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Granulometric Analysis of Spruce Wood Dust

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Abstract

The article deals with the determination of the particle size of spruce wood dust and its moisture originating from briquetting and grinding technology. Particle sizes affect the maximum explosion parameters and humidity affects the explosive limits, which create the risk of explosion in production facilities. Humidity was determined according to the methodology STN EN ISO 1666: 2000 Determination of the amount of moisture. Sieves with apertures of 0.5 mm, 0.25 mm, 0.18 mm, 0.15 mm, 0.125 mm, 0.09 mm, 0.075 mm, 0.063 mm, 0.045 mm, 0.4 mm were selected for sieve analysis. 0.032 mm and 0.001 mm. The sieve analysis was performed according to the internal methodical procedure IM-AS 200. The measured moisture values of the spruce wood dust samples taken from the grinding technology reached an mean of 8.42% humidity and the mean humidity determined for the samples from the briquetting press was 7.25%. Samples taken from briquetting show lower moisture than dust from the grinder, this affects the method of processing, briquette pressing is performed at an elevated temperature, which reduces the humidity of the mixture. By evaluating the particle size samples by sieve analysis, we prove that the spruce wood dust taken from grinding has the highest proportion of 46.74% for the fraction from 0.063 to 0.075 mm and for the fraction from the briquetting press the highest proportion of 45.44% in the fraction from 0.106 to 0.125 mm. The results will be used for explosion prevention and protection in potentially explosive atmospheres of the timber industry working with these types of standing equipment.

Keywords: Grinding and briquetting technologies; Norway spruce (*Picea abies [L.] Karst.*); sieve analysis; wood dust

1 Introduction

Wood dusts are among the combustible organic dusts that are capable of an oxidative reaction. In the form of an aerogel (settled dust) in the air they burn with a flame and after agitation with the air in the form of an aerosol (agitated dust) they form an explosive mixture (Balog, 1999; Tureková, Balog, 2004). In wood processing technologies, wood raw material is processed by woodworking machines of various types, such as saws, milling machines, wood lathes, grinders, etc. Woodworking machines differ in their effect of tools on wood, where a semi-finished or finished product and residual wood in the form of sawdust, shavings and dust are formed. The size fraction of residual wood material, which accumulates in layers in plants or is agitated at the source of processing, depends on the type of machine and its tool. An explosion may occur if the minimum concentration, the presence of the initiation source and the space are met (Balog, 1999; Tureková, Balog, 2004).

The properties of combustible dusts are given by fire engineering parameters, which are determined in laboratories and are not physical constants. Combustible dusts do not show the same values of fire technical characteristics, even if they are produced and processed under the same or different conditions in parts of technological equipment (Damec, 1993; Sklenárová, Štroch, 2019). To assess the fire danger, we determine the fire technical characteristics of settled and agitated dust. The fire-technical parameters of wood dust in the settled state include the following determinations: minimum ignition temperature of settled dust t^u_{min} and the respective ignition ignition time τ_i, flame spread rate, combustion heat and calorific value, critical degradation temperature, critical heat flux of radiant heat to ignite the deposited dust and oxygen number (Cashdollar, 2000). In the turbulent state, the fire technical parameters of wood dusts are determined: minimum ignition temperature of turbulent dust t^r_{min} and corresponding induction ignition time τ_i, lower explosion limit (LEL), maximum explosion parameters (maximum explosion pressure p_{max}, maximum increase in explosion pressure $(dp / dt)_{max}$, cubic constant K_{St}), minimum initiation energy MIE and limit oxygen content (LOC) (Cashdollar, 2000). The study of methods for assessing the risk of ignition of dust / air in an explosive environment by electrostatic discharge was discussed by Gabor et al. laser initiation of PETN-based composites (Pentrit) and submicron coal particles has been addressed and investigated by (Gabor at al., 2019; Aduev et al., 2016). The size of the dust particles affects the explosive atmosphere in operation and the brisance of the explosion. Granulometric analyzes are performed to determine the size of the dust particles and to classify them. The comparison of the results confirmed the proportion of granulomertic fractions of sand abrasive wood typically processed in the furniture industry (beech, oak, spruce, fir and alder) (Marková et al., 2016). The study by Očkajová et al. compared the granulometric composition of grinding powders of selected tree species (beech and oak) and determined the statistical significance of individual factors (type of grinder, wood species, grit grain, direction of grinding), which affected the percentage of fractions < = 0.08 mm. The results confirmed that the use of narrow and hand (belt and disc) grinders caused a high percentage of fractions < =0.08 mm, in all cases above 90% (Očkajová et al., 2018). Kučerka and Očkajová present the results of the particle size distribution of heat-treated oak and spruce wood with a focus on the fine and dust fraction. The results showed in the milling of oak that with increasing wood treatment temperature the proportion of dust fraction increased from 0.40% and during grinding the opposite trend was shown, namely a decrease in the proportion of dust with increasing processing temperature (Kučerka, Očkajová, 2019).

