WOOD RESEARCH
59 (1): 2014
51-66

SOME PROPERTIES OF SEDIMENTED DUSTS FROM SELECTED EXOTIC WOODS

Karel Klouda
State Office for Nuclear Safety
Prague, Czech Republic

Hana Matheisová
Ministry of the Interior – General Directorate of the Fire
And Rescue Services, Technical Institute of Fire Protection
Prague, Czech Republic

Markéta Weisheitelová
National Institute for Nuclear, Chemical and Biological Protection
Kamenná – Milín, Czech Republic

(Received January 2013)

ABSTRACT

Sedimented dusts representing potentially risky waste were obtained by technological processing (grinding) of nine selected exotic woods. This article describes macroscopic properties of the dusts, their microscopic structure and thermal stability (TGA and DSC analysis), depending on the type of the wood, size and shape of particles, effects of extractable wood components on the stability, biological activity of the dusts and their behavior after their exposure to ionizing radiation.

KEYWORDS: Exotic woods, TGA and DSC analysis, sedimented dust, biological activity and luminescence.

INTRODUCTION

Wooden dust is produced in the course of wood processing in joineries and it may form, depending on the particles size (nano- and micro-particles), aerosols or directly sediments. Wooden dusts contain chemical substances that form the wood material, i.e. polysaccharides, such as cellulose and hemicelluloses, aromatic substances, such as lignin and tannins, terpenes, resins, lipids, nitrogen compounds, inorganic substances etc (Jankovský et al. 1999). Depending on the condition of the wood it is not possible to exclude presence of biological organisms, fungi,

mildews and bacteria.

Negative effects of wooden dusts on human organism may occur as a result of their contact with skin, eye mucosa or inhalation via respiratory tract. The smaller the size of the particles the higher their respirability and ability to bond other substances (by sorption or condensation). Dusts of biologically highly aggressive wood species may cause dermatoses, respiratory diseases, allergic respiratory problems (asthma) and they may have carcinogenic effects adenocarcinoma of nasal cavity and paranasal cavity (Bornholdt et al. 2007, Directive cancels OSHA 2007, IARC 1995). Chemical composition of wood means a number of potential risks in contact with a biological system.

One of the risks of nano, micro and sedimented dust particles are their physicochemical hazards, i.e. fire, explosion, uncontrolled and undesired reactions. For this reason we have focused on macroscopic properties of sedimented dusts, their microstructure, thermal stability and effects of extractable components of wood on the stability. We investigated sedimented dusts generated by grinding of selected exotic woods whose distribution in the Czech Republic has been on the rise.

The basic data about the exotic woods used to generate the sedimented dusts are provided in Tab. 1. The table is complemented with data from literature about their processability and toxicity.

Tab. 1: Basic data about the woods from which the sedimented dusts were produced.

Commercial name of the wood	Latin name of the wood species	Occurrence	Notes on wood processing (Roček 2005)	Notes on toxicity (Roček 2005)
Ipé	*Tabebuia* spp.	Central and South America	Planing difficult, powerful machines, very strong, highly resistant	Saw dust and grinding dust containing lapachol as a colorant, irritant, it may damage mucosa and cause skin problems
Jatoba	*Hymenaea* spp.	Central and South America	Cutting requires powerful machines	Risk of mucosa and skin damage
Massaranduba	*Manilkara* spp.	South and tropical America (Brazil, Columbia)	Cutting requires powerful machines	Saw dust may be irritant, wooden dust may cause irritation of mucosa and skin
Merbau	*Intsia bakerie Prain*	Southeast Asia (Indonesia, Malaysia)	Significantly blunts tools, difficult processing, requires special tools	Chemically reacts with iron
Balau, Yellow (Bangkirai)	*Shorea argentea* Fiech.C.E.C.	Southeast Asia (Malaysia, Indonesia)	Difficult processing	Not determined
Faveira	*Porkia* spp.	South tropical America (Brazil, Columbia)	Cutting is easy, no difficulties in processing	Poor resistance against fungi and insects
Garapa*	*Apuleia leiocarpa* Macbr.	South America (Brazil)	Not determined	May cause allergies, toxic
Teak	*Tectona grandis* Linn. f.	Southeast Asia (Indonesia, Burma, Laos)	Cutting less easy, blunts tools	Wood dust irritates skin, contains oily resins, resistant against rotting
Bilinga (Opepe)	*Vaucle and Diderrichii*	West Africa (Sierra Leone, Nigeria, Cameroon)	Cutting requires powerful machines	Resistant against termites, the bark contains alkaloid

MATERIAL AND METHODS

Samples of sedimented dusts were obtained as waste from a technological operation of wood grinding – on an abrasive-band grinding machine HOUFEK, PBH 300 B BASEL, band speed 17 $m.s^{-1}$, abrasive band grade AA 80 a AA 100.

The experiment included determination of the distribution of aerosol nano- and micro-particles, FIT factor as an indicator of quality of a protective respirator etc. Results from the measurements are presented in separate publications (Klouda et al. 2012).

Extraction procedure used for getting material for lignin determination, modification of Klason procedure according to Ritter (Jankovský et al. 1999). We used a combination of ethanol, ethanol-toluene and water and a Soxhlet extractor. Tested biological activity dust wood to *Escherichia coli*.

