

Comparative study on the ignition parameters in layer and cloud different type of protein rich content flours

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Abstract. The purpose of the article is research focused on the study of dust fires and explosions in the food industry, explored the characteristics of dust explosions and presented options for prevention and damage reduction. The determination of the minimum ignition temperature of the dust cloud was carried out using the Godbert-Greenwald furnace for dust cloud and the specific stand for dust layer. The minimum ignition temperature (MIT) is crucial for the assessment of explosion hazards in various materials, including organic materials and protein substances. The ignition temperature can vary significantly depending on factors such as particle size, concentration and environmental conditions. For protein-containing dusts, the minimal ignition temperature can vary, but general estimates and standards provide guidance. The present study successfully identifies a range of flammable organic dusts, including flaxseed flour, oat meal, millet flour, pumpkin seed flour, for which the minimum ignition temperature for dust cloud and layer was experimentally investigated.

1 Introduction

Fires and explosions caused by combustible dusts affect several branches of industry. The explosive properties of combustible dusts are determined by their chemical composition. Powders represent industrial dust obtained from one or more physico-chemical shredding operations. The size of the dust particles influences the parameters of the explosion: the ignition temperature, the explosion limit and the speed of the pressure increase [1]. The sedimentation speed of the dust particles depends in particular on their specific gravity and the temperature. In order for ignition to occur, the dust must exist in suspension [2].

The minimum ignition temperature (MIT) for protein-rich powders varies significantly depending on several factors, including the type of powder, particle size, and the presence of additives. Research indicates that the MIT can be influenced by the powder concentration and the conditions under which it is tested. Protein-rich powders, similar to biomass, exhibit variable ignition temperatures. For example, the addition of fire extinguishing powders can significantly increase the MIT of dust layers and clouds, with a notable increase of 80° C observed with just 15% of an ABC powder added to biomass dust [3].

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The ignition temperature of protein-rich dust clouds, although not directly studied in the provided papers, can be inferred from related research on combustible dusts. The minimum ignition temperature (MIT) is essential for assessing explosion hazards in various materials, including organic and proteinaceous substances. This is a critical factor in the safety of industrial processes handling combustible dusts (food processing, pharmaceuticals) [4].

The minimum ignition temperature of a dust layer depends on several factors, including the type of dust, its thickness, moisture content and ambient conditions. For protein-containing dusts, the MIT can vary, but general estimates and standards provide guidance.

Although the specific ignition temperature for protein-rich dust clouds is not explicitly defined, it is likely influenced by the factors described above, indicating the need for further research in this area. Conversely, the variability of ignition temperatures between different types of dust suggests that protein-rich materials may exhibit unique behaviors that warrant dedicated studies [5].

Food production and processing are processes that also involve a fire risk. From this perspective, factories that produce powdery products are particularly dangerous, since the possibility of a dust explosion must be taken into account. This phenomenon can occur even with the use of modern technological equipment and strict fire safety regulations; therefore, the study and investigation of dust explosions are essential for the development of effective preventive measures [6]. To reduce the risk of fires and explosions, the explosion parameters of combustible dusts must be known, such as the MIT of the dust in cloud and the MIT of the dust in layer form [7].

Proteins are natural macromolecular compounds that are formed [8] as a result of polycondensation reactions involving α -amino acids. The union of amino acid residues is done by peptide bonds. Polycondensation reactions form polypeptides and finally proteins. Hydrolysis of proteins leads to approximately 20 natural amino acids.

Valine, $C_5H_{11}NO_2$, is an essential amino-acid used in the biosynthesis of proteins. The combustion reaction of valine:



When amino acids are burned, it undergoes a complex process of decomposition, including deamination, and dehydration, decarboxylation leading to the formation of various gaseous products [9,10]. The primary gaseous products are carbon dioxide, ammonia, carbon monoxide, and 3-methyl-1-butanamine. Aromatic amino acids also tyrosine may ignite at slightly lower temperatures due to their benzene rings. Smaller amino acids alanine tends to have higher ignition temperatures [11]. Thermal decomposition often occurs before full ignition, producing gases like carbon dioxide, ammonia, and hydrogen cyanide. Amino acids are not highly flammable but can combust at high temperatures in the presence of an ignition source.