The fire performance characteristics include the determination of the minimum initiation energy (MIE). The study tested the initiation of dust explosions by electric discharges of a spark in an explosive dust concentration. Large particles have been found to initiate disintegration at lower voltages than smaller ones (Randeberg, Eckhoff, 2006). Eini et al. collected experimental MIE data from the literature and subsequently created group contribution (GC) models using weighted nonlinear least squares regression. The proposed models provided new tools for computer-aided product design (Eini et al., 2020). New diagnostic capabilities available for dust explosion research in the study were investigated by Schweizer et al. The research was carried out by applying high-speed digital in-line holography (DIH) to volumetric and characterization of dust concentrations near the initiation zone of the device (Schweizer et al., 2020). Pacáková presented in the study statistical evaluations by analysis of variance. The method made it possible to compare the mean values of more than two basic sets. The result was whether a null hypothesis could be accepted at the chosen level of significance (Pacáková, 2009). Bernard et al. explain the Langlie method for determining the parameters (mean energy value E50 and standard deviation σ) of the relevant statistical law. A comparison of normal and lognormal law was achieved and the best agreement was reached with lognormal law (Bernard et al., 2010). Nejtková and Marek mentioned in the article the investigation of two real cases of explosions with subsequent fire. A digital spatial deformation analysis was used to investigate the causes of fires and explosions by the Fire and Rescue Service in the Czech Republic, which was used to examine the scene, subsequent documentation, and digitization of the fire site (Nejtková, Marek, 2019).

Spruce wood dust is created as a residual material in the technology of grinding in woodworking with specific properties. It forms a dispersion system, which is formed by the dispersion of spruce particles in a continuous phase of the dispersing medium. Spruce dust particles with a lower fraction react with air and initiate more brisantly than particles with a higher fraction.

The properties of spruce wood dust determine the fire technical characteristics, which are indicators of the assessment of the risk of fire and explosion. All combustible organic dusts, including spruce wood dust, are heterogeneous materials, which differ significantly in processing in technology, depending on the production machine and the machining tool.

The aim of the study is to statistically evaluate the moisture and size of spruce dust particles from the influence of the type of machinery in the technology. Samples of spruce wood dust were taken from two types of machinery - a grinder and a briquette press in a woodworking plant.

2 Material and Methods

Norway spruce (*Picea abies [L.] Karst*.) is a coniferous tree and is one of our most important commercial trees, both in terms of the production of quality wood, but also in terms of representation in our forests. At present, its representation is around 22%. Spruce wood has excellent mechanical properties and has the most versatile use of our main commercial woods, it is suitable for mechanical processing in the woodworking industry (lumber production), but also for chemical processing - cellulose production (lower quality wood). The wood is coreless with white and mature wood, it is light in color with a yellowish tinge (Zubček, 2019). Norway spruce (*Picea abies [L.] Karst.*) belongs to the mature woody trees (Sarvaš et al., 2015; Račko et al., 2018).

Processing in the woodworking industry often involves, among other things, sanding wood surfaces for proper handling and final product design. The input raw material for briquetting is wood sawdust and dust, which are transported to the line by a screw conveyor from the hopper. They are further divided into individual briquetting presses, which are arranged in sequence. In presses, sawdust and dust are pressed into the shape of briquettes (Mračková, Palugová, 2019).

