THE EMISSIONS EMITTED BY SPRUCE THERMOWOOD WITH AND WITHOUT SURFACE FINISHED

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ABSTRACT

This paper investigates the problematic of VOC emissions emitted by the massive spruce wood and by heat treated wood at temperatures 180 °C and 200 °. In this contribution is investigated the influence on the temperature of the spruce wood heat treatment on the quality and quantity content of volatile organic compounds, especially on the amount of emitted Phenol and Furfural. This contribution researches the correlation between the times after the modification of heat-treated wood and amount and contents of VOC emitted by this heat treated spruce wood. This study contains the results of the influence of finished Spruce heat-treated wood by the water born lacquer on emissions of VOC.

Key words: Spruce massive, TVOC, emissions VOC, finished surface of thermal wood, heat-treated wood, finishing by water born lacquers.

1. INTRODUCTION

The volatile organic compounds emissions emitted by indoor equipment have the significant influence on indoor and outdoor air and on the quality of indoor and outdoor environments.

Outdoors, VOC concentrations are affected by season and temperature [1], proximity to emission sources such as industry, traffic and gas stations, and meteorology, e.g., mixing height, wind speed and precipitation [2]. Indoors, concentrations are affected by outdoor levels due to the exchange of indoor and outdoor air [3], and by the numerous VOC sources present indoors, which include building materials and furnishings (e.g., particle board, under laid floorings, and carpets), cleaning products, moth repellents, solvents, deodorants, fragrances, and hobby supplies (e.g., paints and glues) [4]. VOCs are associated with many routine indoor activities, e.g., cooking, cleaning, and painting [5], storing vehicles and fuel in attached garages [6], storing and using solvents, and tobacco smoking [7]. In most cases, indoor concentrations greatly exceed outdoor levels, showing the dominance of indoor sources [8]. Concentrations may change by season, e.g., closing doors/windows will reduce air exchange rates (AERs) and can increase levels from indoor sources [9].

Wood and wood based products including native wood and modified wood such as heat-treated wood is some of the sources emitted emissions into indoor.

In this contribution it is investigated the influence of the heat-treatment conditions on the quality and quantity contains of the emitted emissions by heat-treated wood so called thermal wood. The next topic, which this article solves, is the influence of finished surfaces on the amount of VOC emissions evaporated from the finished surfaces by the water borne lacquers on heat-treated wood of spruce.

Heat-treated wood is a popular decoration material and it has been used in floor, wall, and ceiling materials and in furniture. Heat-treatment improves dimensional stability of the wood, but there is only little information about the VOC emissions of heat-treated hard wood. [10] The information about evaporated VOC emissions is very important for using this popular heat-treated wood in interior and for the knowing of the possible influences and the impact of the products made from heat-treatment wood on indoor air quality.

The heat-treatment of wood was found to decrease significantly VOC emissions and change their composition. [11] Especially, emissions of terpentines decreased from softwood samples and aldehydes from European aspen samples after their heat-treatment. In agreement with another recent study, the emissions of furfural were found to increase. [12] In contrast to air-dried wood samples, emissions of VOCs were almost in steady state from the heat treated wood samples even in the beginning of the test. [10]

The influence of the temperature of heat-treatments and the time of the emissions measuring after the modification of wood on the quality of indoor air are expressed in connection with the term TVOC (total volatile organic compounds). TVOC is used to express total amount of emitted volatile organic compounds into the indoor air. The TVOC value indicates the level of indoor air pollution.

2. AIM OF THE RESEARCH

The aim of the research was to find diversity of VOCs amount emitted by heat-treated wood samples treated at different temperatures (180 °C and 200 °C) and untreated wood without finished surface and with finished surface by the water born lacquers. The chosen type of soft wood spruce wood has been tested for comparing in view of emitted chemical compounds and their amounts in the dependence of time from the wood treatment and finishing of wood surfaces. Quantitative difference of entire emitted organic compounds showed the measured values of TVOC. We analyzed the important volatile organic compounds in the blend of emissions emitted by tested samples. These analyzed chemical volatile compounds contain 31 volatile organic compounds.

3. MATERIALS, EQUIPMENT AND METHODS

The untreated and heat –treated spruce (spruce *Picea abies*) samples were prepared from the same native wood from the same tree. The pre-dried wood samples were modified at 200 °C and 180 °C in a heat treatment process.

