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MINIMUM IGNITION TEMPERATURES OF FOOD DUST CLOUDS DETERMINATED BY PLANNED EXPERIMENT

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ABSTRACT: This paper is attended to the determination of the minimum ignition temperature of dust cloud of food – wheat flour, corn flour, corn amyloid and potato amyloid. The minimum ignition temperature (MIT) test determines the lowest surface temperature capable of igniting a powder or dust dispersed in the form of a dust cloud. The planned experiment was oriented on finding the influence of air pressure and weight of sample of food dust on the minimum ignition temperature of dust cloud. For laboratory conditions was arranged experiment of two factors, where the weight of sample m and pressure p of air were active factors and the moisture of sample v was passive factor (constant parameter). These parameters were quantitative factors of experiment. The kind of dust was arranged as the qualitative factor of experiment. The minimum ignition temperature of dust cloud was dependent parameter (response of determination).

KEYWORDS: food dust, flammability, dust cloud, minimum ignition temperature, minimum ignition temperature of dust cloud

❖ INTRODUCTION

Although the flammability of gases and vapours is well understood, the hazards associated with dusts are often overlooked. Dust clouds from any source of release including a layer or accumulation may explode. Dusts layers may ignite due to self heating or hot surfaces and cause a fire hazard or over heating of equipment. A wide variety of workplaces may contain activities that produce explosive or potentially explosive atmospheres. Dust explosion hazards are common in industries like coal mining, storage and processing of agricultural products (i.e., starch, flour, sugar, cocoa) and organic dusts (i.e., drugs, dyestuffs, plastics), and the manufacture of metal powders (i.e., aluminium, magnesium). Various unit operations involving combustible solids, such as grinding, drying, dust collection and pneumatic and other modes of transportation, are always exposed to explosion risk [1, 3].

In order to prevent and mitigate the risk coming from these operations, the explosion parameters, such as maximum pressure, maximum rate of pressure rise and deflagration index, minimum explosible dust concentration and minimum ignition temperature, have to be determined. The minimum ignition temperature at which dust clouds ignite is required to prevent the explosion risk arising from the presence of hot surfaces [1].

Hot surfaces capable of igniting dust clouds exist in a number of situations in industry (furnaces and burners, dryers of various kinds). In addition, hot surfaces can be generated accidentally by overheating bearings and other mechanical parts.

If an explosible dust cloud is generated in some uncontrolled way in the proximity of a hot surface with a temperature above the actual minimum ignition temperature, a dust explosion can result. As a consequence, in the prevention and mitigation of dust explosions, it is important to know the minimum ignition temperature of dusts in order to take adequate precautions to ensure that hot surface temperature does not reach this value [1].

EXPERIMENTAL PART. MATERIALS AND PLANNED EXPERIMENT DESCRIPTION

The materials used for study was food dusts. Description of samples of food dusts are listed in Table 1.

Table 1. Description of food dust samples

Food dust	Sample composition	Producer
Wheat flour smooth T-650	Wheat flour	PMaC a.s., Hlavatého 5, Bratislava
Corn flour KRONER	Corn flour	KRONER s r.o., Júlová 12, Bratislava
Corn amyloid - smooth	Smooth corn amyloid	Thymos, spol. s.r.o.
Potato amyloid	Potato amyloid	Amylon, a.s.

The planned experiment was oriented on finding the influence of air pressure and weight of sample of food dust on the minimum ignition temperature of dust cloud. The minimum ignition temperature of dust clouds was determinate according to the norm STN EN 50281-2-1 Electrical apparatus for use in the presence of combustible dust. Part 2-1: Test methods - Methods for determining the minimum ignition temperatures of dust. In this standard test method, dust is dispersed into a heated furnace set at a predetermined temperature.

The dust cloud is exposed to the heated furnace walls for several seconds. A visible flame exiting the furnace provides evidence for ignition [2, 3].

For laboratory conditions was arranged experiment of two factors, where the weight of sample *m* and pressure *p* of air were active factors and the moisture of sample ν was passive factor (constant parameter). These parameters were quantitative factors of experiment. The kind of dust was arranged as the qualitative factor of experiment. The minimum ignition temperature of dust cloud was dependent parameter (response of determination). Table 2 presents experimental conditions for quantitative factors and tolerance of level of each factor.