Sampling of spruce dust from the technology of wood sanding and briquetting

Spruce dust samples were taken from the technology of sanding wood and pressing briquettes directly from the source. Sampling was performed several times according to the following procedure:

1. Switch off the extraction of wood residues so that the residues formed after processing the spruce wood settle in the form of an aerogel.
2. After the dust has settled, proceed with a collecting tool (shovel) and collect the accumulated spruce dust residues from the machine directly at the place of origin.
3. Pour the collected material for the experiment into closable crates so that the percentage of moisture removed does not change.
4. This procedure is performed several times in succession, up to the amount needed for experiments and research.

For granulometric analysis, we collected 200 g of spruce wood dust, which was subjected to moisture determination before analysis.

2.1 Determination of moisture and sieve analysis of spruce wood dust

A Mettler Toledo HS153 moisture analyzer was used to determine the moisture content of the tested spruce wood dust and the evaluation was performed in accordance with the methodology STN EN ISO 1666: 2000 Starch. Determination of the amount of moisture (STN EN ISO 1666: 2000). AS 200 series analytical screening machines are used in the fields of research and development, for particle size analysis. All screening machines of the AS 200 model series work on the principle of electromagnetic drive.

The sieve analysis was performed according to the Internal Methodological Procedure IM-AS 200 entitled: ,,Methodology for determining the grain size of loose wood on the AS 200 sieving machine". Sieve analysis was performed with samples weighing m = 50 g, for a sieving time τ = 15 min on a set of sieves with mesh gaps: 0.5 mm, 0.25 mm, 0.18 mm, 0.15 mm, 0.125 mm, 0.09 mm, 0.075 mm, 0.063 mm, 0.045 mm, 0.4 mm, 0.032 mm and 0.001 mm. The weights of the fractions on the sieves are determined on laboratory scales with a weighing accuracy of 0.01 g.

2.2 Statistical evaluation of explosion experiments of spruce wood dust

As part of the statistical evaluation of data, in addition to the methods of descriptive statistics, we used a two-sample Student´s t-test to verify the statistical significance of the difference in mean moisture of spruce dust particles from two types of technologies - briquetting and grinding.

To approximate the probability distribution of test statistics, we used Student´s t-distribution, which is recommended for small selection ranges ($n < 20$). The tabular and graphical tools MS Excel 2016 was used for statistical evaluation of the data. We used the statistical software STATISTICA 12 to test the hypothesis of equality of mean humidity.

3 Results and Discussion

In the results, we present two types of technologies, from which samples of spruce dust particles come from briquetting and grinding.

3.1 Statistical evaluation of experimental results of spruce wood dust moisture

The results of humidity testing are presented in Tab. 1. Based on the p-value (0.006) corresponding to the result of the t-test, we state that there is a significant difference in the mean humidity of spruce wood dust originating from the two types of technology. Dust from the grinder has a higher humidity than dust from briquetting technology.

Tab 1. Results of a two-sample Student´s t-test

Variable	Briquetting *n* = 5, Grinding *n* = 5								
	Mean (Briquetting)	Mean (Grinding)	St. dev. (Briquetting)	St. dev. (Grinding)	*F*-test	*p*-value	*t*	*df*	*p*-value
Moisture (%)	7,25	8,42	0,54	0,45	1,42	0,741	-3,73	8	**0,006**

In Fig. 1, we observe box plots that represent 95% confidence intervals for the mean moisture value of dust particles originating from the two types of technology monitored. The sample moisture content of spruce dust for the briquette source type was 7.25% and for the grinder type 8.42%. The mean moisture of the briquetting dust particles with 95% confidence is in the range from 6.58% to 7.92%. For the moisture of the grinding dust particles, the lower limit of the 95% confidence interval was calculated to be 7.86% and the upper limit to 8.98%.

