THE EFFECT OF PARTICLE SIZE DISTRIBUTION ON THE EXPLOSIBILITY PARAMETERS OF SOY PROTEIN CONCENTRATES DUST

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ABSTRACT

The paper presents the testing results of soy protein concentrate dust explosibility parameters, including maximum explosion pressure (pmax), maximum rate of explosion pressure rise ((dP/dt)max), and dust explosion severity index (Kst,max), as well as an analysis of the effect of dust particle size distribution on the examined parameters. Laboratory testing of explosibility parameters was carried out on three test samples with particle sizes of 125 µm, 75 µm, and 63 µm. The tests were performed in accordance with the international standard ISO/IEC 80079-20-2:2016. It was found that the 125 µm dust fraction had values of pmax = 6.7 bar and Kst,max = 110 bar·m/s. The 75 µm fraction had values of pmax = 7.0 bar and Kst,max = 137 bar·m/s. The 63 µm fraction had values of pmax = 7.1 bar and Kst,max = 132 bar·m/s.

Keywords: explosion pressure, maximum rate of pressure rise, explosion severity index, soy protein concentrates, particle size distribution

INTRODUCTION

Food industry facilities are often exposed to the risk of fires and explosions, as evidenced by a large number of combustible dust incidents occurring every year. An objective assessment of the potential hazard is difficult to achieve without detailed knowledge of the relevant parameters of the combustible dust used in a specific technological process. It should be emphasised that particle size distribution can significantly affect the explosibility and flammability parameters of dusts [4], [5].

In recent times, increasing attention has been paid to fire and explosion hazards of combustible dusts, which is evidenced by the development of standards covering this area as well as statistical monitoring of data on dust-related incidents. The data collected on combustible dust incidents for the period 2016–2019 in the USA indicate that, on average, 33.2 dust explosions, 29 injuries, and 3 fatalities occur annually [3]. Monitoring the frequency of fires and explosions according to dust type, industrial sector, and the type of equipment is of great importance for the implementation of effective preventive measures. Statistical data from the same source for the above-mentioned period indicate that wood processing products (sawdust, shavings, fibres, pellets) and food products (grain, flour, soy, rice, milk powder, seeds, fertilisers) account for an average of 60% of materials involved in combustible dust fires and explosions. The distribution of explosions and fires according to dust type and industrial sector is shown in Figures 1 and 2.