Measuring devices

Thermal analysis TG-DSC and TGA was measured on STAi 1500 made by Instrument Specialists Incorporated – THASS. Degradation medium – air; airflow – 20 $ml.min^{-1}$; temperature regime – from 25 to 1000°C; heating rate of the sample – 10°$C.min^{-1}$; portions of the samples – 8 – 9 mg.

Microscope Olympus XI71 + CCD camera Olympus DP72 (Olympus Co., Japan).

ATR analysis with FTIR spectrometry was performed on Brucker Sloha/FT-IR spectrometer, ATR crystal (Id. platinum Diamond 1 Refl), software OPUS 6,5, source IR SiC Globar. Measuring parameters: Number of spectrum scans 24, resolution 4.cm^{-1}, spectrum range 375 – 4000.cm^{-1}.

Dust wood was irradiated by a beta source 90Sr/90Y, which is a part of the Risoe system TL/OSL reader DA-20 for optically stimulated luminescence. Stimulation of the samples was performed in a continual regime with blue LED diodes with the power output 50 mW.cm^{-2} for 100 seconds at 30°C.

RESULTS AND DISCUSSION

Determination of quantity of wood removed by grinding

Weighted samples (mostly with identical sizes of surface areas) of exotic woods were ground under identical conditions for 5 minutes on a band grinder. After the grinding the samples were weighted again and the weight loss per 1 cm^2 was calculated. The results provided in Tab. 2 indicate that the biggest loss was found for Garapa wood and the weight losses of Massaranduba, Ipé and Teak were comparable. Merbau wood was found to be the most resistant against grinding. Our comparison of quantities of removed wooden matter using different sizes of grains on the abrasive band has shown that for finer grains the quantity of matter removed by grinding was higher by 20-25 %.

Tab. 2: Determination quantity of wood removed by grinding.

Wood species	Area subject to grinding (cm^2)	Quantity removed by grinding (g)	Quantity removed by grinding per 1 cm^2 (g)
Ipé	371	261	0. 70

Jatoba	371	167	0. 45
Massaranduba	371	246	0. 66
Merbau	371	78	0. 21
Bangkirai	308	195	0. 63
Faveira	371	157	0. 42
Garapa	371	308	0. 83
Teak	331	266	0. 80
Bilinga	466	182	0. 39

Comparison of macroscopic properties of sedimented wooden dusts and their microscopic structures

Macroscopic properties of dust particles of collected samples of sedimented dusts after grinding of the individual wood (see Fig. 1) were described as follows:

- Ipé: fine saw dust with minimum dustiness,
- Jatoba: saw dust of the same size as Ipé but, unlike Ipé, with significant dustiness,
- Massaranduba: coarse saw dust,
- Merbau: the finest saw dust structure, with the highest dustiness,
- Bangkirai: medium size saw dust with a significant representation of finer particles,
- Faveira: similar structure and distribution of fractions as Bangkirai,
- Garapa: fine saw dust with medium dustiness and good powderiness,
- Teak: saw dust with coarse structure and minimum dustiness, which is caused by cohesiveness or aggregation of saw dust,
- Bilinga: coarse structure of saw dust with medium values of dustiness and powderiness.

A summary overview of the identified macroscopic properties is shown in Tab. 3.

Tab. 3: Description of macroscopic properties of sedimented particles.

	Dustiness	Inherent cohesiveness	Powderiness	Size of particles	Structure
Ipé	+	++	+	++	medium coarse
Jatoba	++	+	++	++	coarse
Massaranduba	++	+++	++	+++	coarse
Merbau	+++	+	+++	+	fine
Bangkirai	+	++	++	++	medium coarse
Faveira	+	+++	+	++	medium fine
Garapa	++	+	++	+	medium coarse
Teak	+	+++	+	+++	coarse
Bilinga	++	++	++	++	coarse

Optical magnification was used to investigate shapes and sizes of the particles (Fig. 2) that may play a role in fixation of the particles in the respiratory tract or may affect physical properties of the particles, their thermal stability (see below). As an example we present microscopic images of selected particles with magnification 200 times, where the line under the picture represents 100 micrometers.

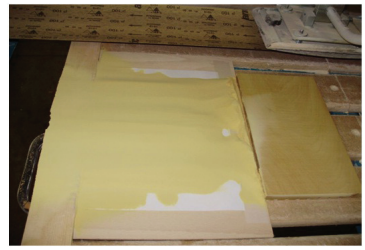

Fig. 1: Sedimented dust produced by grinding of Garapa wood.

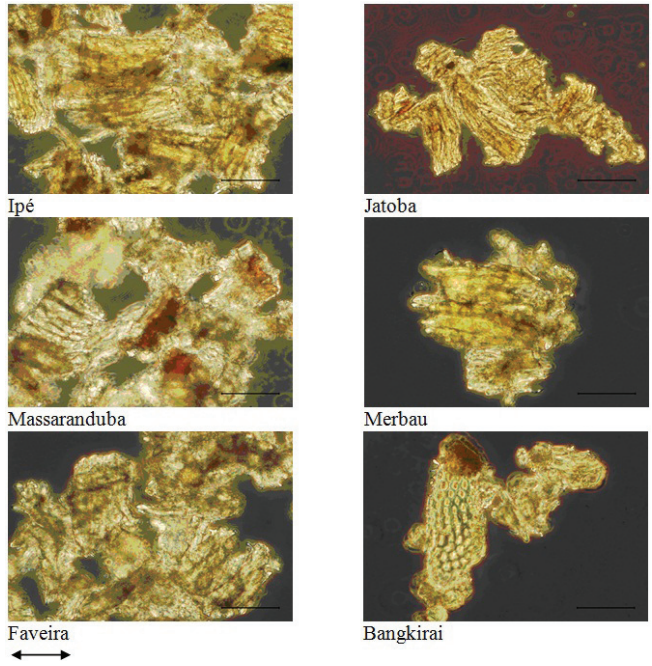

Fig. 2: Microscopic images of sedimented dusts produced by wood grinding.