Table 2. Conditions of experiment and tolerance of level of quantitative factors

Experimental conditions	Tolerance of level of factors
0.01 g ≤ m ≤ 1 g	5 %
0.02 bar ≤ p ≤ 0.5 bar	5 %
0 % ≤ v ≤ 100 %	5 %

The type of planned experiment: 2-factored design with central composition, 5-level with levels -a, -1, 0, 1, a; a = 1.41 for 2 factors. The centre of experimental place: m = 0.505 g, p = 0.26 bar.

When the distribution of probability of anomalies and equality of variances for each measured attributes are normal it is possible to approximate the dependence of response of determination on chosen factors according to the polynomial model. From the data of experiment it is possible for each sort of food dust calculate values of regression coefficient in polynomial function for the minimum ignition temperature:

$$T = b_0 + b_1 m + b_2 p + b_{12} m p + b_{11} m^2 + b_{22} p^2 \quad (1)$$

The estimation can be for two factors projected as the final illative area of dependence $T = f(m, p)$ in experimental space. In case of inadequacy of model on chosen level of significance it will be necessary to think about the increase of place value of regression function.

RESULTS

The plan of the experiments of two – factored experiment and experimentally observed values of minimum ignition temperature of food dust clouds are illustrated in table 3.

Table 3. Plan of the experiments of two – factored experiment and experimentally observed values of minimum ignition temperature of food dust clouds

Number of attempt	Reduced coordinates of experimental point		m [g]	p [bar]	Experimental values of minimum ignition temperatures of wood dust clouds [°C]			
					Wheat flour	Corn amyloid	Corn flour	Potato amyloid
1	-1	-1	0.205	0.11	490	515	530	570
2	+1	-1	0.805	0.11	480	465	555	570
3	-1	+1	0.205	0.41	455	500	495	510
4	+1	+1	0.805	0.41	430	420	445	465
5	-1.414	0	0.081	0.26	490	555	535	550
6	1.414	0	0.929	0.26	450	445	455	465
7	0	-1.414	0.505	0.05	515	570	590	610
8	0	1.414	0.505	0.47	450	450	470	485
9	0	0	0.505	0.26	460	445	465	470
10	0	0	0.505	0.26	455	445	460	465
11	0	0	0.505	0.26	455	450	460	470
12	0	0	0.505	0,26	460	445	460	470
13	0	0	0.505	0.26	460	445	455	470

Arranged experiment was evaluated according to the method of multidimensional regressive analysis and analysis of scatter (according to the Statistical and Power Analysis Software) using the NCSS 2007 program [7, 8]. Table 4 shows measuring accuracy of determination of minimum ignition temperature of food dusts in centre of experiment.

Table 4. Measuring accuracy of minimum ignition temperature of food dusts in centre of experiment

Food dust	Minimum ignition temperature measured in central point [°C]	Variance of temperature in central point [°C]	Percentage error of determination of temperature in central point
Wheat flour	458.0 ± 2.7	7.5	0.60
Corn flour	446.0 ± 2.2	5	0.50
Corn amyloid	460.0 ± 3.5	12.5	0.77
Potato amyloid	469.0 ± 2.2	5	0.48

Comparison of characteristics of estimation with the quadratic model of the peak area response (minimum ignition temperature of dust cloud) for four types of food dusts is shown in Table 5.

Table 5. Comparison of characteristics of estimation
with quadratic model of the peak area response for four types of food dust

Food dust	Indexes of regression equation $T = b_0 + b_1 m + b_2 p + b_{12} mp + b_{11} m^2 + b_{22} p^2$						Estimation reliability (R^2) [%]	Significance level at which is the model adequate
	b_0	b_1	b_2	b_{12}	b_{11}	b_{22}		
Wheat flour	540.2	- 48.5	-316.7	-83.3	31.7	406.1	93	0.01
Corn flour	663.1	-294.5	-674.1	-166.7	216.6	1089.9	87	0.00006
Corn amyloid	648.6	-128.2	-827.5	-416.7	177.2	1494.1	95	0.0033
Potato amyloid	720	-223.8	-1076.8	-250	217.7	1765	98	0.001

Table 6. Values of residual dispersion, F –test and minimum of estimated function T
obtained with quadratic model of the peak area response for four types of food dusts

Food dust	Residual dispersion	F-test	Minimum of estimated function T [°C]	Position data in the minimum of the function T	
				m [g]	p [bar]
Wheat flour	127.14	16.95	419	1.48	0.54
Corn flour	1143.30	228.66	416	0.82	0.37
Corn amyloid	380.15	30.41	433	0.82	0.39
Potato amyloid	244.05	48.81	448	0.72	0.36

Approximations with quadratic model of the peak area response are appropriate only for modelling the distribution of minimum ignition temperature of wheat flour dust.