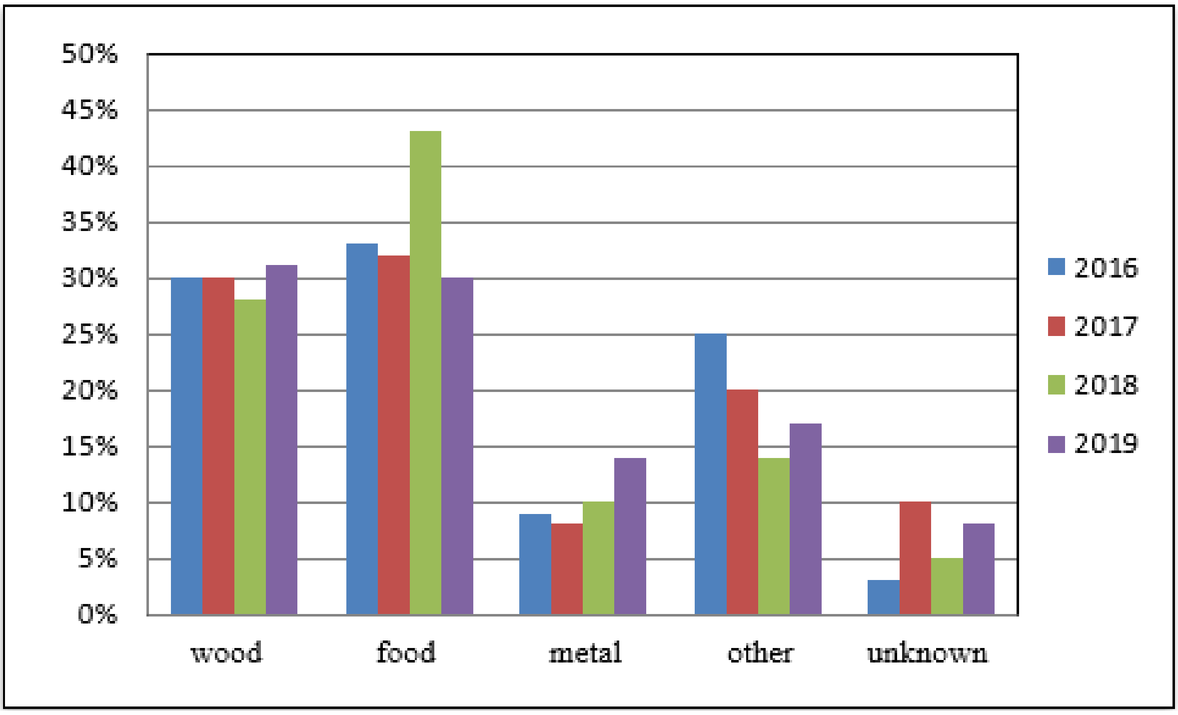

Figure 1. *Distribution of Explosions and Fires According to the Type of Combustible Dust*

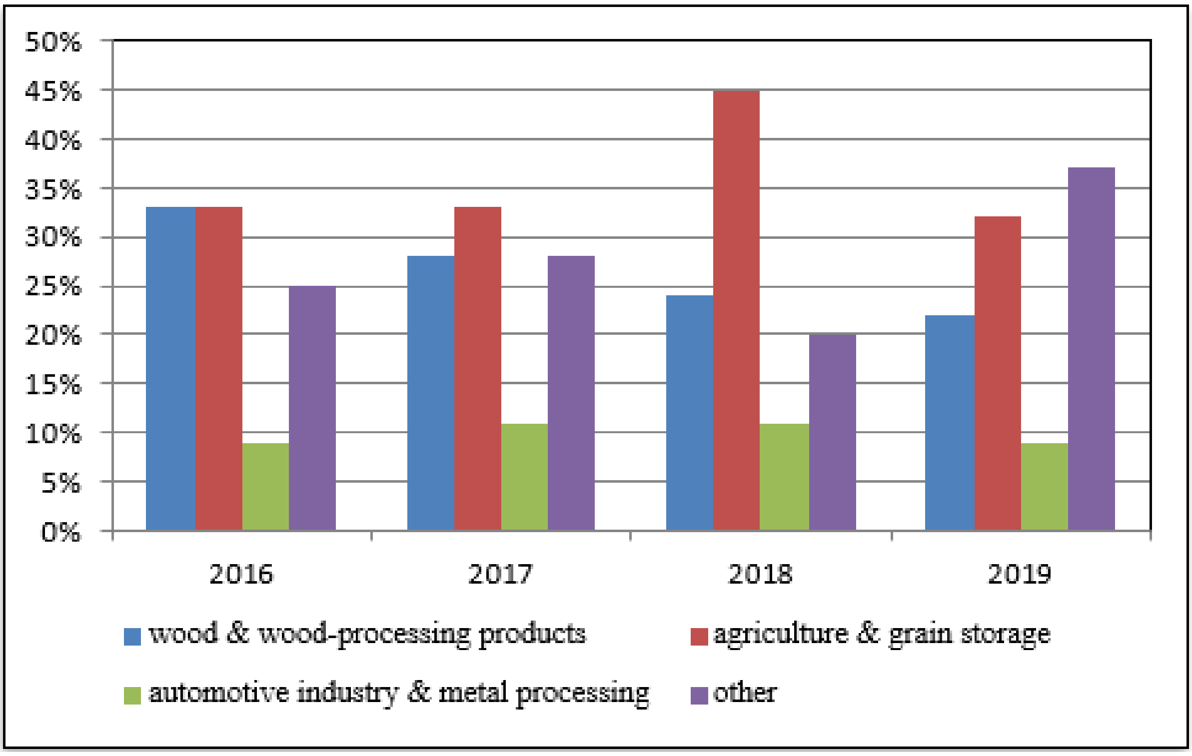

Figure 2. *Distribution of Explosions and Fires According to Industrial Sector*

It was found that the highest percentage of incidents in production processes is associated with dust collection equipment; however, this category shows the lowest proportion of recorded explosions compared to other types of equipment, as shown in Figure 3. The number of fatalities in incidents involving dust collectors is lower than in incidents involving other types of equipment, such as silos, elevators, conveyor belts, etc.