Air-dried wood samples were taken from the normal manufacturing process, wrapped in aluminium foils and delivered to the test laboratory, where wood samples were divided into two halves. The first half of these samples was put into the test chamber. Samples of heat-treated were obtained directly from the production of heat-treated wood. This kind of wood samples were also divided into two halves. One half of these heat-treated samples were put into the chamber immediately after the delivery from the plant, where they were treated. The second halves of untreated and heat treated samples were finished by water born lacquers. The finished samples were situated into chamber 3 hours after finishing. In the present study, air samples were collected continuously onto the Tenax TA until their required testing day was obtained.

3.1. Tested materials:

1. 10 pieces of lamellas made from native spruce wood, each of tested lamellas has these dimensions: 0.74 x 0.04 x 0.001 m, size tested sample: $S=0.6\ m^2$;
2. 10 pieces of lamellas made from spruce heat-treated spruce wood at

the temperature 200 °C, dimensions of one lamella: 0.74 x 0.04 x 0.001 m, size tested sample: S=0.6 m^2;

3. 10 pieces of lamellas made from Spruce heat-treated spruce wood at the temperature 180 °C, dimensions of one lamella: 0.74 x 0.04 x 0.001 m, size tested sample: S=0.6 m^2;
4. l10 pieces of lamellas made from spruce heat-treated spruce wood at the temperature 200 °C, finished surfaces by waterborne lacquers, dimensions of one lamella: 0.74 x 0.04 x 0.001 m, size tested sample: S=0.6 m^2.

3.2 Equipment for measuring emitted emissions

Equipment for collect VOC emissions

Small space chamber VOC - TEST 1000 is a device, which is intended for immediate consumption of air containing VOC emissions and other volatiles from the materials placed in the long term, at constant temperature, humidity, air exchange rate and air flow speed over the sample surface emitting emissions.

Technical parameters during the collection of emissions VOC:

Inner dimensions of space in chamber 1 m^3

Conditions in chamber during the collection of emissions

Air temperature in chamber 23 °C

Air humidity in chamber 50 %

Air changing rate in chamber 1 m^3 per 1 h

Air speed over the tested samples from 0.1 to 0.3 $m.s^{-1}$

Equipment for air sampling

Sampling of air is realized by means of a diaphragm pump air sampler Gilian LFS – 113 SENSIDINE, with air flow of 12 l / ha, desorption tubes (Silco trated Thermal Desorption Tube 786090-100) filled with Tenax TA sorbent in an amount of 100 mg per absorbent tube.

Equipment for analyzing VOC emissions

Gas chromatograph Agilent GC 6890 N with MS (mass spectrometer) detector 5973 with the cryofocusation, the thermal desorption and library of spectra NIS 05, column type HP – 5 (AGILENT USA)

3.3. Methods

Sampling desorption tube samples bleed air containing VOC emissions were then analyzed on a gas chromatograph (6890N HPST) with a mass spectrometer (5973 Network) and thermal desorption (TD Agilent-4) according to the methodology prescribed by the standards: EN ISO 16 000-1 – Indoor air – Part 1: General aspects of sampling, EN ISO 16 000-5 – Indoor air – Part 5: procedure for sampling volatile organic compounds (VOC), EN ISO 16 000-9 – Indoor air – Part 9 Determination of VOC emissions from building materials and furniture, test chamber method.

Methods of VOC testing were set via standards:

ISO 16000: 2004	Indoor air
ISO 16000-1: 2004	General aspects of sampling strategy
ISO 16000-5: 2005	Measurement strategy for (VOCs) volatile organic compounds
ISO 16000-11: 2004	Determination of the emission of volatile organic compounds— sampling, storage of samples and preparation of test specimens

ISO 16000-6: 2005	Determination of volatile organic compounds indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and chromatography using MS/FID
ISO 16000-9: 2004	Determination of the emission of volatile organic compounds—Emission test chamber method

Standard ISO 16000-9 (Emission test chamber method) specifies the time interval of measurement VOC emissions from building materials in the following intervals: 3 hours, 24 hours, 72 hours, 28 days.

In connection with the term VOC there is the new term TVOC (total volatile organic compounds) which is used to describe total amount of volatile organic compounds in the indoor atmosphere. The TVOC value indicates the level of indoor air pollution.

The term TVOC is used for measuring of indoor air composition and for determination of total amount of organic compounds in the air. The TVOC value can be obtained on the gas chromatograph and it is defined as the sum of all peak areas of all VOCs which are emitted between hexane and hexadecane. The sum of areas is then calibrated to the value which is equivalent to the toluene.

