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IDENTIFICATION OF INHALABLE SOFTWOOD DUST AND DETERMINATION OF PARTICLE SIZE DISTRIBUTION IN THE WORKPLACE USING FT-IR SPECTROSCOPIC IMAGING MICROSCOPY

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Abstract: *Workers in the wood processing industry are exposed to severe occupational hazards, such as cuts, amputations, and musculoskeletal injuries, as well as risks associated with wood dust, chemical substances, and high noise levels. These factors can lead to long-term health issues, including respiratory diseases, hearing loss, and damage to the nervous or circulatory systems.The aim of this study is to assess workers' exposure to softwood (fir) dust in the workplace by simultaneously measuring the percentage dispersion of micron-sized particles across different size classes (granulometric dispersion), observed using electron microscopy coupled with an FT-IR detector.*

Keywords: *Inhalable dust, particle size distribution, wood, FT-IR.*

1. INTRODUCTION

Wood is one of the most important renewable resources on the planet. Forests cover approximately one-third of the Earth's total surface, about 3.4 million km². This area represents over 1.0 trillion m³ of total biomass, from which approximately 3.5 billion m³ are harvested annually, with nearly half being used as fuel, predominantly in developing countries [1].

The tree species that grow and are harvested vary considerably between countries. Hardwood species dominate in Italy (oak, chestnut, and beech), while conifers prevail in colder regions such as pine and spruce in the Nordic countries, and pine, spruce, hemlock, cedar, and fir in Canada.

The wood industry produces:

- Raw wood products: roundwood, logs, poles
- Semi-finished wood products: hewn timber, lumber, planks, beams, battens, veneers, panels
- Finished wood products: flooring boards, parquet, cellular panels
- Modified wood products: particleboard (standard, laminated, melamine-coated), fibreboards (MDF, HDF), and cellulose-based products [1].

In Romania, in addition to domestic investors, major multinational companies are present, including Holzindustrie Schweighofer and Kronospan (Austria), Losan (Spain), and Parisot (France). Globally, Romania ranks 27th in furniture production, 22nd in furniture exports, and 36th in furniture imports.

In recent years, there has been a significant increase in the volume of harvested wood, primarily from coniferous species (43%), beech (28%), and oak (9%). The wood processing industry is divided into mechanical and chemical processing. Within mechanical processing, key subsectors include sawmilling, veneer and panel manufacturing, furniture production, and match manufacturing.

Table 1

Nomenclature of some coniferous/ broadleaf trees [1]

Genus and species	Common name
Softwood	
Abies	Fir
Chamaecyparis	Cedar

Genus and species	Common name
Cupressus	Cypress
Larix	Larch
Picea	Spruce
Pinus	Pine
Pseudotsuga menziesii	Douglas Fir
Sequoia sempervirens	Red Wood
Thuja	Thuja
Tsuga	Hemlock

Structurally, there is a significant difference between hardwood (left) and softwood (right - spruce), as illustrated in figure 1.

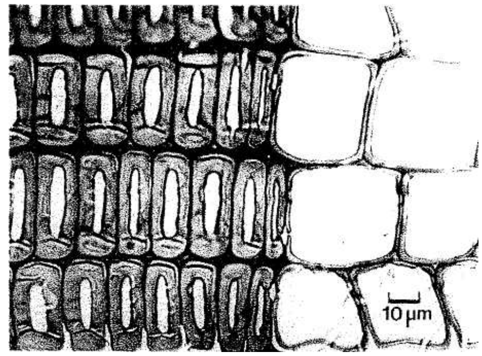


Fig. 1. The difference between hardwood and softwood, seen with the help of light microscopy [2]