The ignition temperature decreases with the current increase of the weight of sample and pressure. The minimum of the estimated function at the pressure 0.54 bar and weight of sample 1.58 g is located outside of the experimental area (figure 1).

Approximations with quadratic model are for other food dusts at significance level 0.01 inadequate; they provide not an adequate predicting ability and need to expand model of cubic effects (figure 2, figure 3, and figure 4).

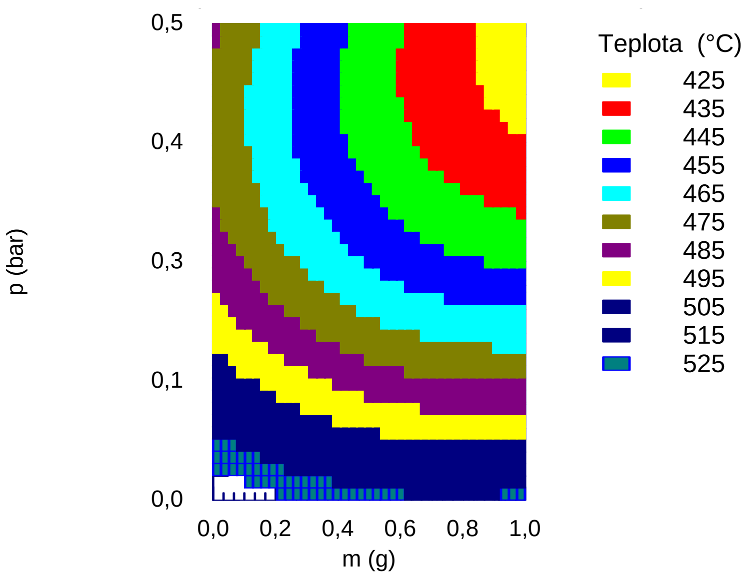

Figure 1. Distribution of minimum ignition temperatures of wheat flour dependent on weight and pressure of getting air - quadratic model

Table 7 shows the characteristics of estimation with the extended model of the peak area response for corn flour and potato amyloid (the models are extended by a member m^2p) and for corn amyloid (the model is extended by a member mp^2 and m^2p).

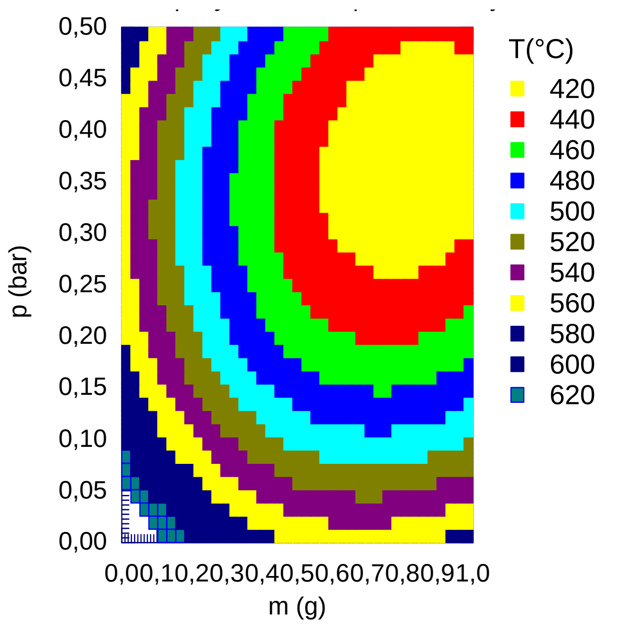

Figure 2. Distribution of minimum ignition temperatures of corn amyloid dependent on weight and pressure of getting air - quadratic model