4 RESULTS OF MEASUREMENTS

The results of measurements of emissions emitted by native Spruce in depending of time after the preparation of sample there are shown in the table 1.

The quality and quantity contains of VOC emissions emitted by heat-treated beech wood in dependence of time after heat-treatment at the temperature 200 °C and 180 °C are shown in the tables 2 and 3. The influence of surface finished on the beech heat-treated at 200 °C is issued in the table 5.

Table 1: The values of VOCs emitted by tested sample untreated wood – spruce

Compound	Spruce wood untreated, after preparation Concentration of VOC ($\mu g/m^3$)[1]				
	3 hours	**24 hours**	**72 hours**	**672**	
Ethyl acetate	< 0.1	< 0.1	(0.2 ± 0.1)	< 0.1	< LOQ[2]
Benzene	< 0.1	(0.2 ± 0.1)	(0.2 ± 0.1)	(0.2 ± 0.1)	
1-Methoxy-2-Propanol	(0.3 ± 0.1)	(0.1 ± 0.03)	< 0.1	(0.8 ± 0.2)	
Pentanal	(2 ± 0.6)	(1.3 ± 0.4)	(1.1 ± 0.3)	(0.6 ± 0.2)	
Trichlorethylene	< 0.1	< 0.1	< 0.1	< 0.1	< LOQ
Toluene	(1 ± 0.3)	(1 ± 0.3)	(1.2 ± 0.4)	(2 ± 0.6)	
Hexanal	(5.4 ± 1.6)	(4.4 ± 1.3)	(3.8 ± 1.1)	(2.1 ± 0.6)	
Tetrachlorethylene	< 0.1	(0.2 ± 0.1)	(0.2 ± 0.1)	(0.2 ± 0.1)	
n-Butyl acetate	(1.3 ± 0.4)	(0.4 ± 0.1)	(0.9 ± 0.3)	(0.9 ± 0.3)	
Furfural	**(7.8 ± 2.3)**	**(2.5 ± 0.8)**	**(1.8 ± 0.5)**	**(1 ± 0.3)**	
Ethylbenzene	(0.7 ± 0.2)	(0.2 ± 0.1)	(0.5 ± 0.2)	(0.7 ± 0.2)	
m,p-Xylene	(1.8 ± 0.5)	(0.8 ± 0.2)	(1.8 ± 0.5)	(2 ± 0.6)	
Styrene	< 0.1	(0.1 ± 0.03)	< 0.1	< 0.1	< LOQ
o-Xylene	(0.4 ± 0.1)	(0.1 ± 0.03)	(0.4 ± 0.1)	(0.4 ± 0.1)	
Butoxy-Ethanol	(0.3 ± 0.1)	(0.1 ± 0.03)	< 0.1	< 0.1	< LOQ
α-Pinene	(0.1 ± 0.03)	(0.1 ± 0.03)	(0.1 ± 0.03)	(0.3 ± 0.1)	

[1] Average of result ± expanded measurement uncertainty

[2] Concentration of VOC less than LOQ ie. the measured value is less than the limit of quantification

Compound	Spruce wood untreated, after preparation Concentration of VOC (μg/m³)[1]				
	3 hours	24 hours	72 hours	672	
Camphene	< 0.1	< 0.1	< 0.1	(0.2 ± 0.1)	
3-Ethyl-Toluene	(0.3 ± 0.1)	(0.3 ± 0.1)	(0.3 ± 0.1)	(0.3 ± 0.1)	
4-Ethyl-Toluene	(0.3 ± 0.1)	(0.3 ± 0.1)	(0.4 ± 0.1)	(0.3 ± 0.1)	
1,3,5-Trimethyl-Benzene	< 0.1	< 0.1	< 0.1	< 0.1	< LOQ
Phenol	**(0.7 ± 0.2)**	**(0.5 ± 0.2)**	**(0.5 ± 0.2)**	**(0.3 ± 0.1)**	
β-Pinene	(0.4 ± 0.1)	(0.4 ± 0.1)	(0.2 ± 0.1)	(0.2 ± 0.1)	
2-Ethyl Toluene	(0.1 ± 0.03)	(0.1 ± 0.03)	(0.1 ± 0.03)	(0.1 ± 0.03)	
Myrcene	< 0.1	< 0.1	< 0.1	< 0.1	< LOQ
1,2,4-Trimethyl-Benzene	< 0.1	(0.2 ± 0.1)	(0.2 ± 0.1)	(0.2 ± 0.1)	
α-Phellandrene	< 0.1	< 0.1	< 0.1	< 0.1	< LOQ
3-δ-Carene	(0.6 ± 0.2)	(0.4 ± 0.1)	(0.4 ± 0.1)	(0.4 ± 0.1)	
1,2,3-Trimethyl-Benzene	(0.1 ± 0.03)	(0.1 ± 0.03)	(0.1 ± 0.03)	(0.1 ± 0.03)	
Limonene	(1.1 ± 0.3)	(0.4 ± 0.1)	(0.4 ± 0.1)	(0.1 ± 0.03)	
γ-Terpinene	< 0.1	< 0.1	< 0.1	< 0.1	< LOQ
Bornyl Acetate	< 0.1	< 0.1	< 0.1	< 0.1	< LOQ
$TVOC_{MS}$	**(44 ± 13)**	**(20 ± 6)**	**(19 ± 6)**	**(17 ± 5)**	