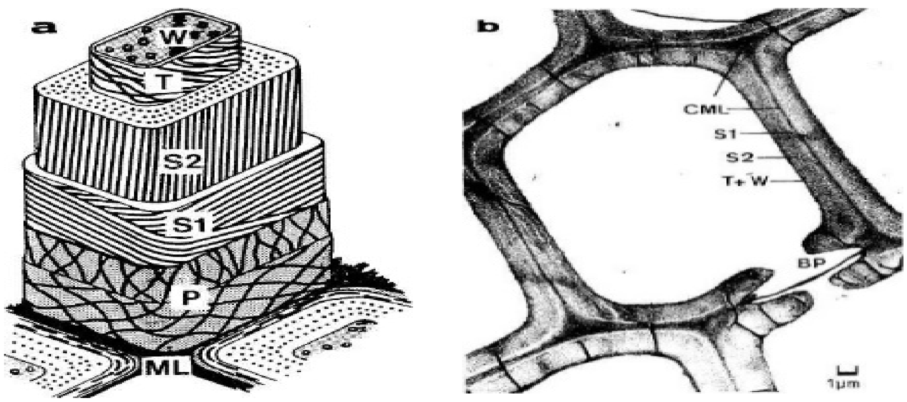


Fig. 2. Structure of hardwood [2]

Caption: (a) Model of a vascular cell (soft tracheid, libriform wood fibres); (b) A cross-section of a conifer tracheid (umbrella fir), with a border pit (BP); transmission electron micrograph. ML, middle lamella; P, primary wall; SI, secondary wall 1; S2, secondary wall 2; T, tertiary wall; W, verrucose layer; LMC, composite middle lamella (ML + P)

In hardwoods, wood cell walls consist of multiple layers with distinct structural and chemical compositions. Individual wood tissue cells are bonded together by the middle lamella, composed mainly of lignin, polysaccharides, and pectin. There is often no clear boundary between the middle lamella and the outermost layer of the cell wall, known as the primary wall, which consists of a network of cellulose fibrils embedded in a lignin matrix. The cell wall structure of hardwood is shown in figure 2.

In Romania, workplace safety and health legislation align with European Directives promoting improved safety and health conditions for workers in the wood industry [2]. Regarding occupational diseases, national regulations include:

- Occupational Health and Safety Law No. 319/2006, as amended (Chapter VI, Section 3 – Occupational Diseases) [2]
- Implementation regulations for Law No. 319/2006, approved by Government Decision No. 1425/2006, with subsequent amendments
- Government Decision No. 1218/2006 (republished in 2021), setting minimum safety and health requirements for worker protection against exposure to chemical agents, carcinogens, and mutagens in the workplace

In Romania, the occupational exposure limit for softwood and hardwood dust is 5 mg/m³, while for cedar wood dust, it is 0.5 mg/m³.

Physical and chemical agents present in wood processing operations can cause health and safety issues such as eye and skin irritation, dermatitis, respiratory effects (including asthma), and even nasal cancer (from hardwood dust exposure). Multiple epidemiological studies have investigated the increased cancer risk, particularly for nasal cavity and paranasal sinus cancers, among workers exposed to wood dust.

2. MATERIALS AND METHODS

The objectives of this study are to measure dust concentrations at two technological operations and to identify workplaces with a higher risk of illness caused by the presence of softwood dust.

To determine the size and nature of the particles, a Shimadzu IRTracer-100 Series Fourier Transform Infrared (FTIR) Spectrometer coupled with an infrared microscope was used.

Fourier Transform Infrared Spectroscopy (FTIR) is a powerful technique used to obtain infrared spectra of a sample's absorption or emission, providing valuable insights into the composition and molecular structure. It works by using an interferometer to modulate the infrared beam before passing through the sample [1].

Advantages of FTIR in substance identification:

- High sensitivity: capable of detecting very small sample quantities.
- High spectral resolution: allows precise identification of molecules by distinguishing small frequency differences.
- Speed: rapid spectrum acquisition, ideal for analysing time-sensitive samples.
- Versatility: suitable for analysing a wide variety of samples, including solids, liquids, and gases.

For the identification of the detected dust type, infrared absorption spectra of collected samples were used, reflecting how specific functional groups interact with infrared radiation. By interpreting these spectra, a detailed image of the material's molecular structure can be obtained, facilitating the identification of the analysed particles.

To assess the risk of worker exposure to softwood (fir) dust, gravimetric and microscopic determinations were performed at a furniture manufacturing and processing company in Petroșani during different technological operations. Ten dust samples were collected and analysed using both gravimetric and conimetric methods. These determinations also allowed for the study of particle dispersion across granulometric classes.