Thermal analysis (TG-DSC and TGA) of sedimented dusts

In general, thermal decomposition of wood may occur in presence of air (termooxidation) or in its absence (pyrolysis, sometimes also called dry distillation) and the final products of thermal decomposition differ accordingly.

For main components of cellulose, hemicelluloses and lignin the thermal stability has been reported in the following order: hemicelluloses is the least stable, followed by glucose and the most stable lignin (Jankovský et al. 1999).

The limit of resistance between those components cannot be accurately defined. When heated, they initially release moisture. The gasification and thermal decomposition of the main components start at ca. 150°C (Zamostny and Kurc 2011).

In the interval 240 - 350°C they degrade to primary products, i.e.:

- products produced by splitting of some functional groups (-$COCH_3$, -COOH, -OCH_3),
- products of depolymerization (mono- and disaccharides),
- products of dehydration (monosaccharide anhydrides – levoglucosan, galoctosan, mannosan),
- products of thermal degradation (splitting of ether and C-C bonds in lignin to produce methoxyphenols, e.g. . guajacol, vanillin, syringol).

In case of thermooxidation – burning - other oxidizing exothermic reactions follow to produce carbon oxides, carboxyl and carbonyl compounds and, naturally, the combustion products also contain monosaccharide anhydrides and the so-called markers, i.e. aromatic compounds such as methoxyphenols, resinous acids and hydroxybenzoic acids. Products of wood pyrolysis are solid (charcoal, active coal), liquid and gaseous.

Liquid products may be divided into wood tar (insoluble), water condensate containing soluble tar and water with admixtures of other substances, where acetic acid prevails.

Both the fractions contain high numbers of chemical compounds with a majority of aromatic components and phenols. Prevailing components of gaseous products include CO, H_2, CH_4 and CO_2. Modern technologies of pyrolytic wood processing (catalyzed pyrolytic procedures, partial oxidation, reduction with hydrogen, fast pyrolysis etc.) enable to partially influence the composition of chemical products of pyrolysis.

Thermogravimetric analysis of wood (Jakab et al. 1997, Wang et al. 2006) has been widely used for investigation of wood pyrolysis (Bilbao et al. 1996, Capote et al. 2011) and for identification of wood type (hard-soft) from the viewpoint of occupational safety (Materazzi et al. 2012).

Other applications of thermogravimetry (TG) include analysis of thermal stability of wood as a composite material in polymer matrix (Atuanya and Ibhadode 2011) and determination of age and corrosion of wood, e.g. in case of historical artifacts made of wood (Emandi et al. 2010, Franceschi et al. 2008, Sandu et al. 2003).

The TG-DSC and TGA analyses were used to determine thermal stability of the individual sedimented dusts in presence of air. All samples, with the exception of the dust from Jatoba wood, demonstrated the same course of decomposition. The first endothermic effect T_1 (probably a release of a part of bound water or volatile components) was followed by two separate exothermic effects: T_2 in the range 279 – 333°C (the lowest value applied for dust from Merbau wood) and T_3 in the range 402 – 437°C (the lowest value applied for dust from Garapa wood) - see the illustrating diagrams of DSC and TGA curves for the quoted woods (Fig. 3 and 4).

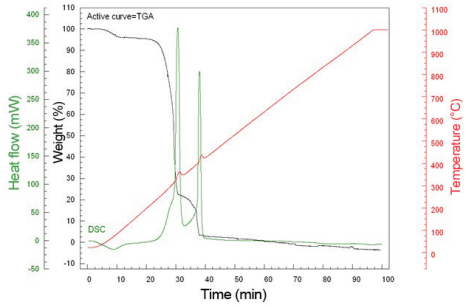

Fig. 3: Curves of TGA and DSC analyses of Garapa wood.

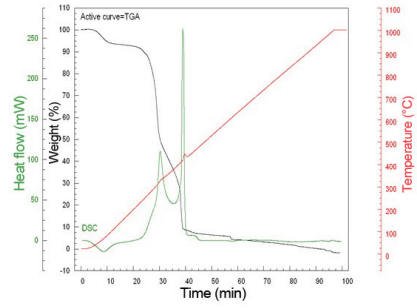

Fig. 4: Curves of TGA and DSC analyses of Merbau wood.

Dust from Jatoba wood decomposed with only one exothermic effect with a high thermal change (Fig. 5 and Tab. 5.)

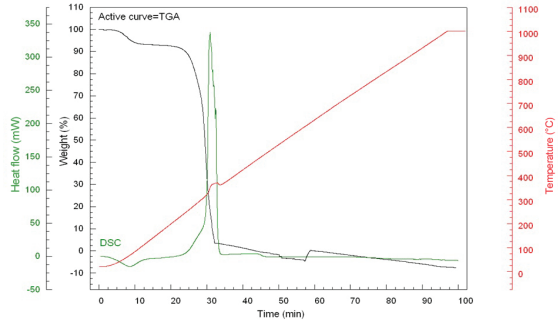

Fig. 5: Curves of TGA and DSC analyses of Jatoba wood.