The present study successfully identifies a range of flammable dusts, including flaxseed flour, oat meal, millet flour, pumpkin seed flour. The samples were characterized by means of IR and gravimetric methods, followed by flammability characterization. Each of these materials was tested to determine their ignition characteristics.

2 Materials and methods

The following protein containing dust were selected, figure 1-4, respectively, oat, pumpkin, flax and millet flour.



Fig. 1 Oat flour



Fig. 2. Pumpkin flour



Fig. 3. Flax flour



Fig. 4. Millet flour

The sample moisture was determined with a thermobalance, Ohaus – type, figure 5, and the granulometric analysis was determined with RETSCH AS 20 type sieving apparatus, figure 6.



Fig. 5. Determination of sample moisture

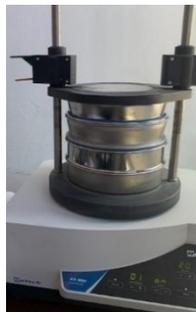


Fig. 6. Granulometric analysis

In table1 is presented the granulometric composition of the selected dust: millet flour, oat flour, flax flour and pumpkin flour.

Table 1. Granulometric analysis of dust

Type of flour	Particle size over 250µm	Particle size 250-125 µm	Particle size 125-63 µm	<63 µm
Millet flour	8.13%	55.72%	30.96%	5.19%
Oat flour	6.29%	58.94%	27.83%	6.94%
Flax flour	66.35%	26.85%	6.16%	0.64%
Pumpkin seeds flour	19.67%	44.04%	32.39%	3.90%

To determine the particle size composition, sieves with mesh sizes of 250 μm , 125 μm and 63 μm and a technical balance were used. The samples were placed on the upper 250 μm sieve, they passed successively through the three sieves, using the RETSCH sieving system.

The composition for the selected flours is given as stated by the producer, and can be seen in the table below, together with the moisture as determined experimentally:

Table 2. Composition and humidity of different type flour

Type of flour	Proteins	Carbohydrates	Lipid	Moisture
Flax flour	34%	38,5%	9,5%	7%
Oat flour	14,7%	68,7%	9,1%	5,9%
Millet flour	11%	72,9%	4,2%	8,6%
Pumpkin seeds flour	54%	15%	14%	4,3%

Comparing the results from table 2, it was concluded that the highest protein and lipid content is in pumpkin seed flour and the lowest in millet flour.

The samples were analysed for the characteristic spectra with a Nicolet IS 50 Thermo-Scientific spectrometer (Figure 7) that has a range from 4000 to 400 cm^{-1} , and an accuracy of 4 cm^{-1} . The advantage of using ATR analysis method is that this method does not actually require a sample preparation whether the sample is a powder, film or even a smooth surface of the finished object. Fourier transform infrared spectroscopy is used to study the structural characteristics of proteins, including those extracted from plant sources such as pumpkin seeds flour.



Fig. 7. Thermo- Scientific spectrometer type Nicolet IS 50 Equipment

The FTIR spectrum of proteins show characteristics amide, C-H, O-H and N-H bands. By analyzing the positions and intensities of these bands, researchers can identify the presence and relative abundance of different functional groups in a protein sample.

Table 3. Type of FTIR bands description

Amide I	1600-1700 cm^{-1}	C=O stretching
Amide II	1500-1600 cm^{-1}	N-H bending
Amide III	1220-1330 cm^{-1}	C-N stretching band
C-H stretch	2800-3000 cm^{-1}	Aliphatic C-H stretching
Broad O-H/N-H	3200-3400 cm^{-1}	Hydrogen bond -moisture content

For the determination of flammability properties the following apparatus were used, in figure 8, MIT of the dust layer and in figure 9, MIT of the dust cloud.