Table 2: VOCs emitted by the tested sample of heat treatd wood – spruce, heat treated at the temperature 200 °C.

Compound	Spruce wood heat treated at 200 °C, after modification Concentration of VOC (μg/m³)			
	3 hours	24 hours	72 hours	672
Ethyl acetate	(0.2 ± 0.1)	(0.2 ± 0.1)	(0.7 ± 0.2)	< 0.1
Benzene	(0.2 ± 0.1)	< 0.1	(0.2 ± 0.1)	< 0.1
1-Methoxy-2-Propanol	(0.1 ± 0.03)	(0.1 ± 0.03)	< 0.1	< 0.1
Pentanal	(0.8 ± 0.2)	(0.3 ± 0.1)	(0.3 ± 0.1)	(0.3 ± 0.1)
Trichlorethylene	< 0.1	< 0.1	< 0.1	< 0.1
Toluene	(0.8 ± 0.2)	< 0.1	(0.8 ± 0.2)	(0.8 ± 0.2)
Hexanal	(1.3 ± 0.4)	(0.1 ± 0.03)	(0.3 ± 0.1)	(0.3 ± 0.1)
Tetrachlorethylene	(0.2 ± 0.1)	< 0.1	(0.2 ± 0.1)	(0.2 ± 0.1)
n-Butyl acetate	(1.6 ± 0.5)	< 0.1	< 0.1	(0.3 ± 0.1)
Furfural	**(207.3 ± 62.2)**	**(32.8 ± 9.8)**	**(77 ± 23.1)**	**(29.7 ± 8.9)**
Ethylbenzene	(0.7 ± 0.2)	< 0.1	< 0.1	(0.2 ± 0.1)
m,p-Xylene	(2 ± 0.6)	< 0.1	(0.2 ± 0.1)	(0.7 ± 0.2)
Styrene	< 0.1	< 0.1	< 0.1	< 0.1
o-Xylene	(0.4 ± 0.1)	< 0.1	(0.1 ± 0.03)	(0.1 ± 0.03)
Butoxy-Ethanol	(0.1 ± 0.03)	< 0.1	< 0.1	< 0.1
α-Pinene	(0.3 ± 0.1)	< 0.1	(0.5 ± 0.2)	(0.1 ± 0.03)
Camphene	(0.2 ± 0.1)	< 0.1	(0.2 ± 0.1)	< 0.1
3-Ethyl-Toluene	(0.4 ± 0.1)	< 0.1	(0.3 ± 0.1)	(0.1 ± 0.03)
4-Ethyl-Toluene	(0.4 ± 0.1)	< 0.1	(0.3 ± 0.1)	(0.3 ± 0.1)
1,3,5-Trimethyl-Benzene	< 0.1	< 0.1	< 0.1	< 0.1
Phenol	**(10.3 ± 3.1)**	**(2.7 ± 0.8)**	**(2.3 ± 0.7)**	**(1 ± 0.3)**
β-Pinene	(0.1 ± 0.03)	< 0.1	(0.2 ± 0.1)	(0.1 ± 0.03)
2-Ethyl Toluene	(0.1 ± 0.03)	< 0.1	(0.1 ± 0.03)	(0.1 ± 0.03)
Myrcene	< 0.1	< 0.1	< 0.1	< 0.1
1,2,4-Trimethyl-Benzene	(0.2 ± 0.1)	< 0.1	(0.2 ± 0.1)	< 0.1
α-Phellandrene	< 0.1	< 0.1	< 0.1	< 0.1
3-δ-Carene	(0.2 ± 0.1)	< 0.1	(0.2 ± 0.1)	(0.1 ± 0.03)
1,2,3-Trimethyl-Benzene	(0.1 ± 0.03)	< 0.1	(0.1 ± 0.03)	(0.1 ± 0.03)
Limonene	(0.7 ± 0.2)	(0.1 ± 0.03)	(0.1 ± 0.03)	(0.1 ± 0.03)
γ-Terpinene	< 0.1	< 0.1	< 0.1	< 0.1
Bornyl Acetate	< 0.1	< 0.1	< 0.1	< 0.1
$TVOC_{MS}$	**(90 ± 27)**	**(80 ± 24)**	**(27 ± 8)**	**(12 ± 4)**