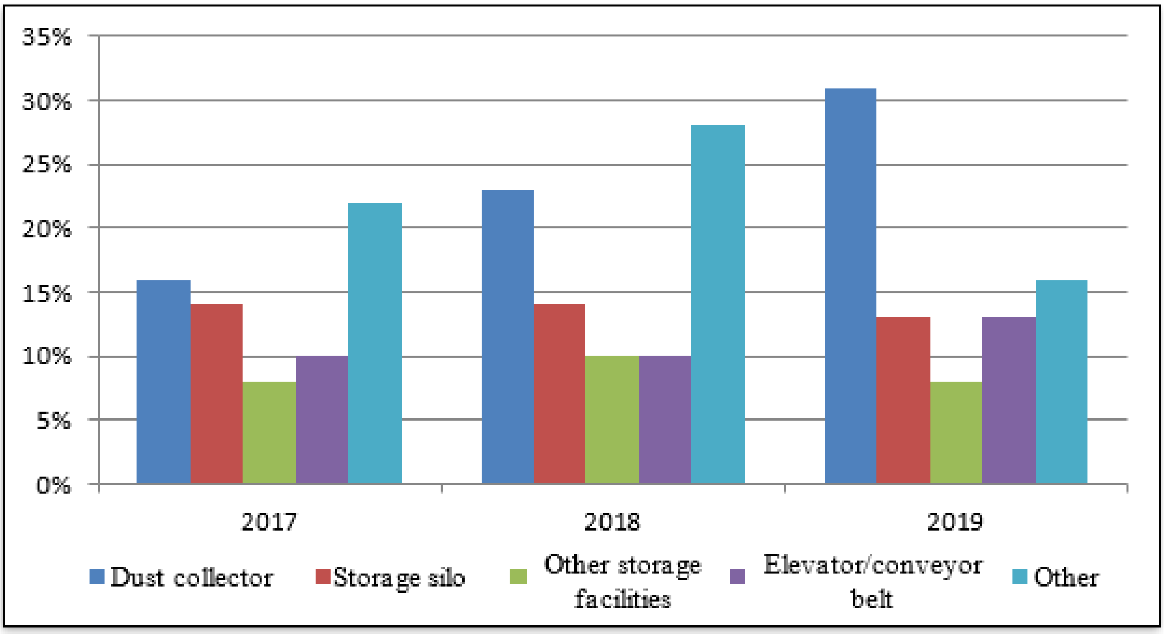

Figure 3. *Incidents Involving Combustible Dusts According to the Type of Equipment in the Production Process*

METHODOLOGY FOR TESTING EXPLOSION PARAMETERS

Knowledge of dust explosibility parameters is necessary for the design of industrial facilities, the correct selection and installation of electrical and mechanical equipment intended for use in potentially explosive atmospheres, the application of protective measures in such facilities, and the classification of hazardous areas.

The ISO/IEC 80079-20-2:2016 standard describes methods for testing combustible dusts and combustible dust layers for the purpose of their identification, in order to enable the classification of areas in which such materials are present [8]. The classification of areas containing combustible dusts is important for the proper selection and installation of electrical and mechanical equipment intended for use in such environments.

Testing of explosibility parameters was carried out in a spherical chamber with a volume of 20 dm^3, type KSEP 20 with accompanying equipment, manufactured by “Kühner” – Switzerland. The following parameters were measured: maximum pressure as a function of dust concentration (pmax), maximum rate of pressure rise as a function of dust concentration ((dP/dt)max), and ignition delay time (t1). The dust explosion was initiated using chemical igniters with a total energy of 10 kJ.