Results of the analyses of thermal decomposition in terms of time, temperature, weigh losses and, particularly, thermal changes accompanying the process are provided in Tab. 4 – 1st endothermic effect, in Tab. 5 – 2nd exothermic effect, Tab. 6 – 3rd exothermic effect.

The value ΔH was calculated as the area of a peak in $kJ.kg^{-1}$ and H_f is the "height" of the peak in mW (using the Intimity PRO software).

Tab. 4.: Results from TG – DSC and TGA analyses – 1st endothermic effect.

Wood species	t_1 (min)	ΔH_1 ($kJ.kg_{-1}$)	H_{f1} (mW)	Δm_1 (%)
Ipé	2.6	405.4	14.9	5.2
Jatoba	2.9	480.1	11.7	6.0
Massaranduba	3.1	470.1	11.1	6.7
Merbau	2.6	495.3	10.5	6.1
Bangkirai	2.4	391.4	9.4	6.5
Faveira	2.8	363.0	14.4	4.5
Garapa	2.1	313.4	14.6	3.8
Teak	2.3	371.9	11.4	4.1
Bilinga	2.1	396.9	12.8	4.6

Tab. 5: Results from TG – DSC and TGA analyses – 2nd exothermic effect.

Wood species	t_2 (min)	T_2 (°C)	ΔH_2 ($kJ.kg^{-1}$)	H_f (mW)	Δm_2(%)
Ipé	27.9	302.5	-886.5	70.1	53.8
Jatoba	28.9	319.3	-6384.1	332.2	88.5
Massaranduba	28.2	301.3	-1243.4	85.1	55.5
Merbau	26.7	279.6	-1075.4	64.4	43.2
Bangkirai	29.8	333.3	-1118.9	81.7	58.1
Faveira	29.4	315.4	-1126.7	169.4	61.6
Garapa	27.5	302.6	-3697.2	349.9	72.0
Teak	29.9	327.4	-860.5	64.6	61.2
Bilinga	29.3	321.1	-1265.0	178.9	59.8

Tab. 6: Results from TG – DSC and TGA analyses – 3rd exothermic effect.

Wood species	t_3 (min)	T_3 (°C)	ΔH_3 (kJ.kg^{-1})	H_f (mW)	Δm_3(%)
Ipé	39.5	434.8	-2018.0	225.3	38.4
Jatoba	-	-	-	-	-
Massaranduba	37.0	407.4	-1977.7	248.7	32.9
Merbau	37.8	416.5	-2239.5	214.2	40.7
Bangkirai	38.5	411.4	-1671.9	185.2	32.2
Faveira	38.7	424.8	-1994.5	232.3	30.0
Garapa	35.9	402.3	-2122.6	273.0	37.6
Teak	39.6	434.8	-1722.0	222.9	40.3
Bilinga	39.7	437.2	-1904.9	220.8	40.4

Explanations:

t - beginning of the thermal process,

T - temperature of the beginning of the thermal process,

ΔH- thermal change accompanying the process (ΔH < 0…exothermic process , ΔH > 0… endothermic process),

Hf - height of the thermal process peak on the DSC curve (calculated by subtracting the value of the thermal flow in mW at the foot of the peak from the value of the peak top),

Δm - weight loss of the sample during the thermal process.

Tab. 7 summarizes overall thermal changes of the processes during the thermal decomposition of sedimented dusts from the investigated wood. The lowest value was measured for the Teak wood – 2210 kJ.kg^{-1}.

Tab. 7: Overall thermal change of the process on the tested woods $\Delta H = \Delta H_1 + \Delta H_2 + \Delta H_3$.

Wood species	ΔH (kJ.kg^{-1})	ΔH_1 (kJ.kg^{-1})	ΔH_2 (kJ.kg^{-1})	ΔH_3 (kJ.kg^{-1})
Ipé	- 2499.1	405.4	- 886.5	- 2018.0
Jatoba	- 5904.0	480.1	- 6384.1	---
Massaranduba	- 2751.0	470.1	- 1243.4	- 1977.7
Merbau	- 2819.6	495.3	- 1075.4	- 2239.5
Bangkirai	- 2399.4	391.4	- 1118.9	- 1671.9
Faveira	- 2758.2	363.0	- 1126.7	- 1994.5
Garapa	- 5506.4	313.4	- 3697.2	- 2122.6
Teak	- 2210.6	371.9	- 860.5	- 1722.0
Bilinga	- 2773.0	396.9	- 1265.0	- 1904.9

On the other side, the biggest thermal change was measured for Jatoba (-5904 kJ.kg^{-1}) and Garapa (-5506 kJ.kg^{-1}). The values were actually double of those measured for the other woods. Unlike Garapa, thermal decomposition of Jatoba occurred with a single exothermic effect at the initial temperature of 319°C, which was not even the highest temperature of the beginning of the first exothermic effect measured in our group of tested woods.