Average of result ± expanded measurement uncertainty

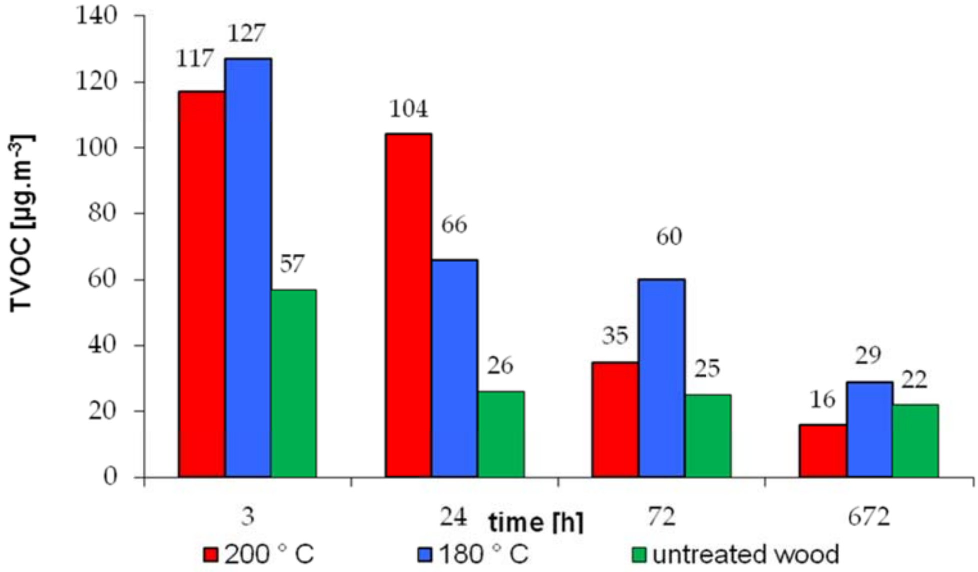

Figure 1: TVOC emissions emitted by heat-treated spruce ("thermally modified wood") at 200 °C and 180 °C and untreated spruce wood

On figure 1 we can see the comparing of amount TVOC emission emitted by heat-treated spruce wood, which was heat treated at the temperature 200 °C and TVOC emitted by heat-treated beech wood, treated at the temperature 180 °C to the untreated wood in the dependence of the time of measurement. The differences of TVOC emissions decrease with the increasing time between the heat–treated wood and the measurement time.

Table 3: VOCs emitted by the tested sample of heat-treated wood – spruce, heat treated at the temperature 180 °C.