Table 1. *Explosibility Parameters and Standards According to Which They Were Determined [6] [7]*

Explosibility Parameter	Definition	Standard	Determination
p_{max}	Maximum explosion pressure (bar)	EN 14034-1:2004+A1:2011	Measurement of explosion pressure as a function of dust concentration in a 20 L test sphere
$(dp/dt)_{max}$	Maximum rate of pressure rise (bar/s)	EN 14034-2:2006+A1:2011	Testing of explosion severity in a test sphere, used for the calculation of the KSt value
K_{St}	Dust explosion severity index (bar·m/s)	EN 14034-2:2006+A1:2011	$(dp/dt)_{\max} \cdot V^{1/3} = const. = K_{St} = K_{\max}$

Prior to experimental testing, three test samples with particle sizes of 125 µm, 75 µm, and 63 µm were prepared by sieving on a vibrating sieve with standardised mesh sizes. The reason for preparing these samples was to investigate the "most unfavourable" case from the standpoint of explosion protection, since finer particles tend to react more violently than coarser ones. In addition, moisture, ash, and volatile matter contents were determined, as they also influence the tested parameters.

Testing of explosibility parameters was performed at dust concentrations of 125 g/m^3, 250 g/m^3, 500 g/m^3, 750 g/m^3, 1000 g/m^3, 1250 g/m^3, and 1500 g/m^3. After the initial test series, the concentration range near the observed maxima of pmax and (dP/dt)max was checked twice. The tests were repeated at the optimal concentration, as well as at the next lower and higher concentrations. The explosibility parameters were defined as the average values of the maximum values obtained from each series.

RESULTS AND ANALYSIS

The results of explosibility parameter testing for three particle size fractions of soy protein concentrates with an average moisture content of 6.17% m/m, ash content of 5.61% m/m, and volatile matter content of 83.33% m/m are presented in Table 2 and Figures 1, 2, and 3.

Table 2. *Explosibility Parameters of Soy Protein Concentrates*

Explosibility Parameters	Values		
	125 µm	75 µm	63 µm
Maximum explosion pressure, p_{max} *(bar)*	6.7	7.0	7.1
Maximum rate of pressure rise, $(dp/dt)_{max}$ *(bar/s)*	406	506	488
Explosion constant, $K_{st,max}$ *(m·bar/s)*	110	137	132
Ignition delay time of the explosive mixture, t_1 (ms)	72	47	42

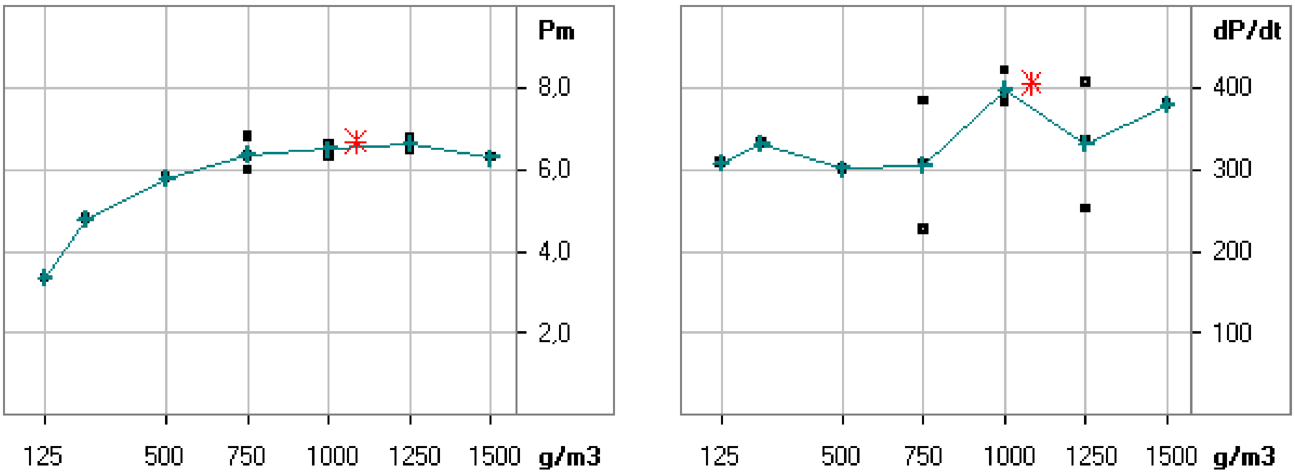

Figure 1. *Graphical Representation of the Increase in pmax and (dP/dt)max Depending on the Dust Concentration for a Particle Size Fraction of 125 µm*