A question remains why the thermal decomposition of sedimented dust from Jatoba wood was so intense with such a high thermal effect. We assume that an important role is played by the shape, size and area of the particles, including their chemical composition on the surface. This has been partly confirmed by thermal decomposition of dust particles after fine grinding of

Garapa wood. The thermal change of the first exothermal effect was more than a double of those measured on the other woods.

Our assumption was subsequently confirmed on sedimented dust from fine grinding of Massaranduba wood - see the course of the curves from TG- DSC and TGA analyses of dusts after medium coarse and medium fine grinding (Figs. 6 and 7).

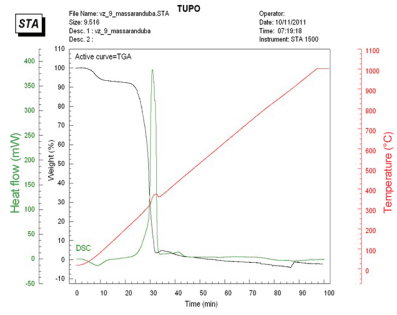

Fig. 6: Curves from the TGA and DSC analyses. Sedimented dust Massaranduba wood, grinding band grain size 100.

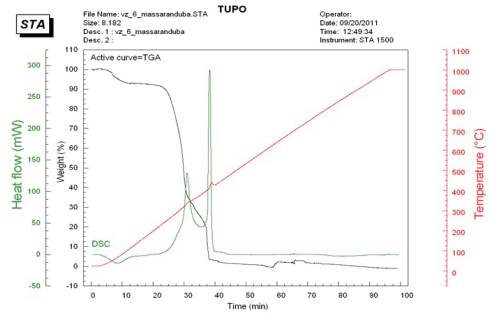

Fig. 7: Curves from the TGA and DSC analyses. Sedimented dust of Massaranduba wood, grinding band grain size 80.

A positive relation between T_2 values (the beginning of the exothermal decomposition) and specific weight and hardness of the original woods has not been found. A certain relation was found between T_2 and macroscopic properties of the dust (Tab. 3), specifically their cohesiveness and size of the particles (see Merbau and Garapa).

Extraction of some samples of sedimented dusts and their thermal stability before and after extraction

Apart from its main components, i.e. cellulose, hemicelluloses and lignin, wood contains tens of minority substances that can be mostly extracted by a combination of polar and non-polar solvents.

The main reason why extractable substances are produced in the wood is the protection the tree against predators (insects, termites, mildew, fungi) willing to consume components of cell walls.

The composition and quantities of extracted substances differ by individual wood species, location, age and selected method of extraction. Extractable substances affect properties of the wood both positively and negatively. They can find e.g. specific use in the pharmaceutical industry, in wine and liquor aging, etc.

From chemical viewpoint, extractable substances may be divided into terpenoides (resins), tanstuffs (tannin), fats (proteins), oils, compounds containing nitrogen, alkaloids, chinones, mono- and oligosaccharides, low-molecular phenolic substances, salts etc.

After completed extraction of selected samples of sedimented dusts we wanted to learn about a change of their thermal stability after removal of extractable substances. The used sedimented dust was from Massaranduba, Garapa and Merbau woods.

The extraction was performed in the following three steps:

Step 1: extraction with 100 ml of ethanol, extraction time 4 hours,

Step 2: extraction with 100 ml of ethanol and toluene mixture, ratio 67:33, extraction time

7.45 hours, washing with water and 50 ml of ethanol,

Step 3: extraction with 200 ml distilled water, extraction time 3.45 hours, washing with cca. 100 ml water and drying at 38°C until a constant weight is achieved.

Sample	Wood species	Weighted quantity (g)	Weight of the sample after drying (g)	Weight loss after extraction (%)
1	MASSARUNDUBA	1	0.79928	20.1
2	GARAPA	0.99992	0.99992	26.3
3	MERBAU	0.99994	0.72814	27.2

Results from the performed TG-DSC and TGA analyses after extraction have been interpreted with diagrams in Figs. 8 - 10 and values provided in Tabs. 8-11.

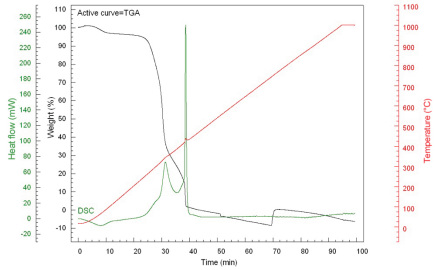

Fig. 8: Curve from the TGA and DSC analyses of the sample No. 1 - Massaranduba after extraction.

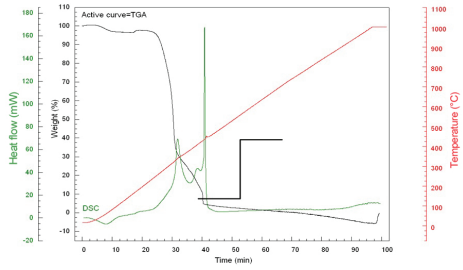

Fig. 9: Curve from the TGA and DSC analyses of the sample No. 2 - Garapa after extraction.

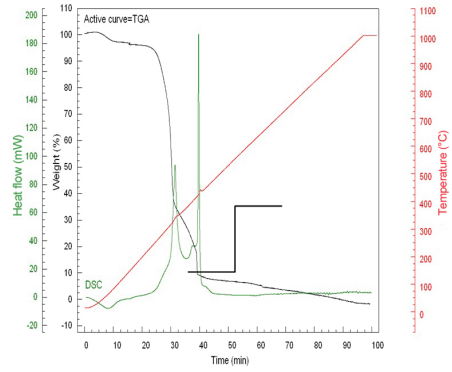

Fig. 10: Curve s of the TGA and DSC analysis of the sample No. 3 - Merbau after extraction.