The gravimetric method for determining airborne suspended dust used by INCD INSEMEX Petroșani complies with STAS 10813/1976 - Air Purity. Determination of Suspended Dust and STAS 10331/1992 - Air Purity. Principles and General Rules for Air Quality Monitoring.

The conimetric determination of airborne particles employs optical microscopy coupled with an FTIR detector.

Granulometric Dispersion Analysis (Dispersometry)

By microscopic examination, the size of at least 100 particles can be identified, and the FTIR technology helps determine the particle type. This allows for the direct percentage expression of particle numbers across the following granulometric classes:

- < 1 μm...%
- between 1-3 μm .... %
- between 3-5 μm .... %
- between 5-7 μm .... %
- between 7-10 μm .... %
- > 10 μm .... %

3. RESULTS AND DISCUSSION

For the gravimetric determination of inhalable dust at workplaces, the APEX device equipped with borosilicate filters was used.

The sampling procedure, concentration calculation, and result presentation followed the standards SR EN 482:2021 and SR EN 689+AC:2019.

The results of inhalable dust in workplace air are presented in Table 2.

To determine particle dispersion across size classes, 10 samples were prepared for wood cutting operations using OCROMAX electronic cutting machine and BNF manual profiling machine. Additionally, 10 samples were prepared for the sanding operation.

The conimetric method is based on retaining dust particles in an impinger by aspirating and bubbling air containing suspended dust particles. The number of fibres in a determined liquid volume is counted and reported to the aspirated air volume and the liquid volume in the impinger.

The collected liquid from the impinger was pipetted, and 2-3 drops were placed on pre-cleaned microscope slides. After drying, coverslips were placed on top and fixed. The Bürker-Türk counting chamber was used for microscopic counting. Particles were counted over at least 4 mm², and the average number of particles per mm² was calculated. Since the chamber height is 1/10 mm, the number of particles per mm² was multiplied by 10 to obtain the number of particles per mm³.

Calculation Formula:

$$N = \frac{n \times h \times 1000 \times c}{V \times 1000} = \frac{n \times h \times c}{V} \quad [\text{particles/cm}^3]$$

where:
n = average number of particles per 1 mm²
h = 10 (for Bürker-Türk chamber)
c = liquid volume in the impinger (cm³)
V = aspirated air volume (cm³)

The result is expressed in particles/cm³.

To determine the number and size of particles, the AIM sight system was used, connected to the AM solution software of the infrared microscope.

Table 2

Concentrations determined in two technological operations carried out over 20 different days

No.	Technological process	Sampling date	Gravimetric concentration measured at 8 hours mg/m^3	Maximum allowed According to HG 1218/2006 mg/m^3
1.	Wood cutting with the OCROMAX electronic machine and the BNF manual profiling machine	18.11.2024	2,09	5
2.		19.11.2024	2,33	
3.		20.11.2024	1,95	
4.		21.11.2024	2,98	
5.		22.11.2024	2,02	
6.		25.11.2024	1,98	
7.		26.11.2024	1,83	
8.		27.11.2024	1,90	
9.		28.11.2024	1,94	
10.		29.11.2024	1,88	
Average value			2,11	

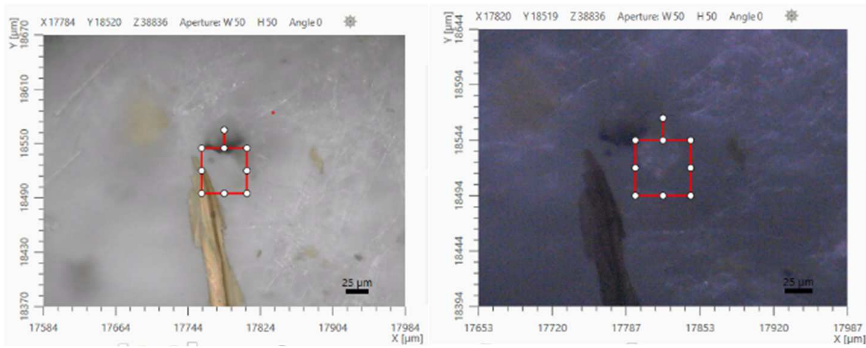
No.	Technological process	Sampling date	Conimetric measured part/cm^3	Maximum allowed According to foreign norms, part/cm^3
1.	Wood cutting with the OCROMAX electronic machine and the BNF manual profiling machine	18.11.2024	802,95	2000
2.		19.11.2024	889,37	
3.		20.11.2024	866,69	
4.		21.11.2024	878,15	
5.		22.11.2024	821,04	
6.		25.11.2024	901,71	
7.		26.11.2024	903,23	
8.		27.11.2024	810,38	
9.		28.11.2024	820,59	
10.		29.11.2024	805,89	
Average value			854,90	