Compound	**Spruce wood heat treated at 180 °C, after modification Concentration of VOC (µg/m³)**				
	3 hours	**24 hours**	**48 hours**	**72 hours**	**28 days**
Ethyl acetate	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1
Benzene	< 0,1	< 0,1	< 0,1	(0,2 ± 0,1)	< 0,1
1-Methoxy-2-Propanol	(0,1 ± 0,03)	< 0,1	< 0,1	< 0,1	< 0,1
Pentanal	(0,5 ± 0,2)	(0,3 ± 0,1)	(0,1 ± 0,03)	(0,3 ± 0,1)	(0,3 ± 0,1)
Trichlorethylene	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1
Toluene	(3,5 ± 1,1)	(0,3 ± 0,1)	(0,5 ± 0,2)	(0,8 ± 0,2)	(0,8 ± 0,2)
Hexanal	(1,3 ± 0,4)	(0,3 ± 0,1)	(0,3 ± 0,1)	(0,3 ± 0,1)	(0,3 ± 0,1)
Tetrachlorethylene	(0,2 ± 0,1)	< 0,1	(0,2 ± 0,1)	(0,2 ± 0,1)	(0,2 ± 0,1)
n-Butyl acetate	(2,1 ± 0,6)	(0,4 ± 0,1)	(0,6 ± 0,2)	(0,6 ± 0,2)	(0,4 ± 0,1)
Furfural	**(194,8 ± 51,3)**	**(144,5 ± 43,4)**	**(155,7 ± 46,7)**	**(117 ± 35,1)**	**(39,7 ± 11,9)**
Ethylbenzene	(1,2 ± 0,4)	(0,2 ± 0,1)	(0,4 ± 0,1)	(0,4 ± 0,1)	(0,2 ± 0,1)
m,p-Xylene	(4,7 ± 1,4)	(0,5 ± 0,2)	(1 ± 0,3)	(1 ± 0,3)	(0,7 ± 0,2)
Styrene	(0,3 ± 0,1)	< 0,1	(0,1 ± 0,03)	(0,1 ± 0,03)	< 0,1
o-Xylene	(0,8 ± 0,2)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,3 ± 0,1)	(0,1 ± 0,03)
Butoxy-Ethanol	(0,1 ± 0,03)	< 0,1	< 0,1	< 0,1	< 0,1
α-Pinene	(0,8 ± 0,2)	(0,3 ± 0,1)	(0,3 ± 0,1)	(0,5 ± 0,2)	(0,1 ± 0,03)
Camphene	(0,2 ± 0,1)	< 0,1	< 0,1	< 0,1	< 0,1
3-Ethyl-Toluene	(0,8 ± 0,2)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,3 ± 0,1)	(0,1 ± 0,03)
4-Ethyl-Toluene	(0,9 ± 0,3)	(0,1 ± 0,03)	(0,3 ± 0,1)	(0,3 ± 0,1)	(0,1 ± 0,03)
1,3,5-Trimethyl-Benzene	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1
Phenol	**(4,7 ± 1,4)**	**(3,3 ± 1)**	**(2,8 ± 0,8)**	**(2,2 ± 0,7)**	**(1,5 ± 0,5)**

Compound	Spruce wood heat treated at 180 °C, after modification Concentration of VOC (μg/m³)				
	3 hours	24 hours	48 hours	72 hours	28 days
β-Pinene	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)
2-Ethyl Toluene	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)
Myrcene	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1
1,2,4-Trimethyl-Benzene	(0,5 ± 0,2)	< 0,1	< 0,1	(0,2 ± 0,1)	< 0,1
α-Phellandrene	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1
3-δ-Carene	(0,2 ± 0,1)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)
1,2,3-Trimethyl-Benzene	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)	(0,1 ± 0,03)
Limonene	(0,6 ± 0,2)	(0,2 ± 0,1)	(0,2 ± 0,1)	(0,2 ± 0,1)	(0,1 ± 0,03)
γ-Terpinene	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1
Bornyl Acetate	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1
$TVOC_{MS}$	**(98 ± 29)**	**(51 ± 15)**	**(65 ± 20)**	**(46 ± 14)**	**(22 ± 7)**

NSLC – not specified limit concentration

In table 2 there are the quality and quantity contains of VOC emissions emitted by heat –treated Spruce wood in dependence of time after heat-treatment at the temperature 200 °C. In the table 3 there are issued the results of the measurements of the contents and the amount of the emissions VOC emitted by heat-treatment wood spruce at the temperature 180°C. The influence of surface finished on the heat-treated wood spruce, treated at 200 °C, is issued in the table 4.

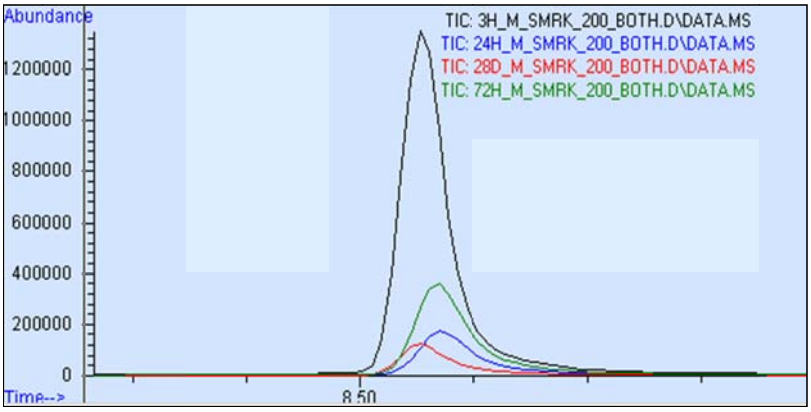

Figure 2: The dependence of the furfural peak size on the time of its measurement after the modification