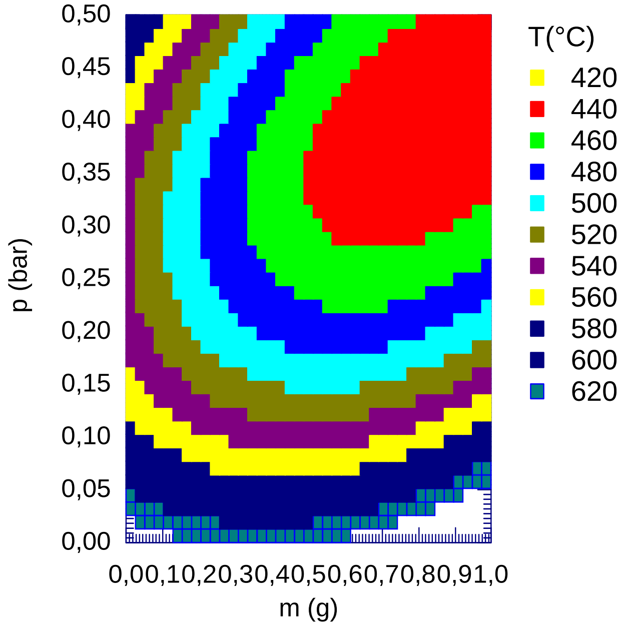

Figure 3. Distribution of minimum ignition temperatures of corn flour dependent on weight and pressure of getting air - quadratic model

Table 7. Comparison of characteristics of estimation with extended model of the peak area response

Food dust	Regression equation	Estimation reliability (R^2) [%]	Significance level at which is the model adequate
Corn flour	$T = 555.46 + 56.34\ m + 32.91\ p + 177.18\ m^2 - 163.67\ p^2 - 2120.63m\ p + 3276.86\ p^2\ m$	99.18	0.054
Potato amyloid	$T = 640.36 - 66.15\ m - 341.81\ p + 271.\ 70\ m^2 + 351.\ 60\ p^2 - 1705.37\ m\ p + 2798.79\ p^2\ m$	99.87	0.24
Corn amyloid [1]	$T = 551.69 + 241.41\ m - 245.75\ p - 314.08\ m^2 + 1089.855\ p^2 - 2228.05\ m\ p + 2040.98\ p\ m^2$	92.69	0.0001
Corn amyloid [2]	$T = 635.66 - 240.26\ m - 420.98\ p + 216{,}58\ m^2 + 603.03\ p^2 - 667.95\ m\ p + 964.01\ p^2\ m$	87.29	0.000035

Remark 1,2: two possibilities for regression equation of corn amyloid

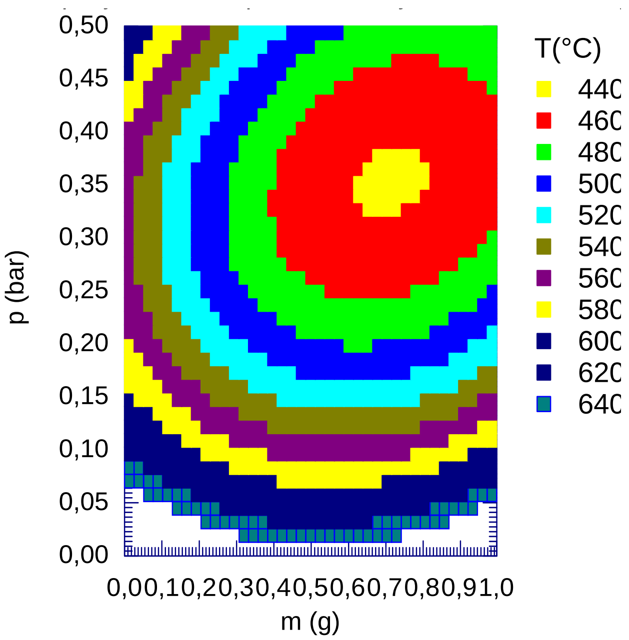

Figure 4. Distribution of minimum ignition temperatures of potato amyloid dependent on weight and pressure of getting air - quadratic model