During this test, the dust layer ignition is recognized when the glowing or flaming burning is observed or the temperature measured by thermocouple of the dust reaches 450°C or the temperature measured by thermocouple of the dust exceed 250K by the temperature of the furnace plate. The test involves placing a layer of inflammable dust in a metal ring with an inner diameter of 100 mm and a thickness of 5±0.1 mm. The temperature of the heated surface is adjusted to the desired level. The minimum ignition temperature is determined in a Godbert Greenwald furnace. The testing platform is equipped with a heating furnace, control system, pressurized air storage tank, valve, dust storage enclosure, and an ignition observation mirror. The furnace maintains a temperature range of 25-1000°C. The process involves weighing a specific amount of powder, setting the temperature of the vertical furnace, and injecting the powder at high speed to form a dust cloud. The ignition is determined visually. The Godberg-Greenwald furnace is vertical, with the bottom open to the bottom. A horizontal tube connects to the dust sample delivered by a glass viewing chamber. The dust to be evaluated is delivered from the sample to the furnace using compressed air. Dust ignition happens when a flame is visible on the device's underside, as shown in the mirror below. Two thermocouples are connected to the Godberg-Greenwald furnace to measure the temperature. The required amount of dust is weighed using a balance. The pneumatic system swirls the dust, bringing it into touch with the hot furnace.



Fig. 8. Dust layer minimal ignition temperature determination

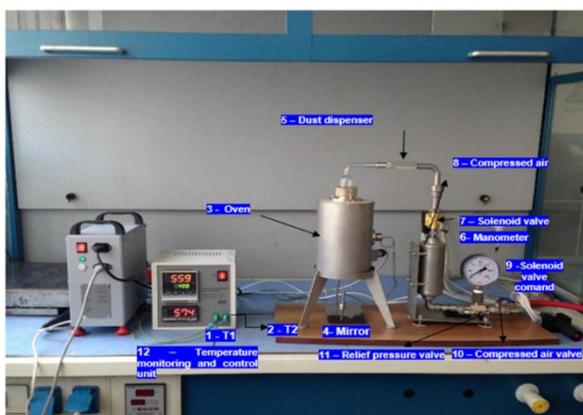


Fig. 9. Apparatus for determining the minimum ignition temperature of the dust cloud

3 Results and discussion

3.1. Sample analyses

The materials were evaluated using infrared spectrometry, FTIR (Fourier Transform InfraRed spectroscopy) equipment type Nicolet IS 50, with integrated ATR (Attenuated Total Reflectance) module, diamond crystal, in the 4000 - 400 cm^{-1} range (fig. 2).

Infrared absorption spectra were acquired at a resolution of 4 cm^{-1} using the ATR analysis technique, attenuation of total reflection, which was performed directly on the materials - non-destructive analysis. Each spectrum was scanned 32 times. The experimental results were analyzed using the OMNIC software (Thermo Nicolet Corporation). Amino acids and peptides contain fundamental bonds such as C=O, C-N, and N-N. Amide I band, typically found in the 1600-1700 cm^{-1} region, is associated with C=O stretching vibration of the peptide bond. Amide II band located in the 1500-1600 cm^{-1} region; this band arise from the N-N bending and C-N stretching vibration. The amide I band (around 1650 cm^{-1}) is primarily associated with C=O stretching vibrations, while the amide II band (around 1540 cm^{-1}) is linked to N-H bending and C-N stretching. The characteristic FTIR spectrum are given in the figures 10-14 below.