Tab. 8: Thermal effect corresponding to the 1st weight loss.

Sample	t_1 (min)	T_1 (°C)	ΔH_i (kJ.kg^{-1})	H_{fi} (mW)	Δm_i (%)
1	1.9	25	314.6	7.9	3.7
2	2.5	25	273.9	5.1	3.1
3	1.6	25	309.2	7.7	3.4

Tab. 9: Thermal effect corresponding to the 2nd weight loss.

Sample	t_2 (min)	T_2 (°C)	ΔH_i (kJ.kg^{-1})	H_{fi} (mW)	Δm_i (%)
1	27.7	300.2	- 1100.5	51.5	62.4
2	27.6	305.4	- 941.1	48.6	63.8
3	27.1	292.7	- 1041.9	74.2	58.5

Tab. 10: Thermal effect corresponding to the 3rd weight loss.

Sample	t_3 (min)	T_3 (°C)	ΔH_i (kJ.kg^{-1})	H_{fi} (mW)	Δm_i (%)
1	35.8	391.3	- 1780.6	213.6	32.7
2	36.0	387.8	- 1373.2	136.8	25.5
3	35.1	383.8	- 1370.5	159.4	26.2

The continual transition between the 1st and the 2nd exothermic effects which prevails in non-extracted dusts was measured for Massaranduba wood (Fig. 8). For the other samples a minor exothermic effect was identified between them (Figs. 9, 10 - see the arrow). The thermal change in these cases was calculated in relation to weight losses – see Tab. 10.

When comparing summary values of ΔH (Tab. 11), we can see that after the extraction of the sedimented dusts the overall thermal change during their decompositions was lower in comparison with the initial dusts: for Massaranduba it was only by 10, for Garapa by 35 and the biggest difference was found for Merbau by 39 %.

Tab. 11: Comparison of values of thermal effects during thermal decomposition (weight loss) of sedimented dusts before and after the extraction for Massaranduba, Garapa and Merbau woods.

Wood species	ΔH a) (kJ.kg^{-1})	ΔH_1 (kJ.kg^{-1})	ΔH_2 (kJ.kg^{-1})	ΔH_3 (kJ.kg^{-1})
Massaranduba Massaranduba-Ext.	-2751.0 -2566.5	470.1 314.6	-1243.4 -1100.5	-1977.7 -1780.6
Garapa Garapa-Ext.	-5506.4 -2040.0	313.4 273.9	-3697.2 -941.1	-2122.6 -1373.2
Merbau Merbau-Ext.	-2819.6 -2103.2	495.3 309.2	-1075.4 -1041.9	-2239.5 -1370.5

a) ΔH = ΔH1 + ΔH 2 + ΔH 3

The following Figs. 11 - 13 present individual TGA and DSC curves for sedimented dusts of the individual woods before and after extraction. It is obvious that, with the exception of Garapa (units of minutes), the shifts of DSC curves for the other woods are negligible. There are some differences in the TGA curves, particularly for dusts from Garapa and Merbau woods for the third weight loss m^3 which is significantly smaller than the one before the extraction.

We can also conclude that the initial temperatures T_2 of decomposition for dusts before and after extraction are essentially identical, while a certain shift to lower values T_3 was recorded for extracted dusts (the highest for Merbau 33°C)

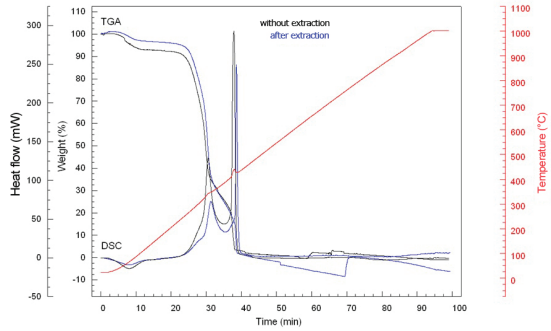

Fig. 11: Comparison of TGA and DSC curves of the sample No. 1 - Massaranduba after extraction and without extraction.

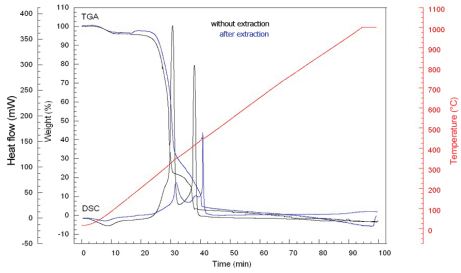

Fig. 12: Comparison of TGA and DSC curves of the sample No. 2 - Garapa after extraction and without extraction.

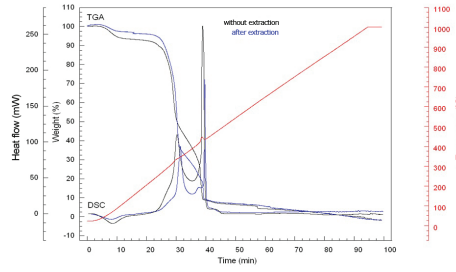

Fig. 13: Comparison TGA and DSC curves of the sample No. 3 - Merbau after extraction and without extraction.