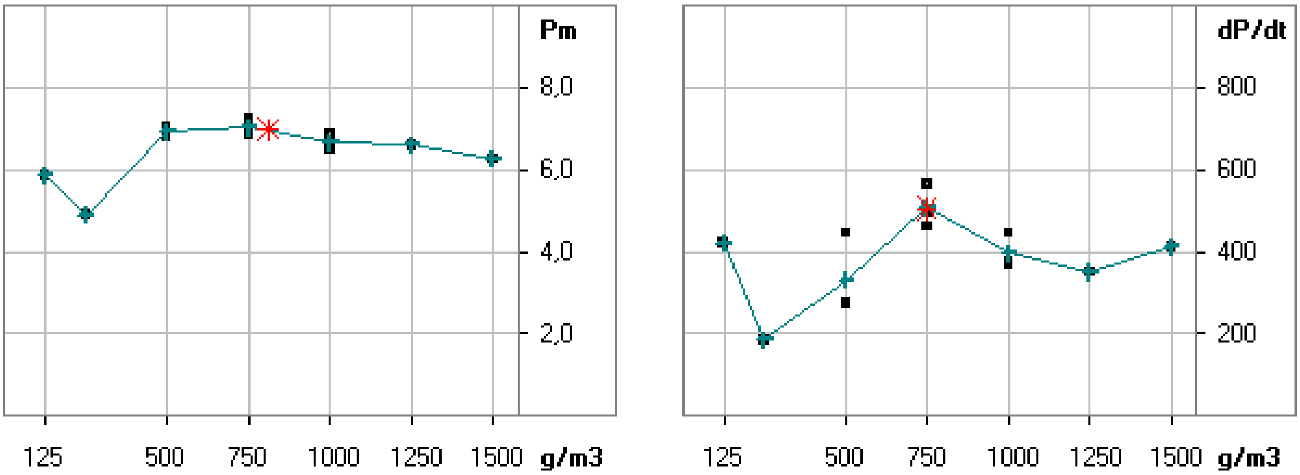

Figure 2. *Graphical Representation of the Increase in pmax and (dP/dt)max Depending on the Dust Concentration for a Particle Size Fraction of 75 µm*

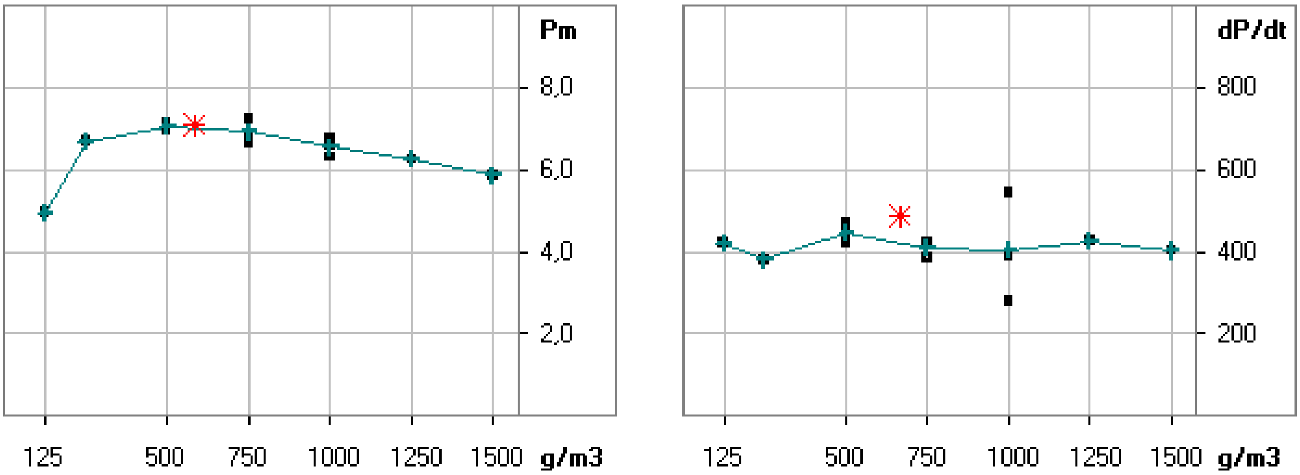

Figure 3. *Graphical Representation of the Increase in pmax and (dP/dt) max Depending on the Dust Concentration for a Particle Size Fraction of 63 µm*

Observing the graphical representations in Figures 1, 2, and 3, changes in the explosibility parameters with respect to the particle size distribution of the tested dusts are evident. The highest maximum explosion pressure was obtained for the 63 µm particle size fraction and amounts to 7.1 bar. The results of the study confirm the rule that the maximum explosion pressure and maximum rate of pressure rise are achieved at lower dust concentrations with decreasing particle size [5].