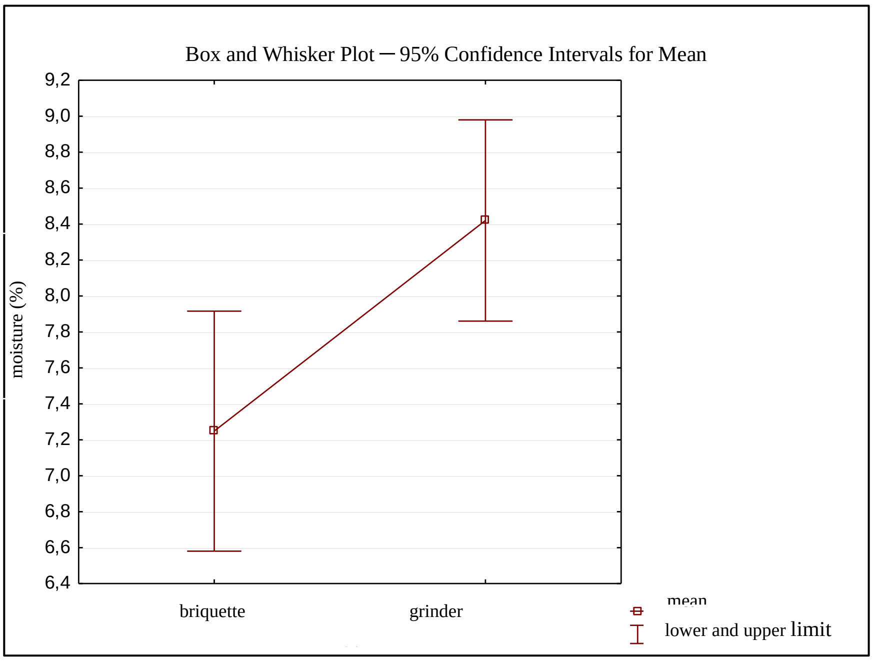

Fig 1. 95% confidence intervals for mean moisture values presented by a box graph of spruce wood dust

3.2 Statistical evaluation of experimental results of sieve analysis of spruce wood dust

The results of the sieve analysis of spruce wood dust are presented in Tab. 2 by means of the mean values for three experimental measurements. The content of the sieve representing the amount of trapped dust particles is given in absolute units (g) and relative.

Tab. 2 Weights and percentages of spruce dust particles from the briquetting press and grinder collected in individual sieves.

Sieves with the size of holes (mm)	briquette (g)	briquette (%)	grinder (g)	grinder (%)
0.500	0.00	0.00	0.00	0.00
0.250	4.47	8.93	1.60	3.20
0.180	8.05	16.09	2.79	5.59
0.150	5.33	10.67	1.84	3.69
0.125	2.09	4.19	3.77	7.53
0.106	22.72	45.44	3.10	6.19
0.090	3.08	6.16	3.49	6.99
0.075	3.91	7.82	3.36	6.72
0.063	0.06	0.13	23.37	46.74
0.045	0.10	0.21	4.49	8.99
0.040	0.08	0.16	1.61	3.22
0.032	0.06	0.12	0.48	0.95
0.001	0.04	0.09	0.10	0.19

The relative abundances from the table are graphically presented by means of a bar diagram in Fig. 2. The highest percentage of spruce dust particles from the grinder, which represents 46.74%, is observed with a fraction of 0.075 to 0.063 mm and from the briquette press with a value of 45.44% for the fraction with a particle size of 0.125 to 0.106 mm.