No.	Technological process	Sampling date	Gravimetric concentration measured at 8 hours mg/m^3	Maximum allowed According to HG 1218/2006 mg/m^3
1.	Sanding wood with a hand sander	02.12.2024	2,80	5
2.		03.12.2024	2,99	
3.		04.12.2024	4,91	
4.		05.12.2024	2,95	
5.		06.12.2024	3,11	
6.		09.12.2024	4,54	
7.		10.12.2024	4,10	
8.		11.12.2024	4,99	
9.		12.12.2024	3,19	
10.		13.12.2024	4,21	
Average value			3,73	

No.	Technological process	Sampling date	Conimetric measured part/cm^3	Maximum allowed According to foreign norms, part/cm^3
1.	Sanding wood with a hand sander	02.12.2024	1224,44	2000
2.		03.12.2024	1161,96	
3.		04.12.2024	1167,42	
4.		05.12.2024	1002,83	
5.		06.12.2024	1294,30	
6.		09.12.2024	1248,19	
7.		10.12.2024	1227,00	
8.		11.12.2024	1166,00	
9.		12.12.2024	1094,01	
10.		13.12.2024	1413,85	
Average values			1176,24	

From the analysis of results (Table 2), it was observed that both gravimetric and conimetric dust concentrations were higher during the sanding operation compared to wood cutting with the OCROMAX electronic machine and the BNF manual profiling machine which is an increased risk of illness for workers.

To improve particle visualization, the software allowed for contrast adjustment of images (fig. 3) and for application of filters to enhance out-of-focus images.



Original image Contrast image of infrared observation

Fig. 3. Clarification of images for automatic particle counting

Using the prepared filters, the microscope was used to measure the micrometric sizes of 100 identified particles across multiple 1 mm sections. This allowed for direct percentage distribution of dust particles into granulometric classes: <1 µm, 1 – 3 µm, 3 – 5 µm, 5 – 7 µm, 7 – 10 µm, >10 µm.

The results of microscopic readings for samples collected during wood cutting with the OCROMAX electronic machine and BNF manual profiling machine are summarized in Table 3.

Table 3

Percentage of inhalable wood dust based on particle size class for the wood cutting operation

Sample no.	Percentage according to granulometric class [%]					
	< 1 µm	1÷3 µm	3÷5 µm	5÷7 µm	7÷10 µm	> 10 µm
1	32	38	8	3	6	20
2	33	33	10	2	4	19
3	26	30	9	5	3	19
4	23	41	6	3	5	20
5	25	35	11	4	6	21
Average	**27,8**	**35,4**	**8,8**	**3,4**	**4,8**	**19,8**

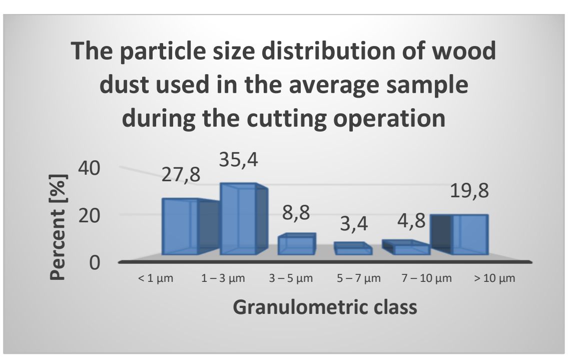


Fig. 4. Granulometric dispersion of wood dust analysed in samples for the wood cutting operation

According to Table 4, the average percentage values of dust particles by size classes (in the automatic cutting process) indicate that 72% of the inhalable fraction consists of particles smaller than 5 µm (the respirable fraction).