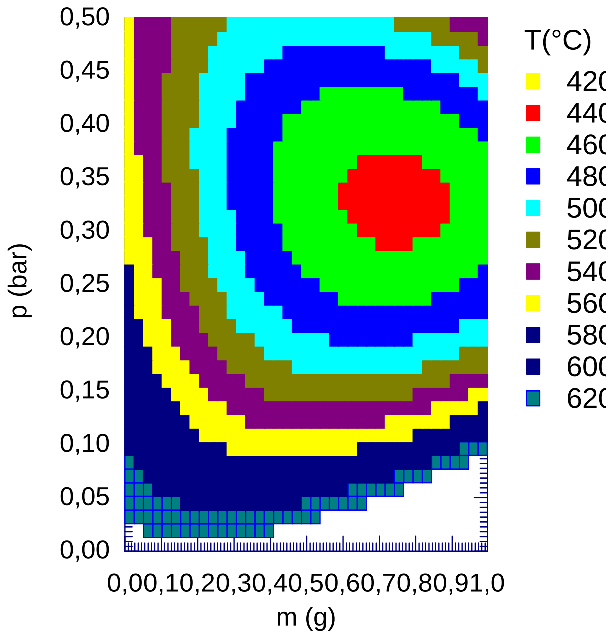

Figure 5. Distribution of minimum ignition temperatures of potato amyloid dependent on weight and pressure of getting air - model extended by a member mp^2

Table 8. Values of residual dispersion, F –test and minimum of estimated function T obtained with extended quadratic model of the peak area response

Food dust	Residual dispersion	F-test	Minimum of estimated function T [°C]	Position data in the minimum of the function T	
				m [g]	p [bar]
Corn flour	82.44	6.60	432.4	0.81	0.34
Potato amyloid	10.24	2.05	445.2	0.74	0.33
Corn amyloid [1]	958.02	191.60	417.23	0.655	0.38
Corn amyloid [2]	1672.72	334.54	415.92	0.82	0.35

Remark 1,2: two possibilities for regression equation of corn amyloid

Approximation of sought-after dependence with quadratic model extended with member mp^2 is appropriate for corn flour and potato amyloid. F-test does not show at significance level 0.01 the existence of statistic-considerable difference between the result of the regression estimation and the ignition temperature determined by the experiment in compare with the experimental error of ignition temperature (table 7, table 8).

Potato amyloid sample - While increasing sample weight from 0 to 0.74 g and the pressure from 0 to 0.33 bar the minimum ignition temperature of the potato amyloid dust decreases. The minimum ignition temperature decreases at the pressure values above 0.33 bar and increasing weight in the range from 0 to 0.74 g, it also decreases at the weight values above 0.74 g and increasing pressure in the range from 0 to 0.33 bar. The lowest value 445.2 °C reaches in the minimum at 0. 33 bar and 0.74 g. However, the minimum ignition temperature increases with the increase of weight and pressure (figure 5).

Corn flour sample - The minimum ignition temperature of the corn flour sample decreases with the increase of sample weight in the range from 0 to 0.81 g and the pressure from 0 to 0.34 bar. The minimum ignition temperature decreases at the pressure values above 0.34 bar and increasing weight in the range from 0 to 0.81 g, it also decreases at the weight values above 0.81 g and increasing pressure in the range from 0 to 0.34 bar. The lowest value 432.4 °C reaches in the minimum at 0.34 bar and 0.81 g. However, the minimum ignition temperature increases with the increase of weight and pressure (figure 6).

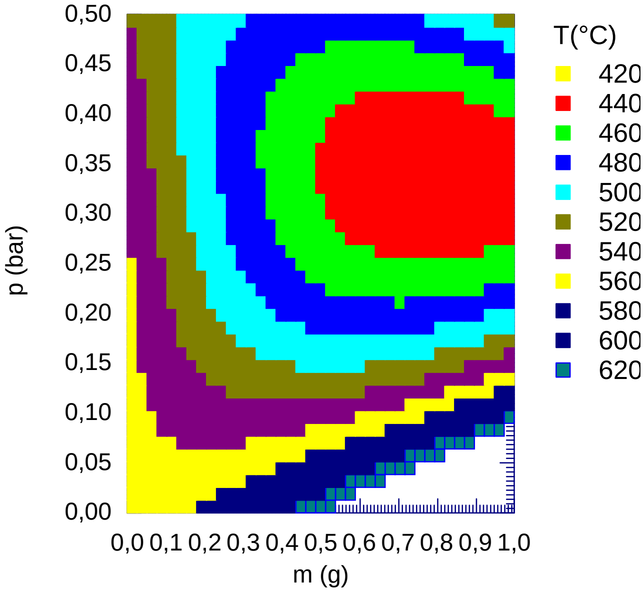

Figure 6. Distribution of minimum ignition temperatures of corn flour dependent on weight and pressure of getting air - model extended by a member mp^2

