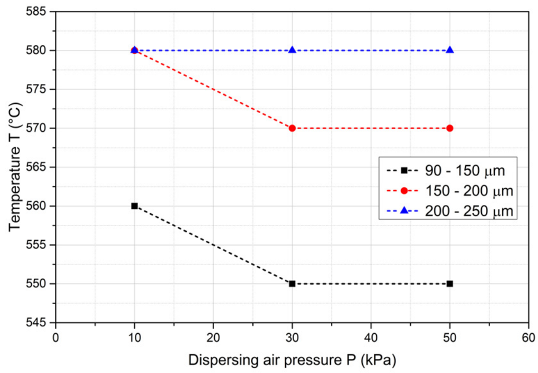

Figure 6 Dependence of MIT of ground sweet pepper on particle size and air dispersing pressure for a sample weight of 0.5 g

Figure 6 shows that the MIT of 200 - 250 µm fraction was 580 °C at all dispersing air pressures.

MIT for a fraction of 150 - 200 µm was 570 °C and at pressures of 30 kPa and 50 kPa. MIT for a fraction of 200 - 250 µm was 550 °C and at pressures of 30 kPa and 50 kPa.

Conclusion

The minimum temperature at which dust clouds ignite is one of the most important factors in industries where explosions can arise from hot surfaces. This paper presents the results of experimental research related to the determination of combustible dust cloud ignition parameters (i.e., minimum ignition temperature) of ground sweet pepper in a G-G furnace.

Since paprika is ground in large quantities in the food industry (as a foodstuff, a dye...), it is likely that an explosion of dispersed dust from the hot surface may occur. Therefore, it is necessary to know all its parameters, while the ignition temperature may depend on the size of the particles. As a result, it is recommended to monitor the surface temperature of devices and their parts (mainly grinding devices) and to adapt explosion prevention measures accordingly.

Results show that MIT depends on the particle size of the fraction. At a constant dust concentration, the MIT decreased as the particle size decreased. Also, with increasing dispersing air pressure, the MIT decreased. The minimum ignition temperature of ground sweet pepper at 550 °C was observed at a pressure of 30 a 50 kPa and a sample weight of 0.5 g.

Considering the lack of professional publications on special types of food spices in the database, further research will focus on the fire and explosion parameters of these spices.

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