Non-hazardous particles larger than 10 µm account for 20% of the inhalable fraction, representing a very small proportion of the total particles. This increases the risk of worker illness due to exposure to wood dust.

The case study findings suggest that prolonged exposure to fine particles smaller than 5 µm significantly increases the risk of occupational diseases. [3]

The microscopic analysis results of the five samples collected during the sanding operation are summarized in Table 4.

Table 4

Percentage of inhalable wood dust based on particle size class for the sanding operation

Sample no.	Percentage according to granulometric class [%]					
	< 1 µm	1÷3 µm	3÷5 µm	5÷7 µm	7÷10 µm	> 10 µm
1	45	23	5	3	3	22
2	47	26	4	4	2	18
3	49	25	6	4	3	14
4	45	24	5	3	2	13
5	45	25	6	5	5	19
Average	**46,2**	**24,6**	**5,2**	**3,8**	**3,0**	**17,2**

According to Table 4, the average percentage values of dust particles by size classes (for automatic cutting) indicate that 76% of the total/inhalable fraction consists of particles smaller than 5 µm (the respirable fraction). Among these, 70.8% are particles smaller than 3 µm (the alveolar fraction).

Non-hazardous particles larger than 10 µm account for 17% of the inhalable fraction, again representing a very small proportion of the total particles, further increasing the risk of worker illness due to wood dust exposure.

The case study confirms that prolonged exposure to fine particles smaller than 5 µm significantly increases the likelihood of respiratory diseases.

In conclusion, the risk of worker illness is higher during sanding compared to mechanical cutting, due to the greater number of fine particles (<5 µm) inhaled. [4]

To obtain a clearer characterization of the dust particles, scanning electron microscopy (SEM) coupled with FTIR analysis was employed to study and examine the morphology of wood dust collected on the filters (fig. 6).

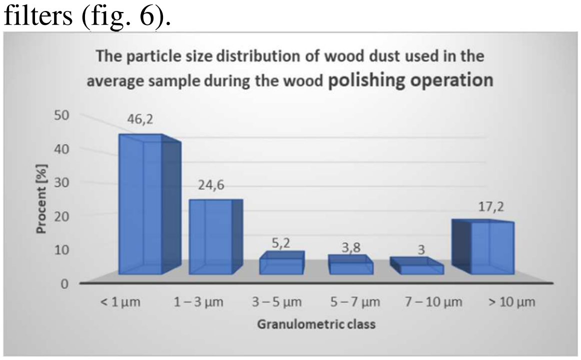
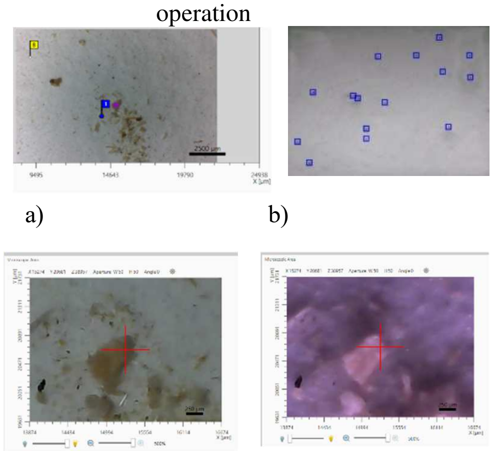


Fig. 5. Granulometric dispersion of wood dust analysed in the average sample for the sanding operation



a) b)

c) d)

Fig. 6. Microscopic images of wood dust
(a) Wide-field camera zoom 5x for particle identification,
(b) Automatic identification of wood particles,
(c) Measurement of wood fibres in visible observation chamber, (d) Infrared observation chamber

The images in Figure 6 show the dust sample at different magnifications and contrasts. [5]