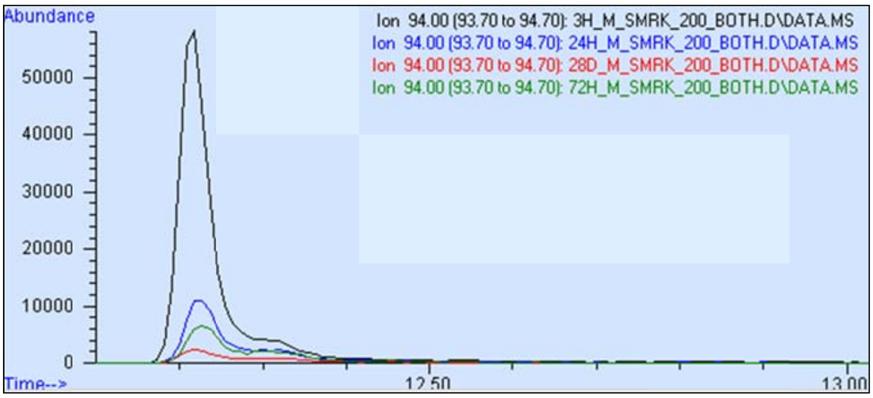

Figure 3: The dependence of the Phenol peak size on the time of its measurement after the modification

Table 4: VOCs emitted by the tested sample of heat-treated wood – spruce, heat treated at the temperature 200 °C with the finished surface by the water borne lacquer.

Compound	without finishing	after finishing			
	Concentration of VOC (µg/m^3)				
		3 hours	24 hours	72 hours	672 hours
Ethyl acetate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Benzene	(0.1 ± 0.03)	< 0.1	< 0.1	(0.1 ± 0.03)	(0.1 ± 0.03)
1-Methoxy-2-Propanol	(0.4 ± 0.1)	< 0.1	(0.3 ± 0.1)	(0.4 ± 0.1)	< 0.1
Pentanal	(0.1 ± 0.03)	(0.1 ± 0.03)	(4.4 ± 1.3)	(0.3 ± 0.1)	(0.6 ± 0.2)
Trichlorethylene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Toluene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Hexanale	(0.3 ± 0.1)	< 0.1	(0.2 ± 0.1)	(0.4 ± 0.1)	(2.2 ± 0.7)
Tetrachlorethylene	< 0.1	< 0.1	< 0.1	< 0.1	(0.1 ± 0.03)
n-Butyl acetate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Furfural	**(5.8 ± 1.7)**	**(50 ± 15)**	**(26.8 ± 8)**	**(11 ± 3.3)**	**(10.7 ± 3.2)**
Ethylbenzene	< 0.1	(0.1 ± 0.03)	< 0.1	< 0.1	< 0.1
m,p-Xylene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Styrene	< 0.1	(1 ± 0.3)	< 0.1	< 0.1	< 0.1
o-Xylene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Butoxy-Ethanol	**(0.2 ± 0.1)**	**(445.7 ± 133.7)**	**(665 ± 200)**	**(248 ± 74.4)**	**(138.5 ± 42)**
α-Pinene	(0.1 ± 0.03)	< 0.1	< 0.1	(0.1 ± 0.03)	(0.1 ± 0.03)
Camphene	< 0.1	< 0.1	(0.2 ± 0.1)	< 0.1	< 0.1
3-Ethyl-Toluene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
4-Ethyl-Toluene	(0.2 ± 0.1)	(0.4 ± 0.1)	< 0.1	(0.1 ± 0.03)	(0.2 ± 0.1)
1,3,5-Trimethyl-Benzene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Phenol	**(1.2 ± 0.4)**	**(2.2 ± 0.7)**	**(2.7 ± 0.8)**	**(1 ± 0.3)**	**(4.5 ± 1.4)**
β-Pinene	< 0.1	< 0.1	< 0.1	< 0.1	(0.2 ± 0.1)
2-Ethyl Toluene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Myrcene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
1,2,4-Trimethyl-Benzene	< 0.1	(0.3 ± 0.1)	< 0.1	< 0.1	< 0.1
α-Phellandrene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
3-δ-Carene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
1,2,3-Trimethyl-Benzene	(0.1 ± 0.03)	(0.2 ± 0.1)	(0.1 ± 0.03)	(0.1 ± 0.03)	(0.1 ± 0.03)
Limonene	< 0.1	(0.5 ± 0.2)	(1.2 ± 0.4)	(2 ± 0.6)	< 0.1
γ-Terpinene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bornyl Acetate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
$TVOC_{MS}$	(14 ± 4)	(2536 ± 761)	(2442 ± 732)	(520 ± 156)	(325 ± 98)