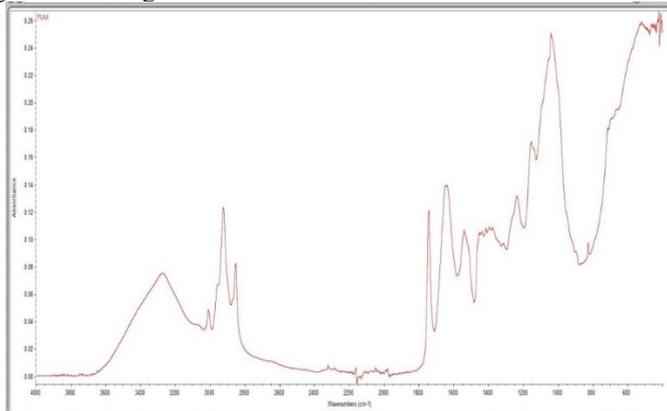


Fig. 10. Flax flour FTIR spectrum

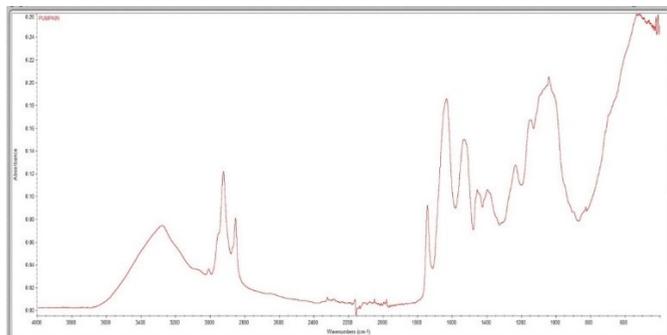


Fig. 11. Pumpkin seeds flour FTIR spectrum

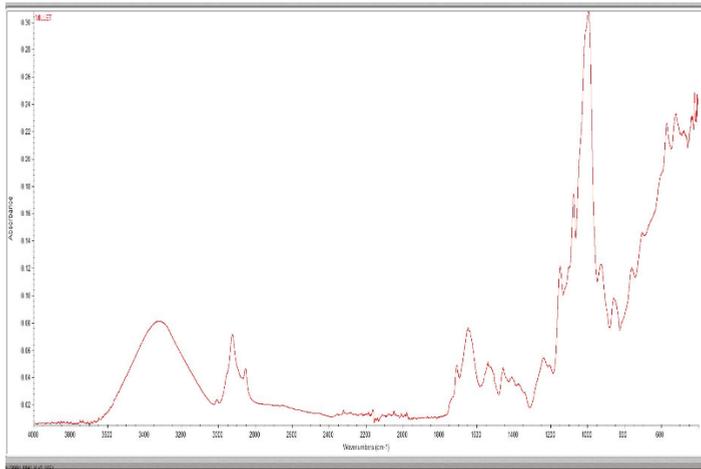


Fig. 12. Millet flour FTIR spectrum

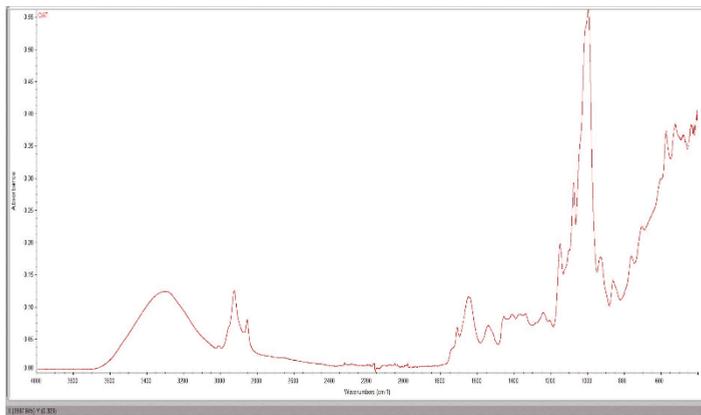


Fig. 13. Oat flour FTIR spectrum

FTIR spectra show characteristic absorption bands for various functional groups present in proteins, including amide groups and side chains of amino acids.