We performed an FTIR analysis for extracted dusts of the woods. The obtained spectrums differed from those of the initial dusts in the area of wave numbers higher than 3500.cm^{-1}. Some minor absorbances may correspond to valence vibrations of –OH groups (alcohol, phenol and carboxyl groups) or –NH groups (amines and amides). All woods after extraction demonstrated a shift of maximum values of main absorbances of valence vibrations of the –OH and C-H groups to lower values.

IR spectrums of Massaranduba wood before and after the extraction are provided for illustration (Fig. 14). We assume that after the extraction the compact structure of the wood became looser which enabled vibration of some bonds (groups) that had been suppressed in the original wood.

As a complementary experiment to investigate properties of wood dusts we tested biological activity to *Escherichia coli* (Esco) for all 9 woods. Turbid Esco solution (approximate value 10^6) was placed on TSA agar, after drying a small quantity of wood dust was applied and left to cultivate at 37°C. In all cases, with the exception of Merbau wood, Esco grew. Biological activity (disinfecting effect) to Esco has been demonstrated only for dust from Merbau wood.

For randomly selected samples of wood dusts (Massaranduba, Teak, Garapa) we performed a test to determine their ability of luminescence after exposure to ionizing radiation. The following three preconditions need to be fulfilled for the luminescence to occur (McKeever et al. 1995,

Better-Jensen et al. 2003):

- The concerned material must be an insulator or semi-conductor (metals do not demonstrate luminescence properties),
- The material must have some ability to conserve a certain portion of the absorbed energy from ionizing radiation,
- The absorbed energy must be released either by heating (i.e. thermo-luminescence, TL) or illumination of the material (i.e. optically stimulated luminescence, OSL).

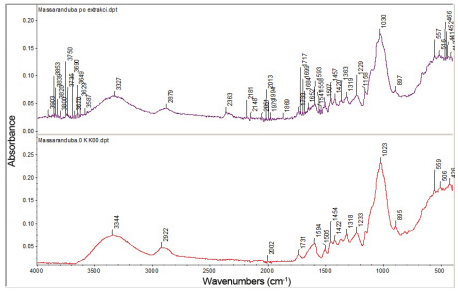

Fig. 14: IR-spectrums of Massaranduba wood dust after extraction (upper diagram) and before extraction (lower diagram).

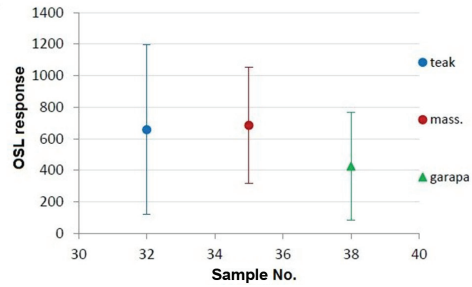

Fig. 15: Average OSL responses with standard deviations (x= sample No., y= OSL response).

Three samples of each wood (Teak, Massaranduba, Garapa – each of 5 mg) type were irradiated for 1000 seconds (ca. 100 Gy). Average OSL responses related to sample weight with standard deviations are provided in the diagram (Fig. 15).

Subsequently, linearity was determined, i.e. increase of the OSL signal with an increasing dose. OSL responses for samples irradiated for 0, 50, 100, 500, 1 000, 2 000 and 3 000 seconds, i.e. doses of ca. 0, 5, 10, 50, 100, 200 and 300 Gy are provided in the diagram (Fig. 16).

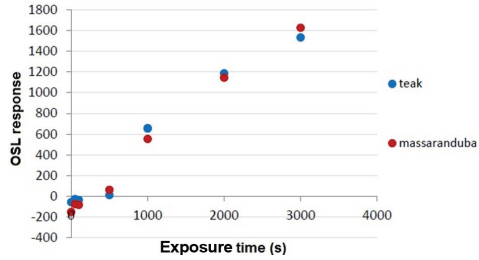

Fig. 16: OSL response depending on the dose (x = exposure time, y= OSL response).

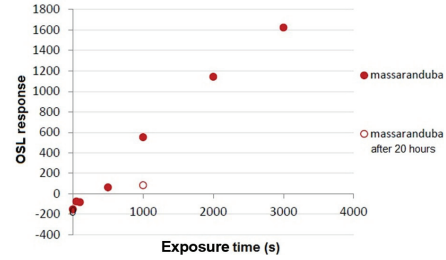

Fig. 17: OSL response for samples evaluated immediately after the irradiation and 20 hours after the irradiation (x= sample No., y= OSL response).

The OSL response can be differentiated from the background only for doses from ca. 100 Gy. For lower doses the responses were at the same level as the background, i.e. it is impossible to differentiate the irradiated sample from a non-irradiated one.

The OSL response does not remain constant in time after the irradiation but it decreases

as a result of thermal fading. The decrease depends on the time after the irradiation. For Massaranduba wood the OSL response 20 hours after the irradiation corresponded to the OSL response of a non-irradiated sample - see diagram (Fig. 17).

CONCLUSIONS

One of our objectives was to find a general relation between the behavior of dusts of exotic woods in the tested intervals and the basic physical parameters of the initial woods, such as e.g. specific weight, hardness etc. However, in all cases we found certain individual features in the behavior of the woods.