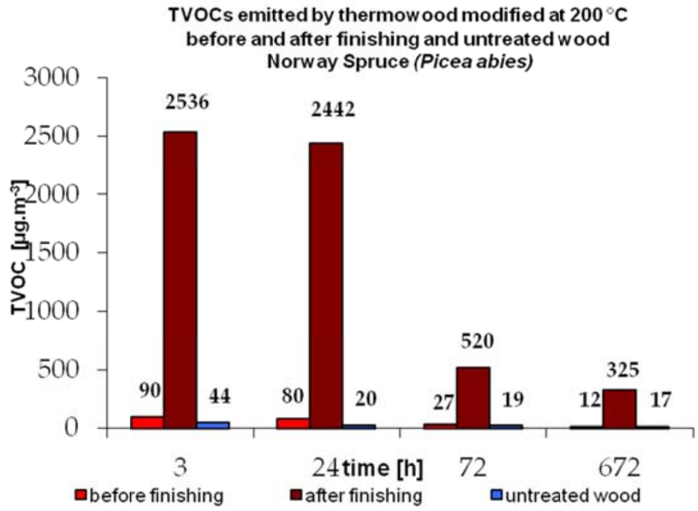

Figure 4: Comparing emissions emitted by unfinished and finished spruce heat treated Spruce wood at 200 °C

On the figure 4 is presented the influence of finishing tested samples by water-borne lacquers on the amount of TVOC emissions. The finishing by water-borne lacquers has great impact of amount TVOC emitted emissions. The emissions increase immediately after finishing twenty times in comparing to the emissions emitted by the same samples without surface finishing.

5. DISCUSSION

TVOC emissions were significantly higher from heat-treated than from normal air-dried wood samples. Terpentines were the main compounds emitted from softwoods (Scots pine and Norway spruce) and heat-treatment decreased especially their emissions. Terpentines partly evaporate and partly degrade during the heat-treatment process [15]. 4-methyl-1-(1-methylethenyl)-benzene (p-cymenene) and 1-methyl-2-(1-methylethyl)-benzene (o-cymene) were detected in higher extent in air-dried than in heat-treated softwood samples. These compounds are degradation products of camphene, delta-carene, and limonene [15].

Emissions of aldehydes (furfural and hexagonal) and carboxylic acids (acetic acid) were the most dominating compounds in heat-treated softwood samples. In agreement with [16], emissions of furfural increased and those of hexagonal decreased in heat-treated wood samples when compared to the air-dried ones. This phenomenon was observed in all the wood species. This could also be expected, because hexanal belongs to the prevailing aldehydes in natural wood whereas furfural is a major degradation product of hemicelluloses.

VOC emission profile changed dramatically during the heat treatment process. Although VOC emissions were lower from the heat-treated than air-treated wood samples, oxidized organic compounds were also formed during the treatment. These have more unpleasant odour and are typically more irritating than terpenes which dominate in the emissions of native softwoods. However, air-dried wood samples also emitted oxidized organic compounds, and terpentines might be oxidized to aldehydes and acids during the usage of the wood product (especially when there is ozone present in air). In the present study, emissions of wood species were tested a one month. Actually, VOC emissions from wood (as any other materials) in constant conditions keep decreasing at least one year. However, TVOC emissions from heat-treated wood products were relative low already in the first test days.

6. CONCLUSIONS

Based on the obtained results (tables 1, 2, 3, figure 1) it is possible to conclude that the heat-treated modification increases the quantity and quality contents of VOC emissions.

The main difference consists in the amount of emitted furfural and phenol in the blend of gaseous evaporated by heat- treated spruce in normal conditions. Great influence on the emitted furfural amount has the temperature of heat-treatment. The higher temperature during the Spruce treatment means higher amount of furfural emissions. TVOC, the indicator of indoor air quality, depends on the temperature of the modification. It is possible to state that Furfural and Phenol are typical chemicals, which result in degradation of wood components. The finished surface by the water born lacquer doesn't decrease the emissions escaping from heat-treatment. Spruce wood does not even increase the quantity of evaporated VOC emissions from these samples.

It is very important in the next step of this research to focus on the study of the influence of heat treatment on VOC emissions emitted by different kinds of wood and to study the influence of heat-treated wood finished surfaces, especially do find out the correlation between the kind of surface finishing and VOC emissions; the relation of the quality and quantity emitted emissions VOC by the thermal wood on the way of finishing of the heat-treatment wood.

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