3.2. Experimental ignition test

The minimum ignition temperature of the combustible dust in cloud form was determined for flaxseed, pumpkin seed, oat and millet flour, the results are given in the table 4:

Table 4. Minimum ignition temperature of dust cloud

Flax flour	560°C
Oat flour	470°C
Millet flour	450°C
Pumpkin seeds flour	490°C

Comparing the results we can conclude that the highest minimum ignition temperature of the dust cloud determined experimentally was found in the case of flaxseed flour. Pumpkin seed flour is the richest content in proteins and oil also shows a higher cloud ignition temperature of 490° C compared to millet flour was 450°C. Flaxseed flour has a higher minimum cloud ignition temperature 560°C possibly due to its high oil content and agglomeration tendency as stated in the literature, flaxseed flour is characterized by its high

oil content and tendency to agglomerate, which significantly influences its application in food products [12].

The minimum ignition temperature of the combustible dust layer was determined for flaxseed, pumpkin seed, oat and millet flour and the results are given in the table 5:

Table 5. Dust layer ignition temperature

Oat flour	>400°C
Pumpkin seeds flour	> 400°C
Flax flour	> 400°C
Millet flour	> 400°C

Dust layer ignition temperature for oat flour, pumpkin seeds flour, flax flour and millet flour was determined experimentally to be over 400 °C. The ignition temperature of the dust layer for flours, as determined through experimentation, exceeds 400°C mainly due to the restricted oxygen supply within the densely packed dust layer and the energy needed for the thermal breakdown of organic materials. In a dust layer experiment, the powder is compacted, resulting in a medium with low porosity. In contrast to a dust cloud where particles are dispersed in air, the dense structure of the layer limits the oxygen flow. All four types of flours—oat, pumpkin seeds, flax, and millet—are organic substances abundant in complex carbohydrates, fats, and proteins. These macromolecules are not easily ignitable. For ignition to occur, they require a considerable amount of thermal energy to decompose these large molecules into smaller, more volatile, and flammable compounds. This transformation, referred to as pyrolysis, is essential for ignition, and the dust itself possesses insulating properties, with the dust layer functioning as an insulator that retains heat. Nevertheless, the heat must still reach a sufficient level to surmount the energy barrier required to break the chemical bonds and induce auto-ignition. This phenomenon is observed at temperatures exceeding 400°C.

Typically, materials that contain a greater amount of protein and oil are associated with reduced ignition temperatures, as these elements are more flammable than carbohydrates such as starch. The comparatively lower ignition temperature of millet flour, oat flour, and pumpkin seed flour in relation to flaxseed flour can be attributed to their respective compositions. The elevated ignition temperature of flaxseed flour might be due to its propensity to clump together, which prevents the creation of a uniform, ignitable dust cloud.

4 Conclusions

In respect to the flammability properties the data clearly indicates a distinct hierarchy in minimum ignition temperatures: Flaxseed flour > Pumpkin seeds flour > Oat flour > Millet flour. Flaxseed flour exhibits the highest ignition temperature, whereas millet flour presents the lowest. Pumpkin seed flour has a high oil content as stated in the literature, which can increase the risk of self-heating and the minimum ignition temperature in the cloud is quite high. Oat flour has a relatively high minimum ignition temperature, similar to related cereals. Flaxseed flour has the higher minimum cloud ignition temperature 560°C probably due to its high oil content and agglomeration tendency. Millet flour generally has a lower minimal ignition temperature, which means it is slightly more flammable in cloud form.

The minimum ignition temperature of powders is an important feature for determining explosion danger. The minimum temperature at which protein-rich dust clouds ignite is thought to be highly relevant in industries where explosions and fires might occur as a result of contact with heated surfaces. The minimum ignition temperature is the lowest surface temperature that can ignite a powder or dust spread in the form of a dust cloud, and it is important for determining the maximum working temperature of electrical and mechanical

equipment utilized in dusty conditions. The minimum ignition temperature of combustible dust is particularly important for the design of preventive measures against dust explosions. It significantly influences safety protocols, as understanding this parameter helps mitigate the risks associated with both dust layers and dust clouds in various industrial environments. It is particularly important to understand the danger represented by dusty materials and the level of awareness to be preceded by taking measures represented primarily by the properties of the substances used in the technological process.

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