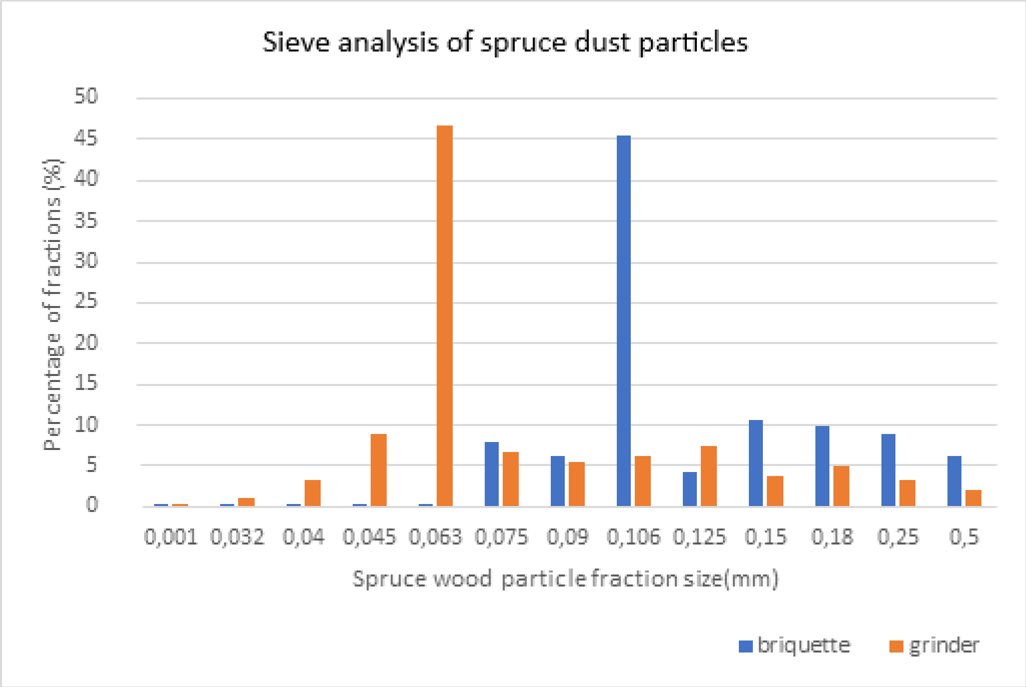

Fig. 2 Graphical representation of particle sizes of spruce dust particles from a briquetting press and grinder with their percentage

In figure 3, we observe a polygon of cumulative masses expressed in percent, by means of which we demonstrate the gradual fall of spruce dust particles through the system of used sieves.

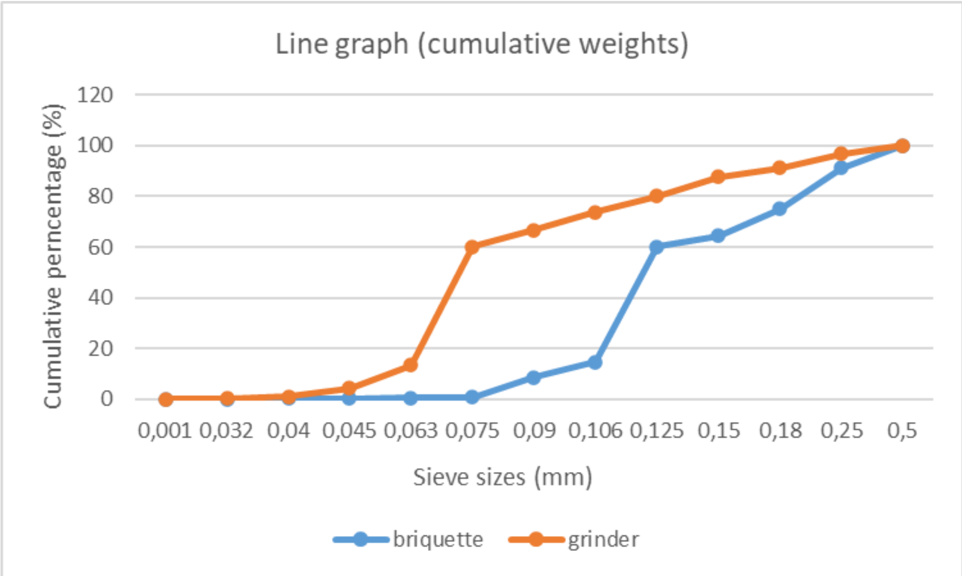

Fig. 3 Cumulative weights of forged spruce dust particles for two types of technology used - briquetting press and grinder.

4 Conclusions

Statistical analysis of data obtained from samples of spruce wood dust originating from two types of technologies - briquetting and grinding, determined the following monitored effects:

- the dry explosive mixture has the greatest range of explosiveness. With dusts with increasing moisture content, the explosive range narrows and at 20% humidity, the dust is almost non-explosive. From the experimentally determined results of spruce dust particles taken from briquetting and grinding technology, we confirmed a statistically significant difference in humidity. Both dispersion mixtures have a humidity well below 20%, we can say that they are flammable and create an explosive atmosphere after agitation.

- from a production point of view, the grinding of spruce wood material results in a high concentration of the dispersion mixture, which could reach the value of the lower explosion limit; According to the National Council of the Slovak Republic no. 393/2006 Coll. On minimum requirements for ensuring safety and health protection at work in an explosive environment, built-in suction device.

- during briquetting, wood sawdust and dust are transported to the line by a screw conveyor from the hopper and further divided into briquetting presses. The concentration of dust in the air is low, due to the feedstock, which has a higher particle size.

- the results will be used for explosion prevention and protection in potentially explosive atmospheres in the woodworking industry in grinding and briquetting technologies.

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