For example, except for Jatoba wood dust, pyrolysis of dusts from all the other woods resulted in two exothermic effects. Merbau wood dust, as the only one, demonstrated certain biological activity and was most resistant to grinding.

Grinding of Garapa wood produced the highest quantity of dust and its pyrolysis was accompanied by big thermal effects that were, similarly as in case of Jatoba wood, two times bigger than thermal effects of the other woods; after extraction the second exothermic effect shifted to a higher temperature and the thermal effect was smaller.

Macroscopic properties differed for most of the woods and the same applied for shapes of the particles etc.

This means that more attention shall be paid during their processing and individual approach should be taken to each of the woods from the viewpoint of processing technology, toxicity of aerosol and sedimented particles and from the viewpoint of fire and explosion prevention.

REFERENCES

1. Atuanya, L.U., Ibhadode, A.O.A., 2011: Charakterization of Okhuan (*Brachystegia nigerica*) wood as a potential reinforcement for polymer composites. Inter. J. Engin. Technol. 11: 68-76.
2. Boetter-Jensen, L., McKeever, S.W.S., Wintle, A.G., 2003: Optically stimulated luminescence dosimetry. Elsevier Science B.V., Amsterdam. Pp 311-344.
3. Bilbao, R., Mastral, J.F., Aldea, M.E., Ceamanos, J., 1996: Modeling of pyrolysis of wet wood. Journal of Analytical and Applied Pyrolysis 36(1): 81-97.
4. Bornholdt, J., Saber, A.T., Sharma, A.K., Savolainen, K., Vogel, U., Wallin, H., 2007: Inflammatery response and genotoxicity of seven wood dusts in the human epithelial cell line A549. Mutar Res., 632(1-2): 78-88.
5. Capote, J.A., Alvear, D., Lázaro, M., Abreu, O., Puente, E., 2011: Pyrolysis characterization of *Eucalyptus globulus* samples trought simultaneus thermal analysis. Chia Laguna, Cagliari, September 11 – 15, 2011, Sardinia, Italy.
6. Directive cancels OSHA Instruction, 2007: CPL 03-00-006 Combustible dust.
7. Emandi, A., Budrugeac, P., Emandi, I., Stanculescu, I., Bugheanu, P., 2010: The assesment of the decayed lime wood polymeric components by TG and FT-IR parameters correlation. International Journal of Conservation Science 1(4): 211-218, ISSN 2067-533x.
8. Franceschi, E., Cascone, I., Nole, D., 2008: Thermal, XRD and spetrophotometric study on artificially degraded woods. Journal of Thermal Analysis & Calorimetry 91(1): 119-125.
9. IARC, 1995: Wood dust. IARC Monogr Eval Carcinog. Risks Hum. 62: 35-215.

10. Jakab, E., Faix, O., Till, F., 1997: Thermal decomposition of milled wood lignins studied by thermogravimetry/mass spektrometry. J. Anal. Appl. Pyrolysis 40-41: 171-186.
11. Jankovský, M., Lachman, J., Staszková, L.,1999: Chemistry of wood. (Chemie dřeva). Česká zemědělská univerzita, Prague, 211 pp (in Czech).
12. Klouda, K., Cejpek, J., Večerková, J., Houšková, J., 2012: Determination of respirator effectiveness during grinding of exotic woods. (Stanovení účinnosti respirátoru při broušení exotických dřev). Bezpečnost a ochrana zdraví při práci 2012, VŠB-TU Ostrava. Pp 31-36 (in Czech).
13. Materazzi, S., Vecchio S., De Angelis Curtis, S., 2013: Thermal analysis and health safety. Thermoanalytical characterization of hardwood softwood dust. J.Therm. Anal. Calorim. 112(1): 529-533.
14. McKeever, S.W.S., Moscovitch, M., Townsend, P.D., 1995: Thermoluminescence dosimetry materials: Properties and uses. Nuclear Technology Publishing, Ashford, 204 pp.
15. Roček, I., 2005: Woods of tropical regions. (Dřeva tropických oblastí). Česká zemědělská univerzita, Prague, 327 pp (in Czech).
16. Sandu, I.C.A., Brebu, M., Luca, C., Sandu, I., Vasile, C., 2003: Thermogravimetric study on the ageing of lime wood supports of old paintings. Polym. Degrad. Stab. 80(1): 83-91.
17. Wang, J., Wang, G., Zang, M., Chen, M., Li, D., Fanfei, M., Chen, M., Zhang, S., Ren,Z., Yan,Y., 2006: A comparative study of thermolysis characteristics and kinetics of seaweeds and fir wood. Proces Biochemistry 41(8): 1883-1886.
18. Zamostný, P., Kurc, L., 2011: Influence of conditions and the composition of the raw material for the pyrolysis of wood mass. (Vliv podmínek a složení suroviny na pyrolýzu dřevní hmoty). Chem.listy 105: 458-466 (in Czech).

Karel Klouda
State Office for Nuclear Safety
Senovážné Nám. 9
110 01 Prague 1
Czech Republic
Corresponding author: Karel.Klouda@sujb.cz

Hana Matheisová
Ministry of the Interior – General Directorate of the Fire and Rescue Services
Technical Institute of Fire Protection
Písková 42
143 00 Prague 4 – Modřany
Czech Republic

Markéta Weisheitelová
National Institute for Nuclear, Chemical and Biological Protection
262 31 Kamenná – Milín
Czech Republic