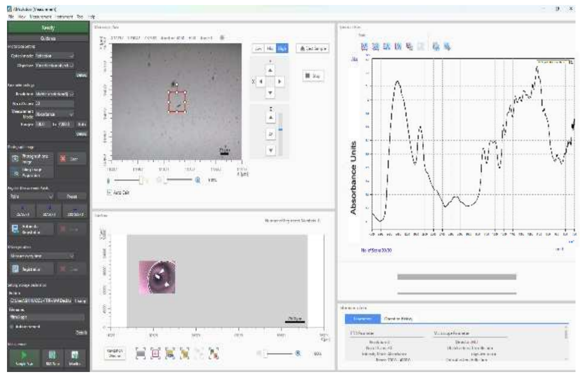


Fig. 7. Identification of fir wood fibers using FTIR spectroscopy

Wood is primarily composed of three molecular components: cellulose, hemicellulose, and lignin, each with distinct characteristics and specific FTIR absorption patterns [6]. Figure 7 presents the FTIR spectrum of softwood, as identified in a filter sample, highlighting its characteristic functional groups. The obtained spectrum was matched with the Fourier-transform infrared (FTIR) spectral library for identification. [7]

For each analysed sample, it was determined whether the identified particles originated from wood dust or another source. [8]

4. CONCLUSION

Workers involved in wood processing are exposed to wood dust particles. This study analyses the occupational health risks faced by workers processing softwood, focusing on the nature and granulometry of inhaled dust particles in this industry.

Wood dust present in work environments can cause various occupational diseases, including eye and skin irritation, dermatitis, allergic and chronic bronchitis, acute and chronic asthma, bronchopulmonary diseases, and nasal cancer—particularly in cases of exposure to fir wood dust. [2]

The assessment of worker health risks due to wood dust exposure requires both a technical-engineering approach, involving gravimetric determination of dust concentrations in the workplace, and a medical approach, which is beyond the scope of this study.

To evaluate workers' exposure risk to softwood (fir) dust in the work environment, simultaneous measurements of particle size distribution (dispersometry) were conducted. Additionally, the results were analysed using scanning electron microscopy coupled with an FTIR detector, leading to the following key findings:

- The gravimetric dust concentration during sanding operations was 3.73 mg/m³, which is higher than the concentration recorded during wood cutting (2.11 mg/m³). However, both values remain below the maximum allowable limit set by Romanian regulations.
- During the mechanical cutting process, 72% of respirable particles were smaller than 5 µm, while 63% of alveolar particles were smaller than 3 µm, from the total dust suspended in the workplace air.
- During the mechanical planing/sanding process, 76% of respirable particles were smaller than 5 µm, and 70.8% of alveolar particles were smaller than 3 µm, from the total dust suspended in the workplace air.

To ensure that the counted particles were indeed wood particles, each sample was analysed using a Fourier-transform infrared (FTIR) spectrophotometer, and the obtained spectra were matched against the AIM sight spectral library for identification.

In conclusion, although gravimetric standards are met, particle dispersion analysis clearly indicates that a significant number of respirable and alveolar particles are present in the air within workspaces.

These particles pose a serious health risk to workers, particularly during mechanical planing and sanding operations.

5. ACKNOWLEDGEMENTS

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6. REFERRING

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Identificarea pulberilor inhalabile de lemn de esență moale și stabilirea dispersiei granulometrice a particulelor din mediu de muncă prin utilizarea microscopiei de imagistică spectroscopică FT-IR

Lucrătorii din industria de prelucrare a lemnului sunt expuși riscurilor de accidente grave, cum ar fi tăieturi, amputări și leziuni musculare, dar și pericolele generate de praf de lemn, substanțe chimice și zgomot puternic. Acestea pot cauza probleme de sănătate pe termen lung, cum ar fi afecțiuni respiratorii, pierderea auzului și leziuni ale sistemului nervos sau circulator. Scopul acestui studiu este de a evalua riscul de expunere a lucrătorilor la pulberile de lemn de esență moale (brad) în mediul de lucru, prin realizarea simultană a măsurătorilor dispersiei procentuale pe clase de mărimi ale particulelor micrometrice (dispersometria), observate cu ajutorul microscopiei electronice cuplată cu detector FTIR.

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