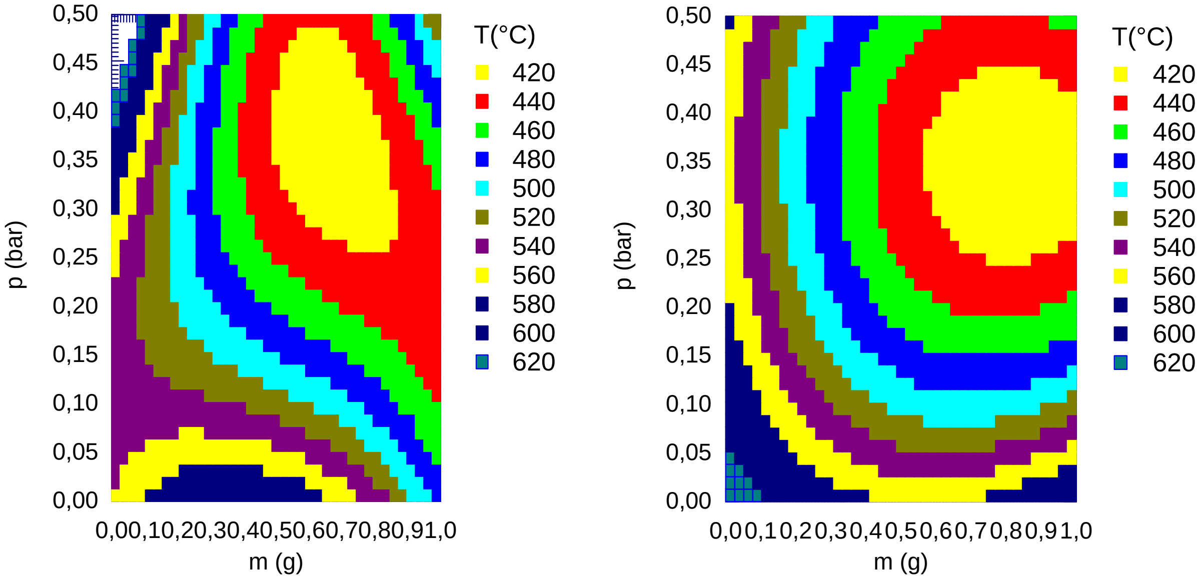

Figure 7. Distribution of minimum ignition temperatures of corn amyloid dependent on weight and pressure of getting air (model extended by a member mp^2 - right, model extended by a member m^2p- left)

For quadratic model for the peak area response extended with member mp^2 for corn amyloid the reliability increased, but has weak predicting ability. It is necessary to find another type of regression function (figure 7, table 7, table 8).

❖ CONCLUSION (SUMMARY)

The influence of the pressure and the weight of the dust sample on the minimum ignition temperature of the dust cloud were observed using the planned experiment. This experiment provides the approximations with the polynomial model that enables to estimate the minimum ignition temperature of the food dust cloud in dependence on the pressure and sample weight.

Approximations with quadratic model of the peak area response are appropriate only for modelling the distribution of minimum ignition temperature of wheat flour dust. Approximations with quadratic model are for other food dusts at significance level 0.01 inadequate; they provide not an adequate predicting ability and need to expand model of cubic effects. Approximation of sought-after dependence with quadratic model extended with member mp^2 is appropriate for corn flour and potato amyloid. F-test does not show at significance level 0.01 the existence of statistic-considerable difference between the result of the regression estimation and the ignition temperature determined by the experiment in compare with the experimental error of ignition temperature.

For quadratic model of the peak area response extended with member mp^2 for corn amyloid the reliability increased, but has weak predicting ability. It is necessary to find another type of regression function.

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