For the 125 µm particle size fraction of the tested dust, pmax = 6.7 bar and (dP/dt)max = 406 bar/s were obtained at a dust concentration between 1000 and 1250 g/m^3.

For the 75 µm particle size fraction, pmax = 7.0 bar was obtained at a dust concentration between 750 and 1000 g/m^3, while (dP/dt)max = 506 bar/s was obtained at a dust concentration of 750 g/m^3.

For the 63 µm particle size fraction, pmax = 7.1 bar and (dP/dt)max = 488 bar/s were obtained at a dust concentration between 500 and 750 g/m^3.

The ignition delay time of the explosive mixture for the 63 µm particle size fraction is the lowest and amounts to 42 ms, while for the 125 µm particle size fraction it is the highest and amounts to 72 ms. It was observed that the minimum ignition delay time for the tested 63 µm dust fraction occurs independently of the maximum explosion pressure and the maximum rate of explosion pressure rise, which is not the case for the other two tested samples. The highest value of the explosion constant is 137 m·bar/s, while the lowest is 100 m·bar/s. According to the explosion constant parameter (Kst,max), all three tested samples are classified into explosion class 1 (St1 < 200 m·bar/s), with weak or moderately explosive severity [1], [2].

CONCLUSION

The testing presented in this paper was carried out with the aim of obtaining relevant data on the effect of particle size distribution on the explosion parameters of soy protein concentrates for the "most unfavourable" cases from the standpoint of explosion protection. The value of the explosion constant together with the maximum explosion pressure is a measure of the explosion hazard that the tested soy protein concentrate dust introduces into the process, the knowledge of which is, among other things, necessary for the application of protective measures in plants and for the classification of hazardous areas.

Laboratory testing of explosibility parameters was carried out on three test samples with particle sizes of 125 µm, 75 µm, and 63 µm. It was found that with decreasing particle size of soy protein concentrates, the values of the explosion constant (max. 137 m·bar/s) and the explosion pressure (max. 7.1 bar) increase. The difference between the highest and lowest maximum explosion pressure is 0.4 bar, while the difference between the highest and lowest values of the explosion constant is 27 m·bar/s.

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UTICAJ GRANULOMETRIJSKOG SASTAVA NA PARAMETRE EKSPLOZIVNOSTI PRAŠINE SOJINIH PROTEINSKIH KONCENTRATA

SAŽETAK

Članak prikazuje rezultate ispitivanja parametara eksplozivnosti prašine sojinih proteinskih koncentrata: maksimalnog pritiska eksplozije (pmax), maksimalnog vremenskog porasta pritiska eksplozije (dp/dt)max, indeksa jačine eksplozije prašine (Kst,max) i analizu uticaja granulacije čestica prašine na ispitivane parametre. Laboratorijska ispitivanja parametara eksplozivnosti su izvršena na tri ispitna uzorka granulacije čestica 125 µm, 75 µm i 63 µm. Ispitivanja su provedena u skladu sa međunarodnom normom ISO/IEC 80079-20-2:2016. Ustanovljeno je da granulacija čestica ispitivane prašine 125 µm ima vrijednosti pmax= 6,7 bar i Kst,max = 110 bar·m/s. Granulacija čestica ispitivane prašine 75 µm ima vrijednosti pmax= 7,0 bar i Kst,max = 137 bar·m/s. Granulacija čestica ispitivane prašine 63 µm ima vrijednosti pmax = 7,1 bar i Kst,max = 132 bar·m/s.

Ključne riječi: pritisak eksplozije, maksimalni vremenski porast pritiska, indeks jačine eksplozije, sojini proteinski koncentrati, granulacija čestica

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