

## STUDIES ON CHEMICAL COMPOSITION OF WOOD ON THE BASIS OF INFRARED SPECTROSCOPY

### II. Determination of Holocellulose and Lignin Content with the Use of Various Base Lines of 1515 (1510) $\text{cm}^{-1}$ Band

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Lignin and holocellulose contents were calculated in wood degraded by chemical and biological agents on the basis of absorbance of the bands  $1515 \text{ cm}^{-1}$  (pine) and  $1510 \text{ cm}^{-1}$  (beech) with the use of three various base lines: I – parallel to the line of spectrum shift going through the absorption minimum at  $1880 \text{ cm}^{-1}$ , II – line connecting absorption minima at  $1880$  and  $780 \text{ cm}^{-1}$ , III – line connecting absorption minima at  $1555$ ,  $1402$  and  $1295 \text{ cm}^{-1}$ . Calculations were made on the basis of absorbance without the inside standard ( $A_i$ ) and with the inside standard ( $A_i/A_{1378}$ ). The results of calculations of the percentages of holocellulose and lignin with determinations made on the chemical way and on the basis of heat of combustion were compared. The smallest differences were obtained with the use: for pine base line I and II with the inside standard, for beech base line III without the inside standard. Standard deviations of those differences ( $\rho$ ) are for pine wood: holocellulose 3.16 and 3.61%, lignin 3.74 and 3.86% respectively. For beech wood those deviations are: holocellulose 4.56%, lignin 5.95%.

### INTRODUCTION

For the measurements of the absorbance of IR spectrum bands few kinds of base lines were used: a straight line parallel to the spectrum shift (Töppel 1957, Vodnansky, Slabina, Schneider 1963), straight line going at an angle to the line of spectrum shift (Karklin, Erinsch 1974), once broken line (Kawamura, Bland 1967) and several times broken line, passing through particular individual minima of absorption (Marton, Sparks 1967, Sarkanen, Chang, Allan 1967). A comparison of the mentioned kinds of base lines was primarily conducted by

Karklin and Erinsch (1971). Actually a need arose to unify the approach to the meaning of the kind of base line and of the inside standard in quantitative determination of holocellulose and lignin. Presented investigations are based on the statement, that the band most dependent on those chemical constituents of wood is that of  $1515$  ( $1510$ )  $\text{cm}^{-1}$ . (Jayme, Rohman 1965; Mitchell, Watson, Higgins 1965; Dziurzyński, Supiński, Surmiński 1988). It was also experimentally proved that there exist straight lines of regression between absorbance of this band and the lignin content (Marton, Sparks 1967, Karklin, Belkova, Gromow, Eidus 1977). Such straight lines were proposed as adjustment lines for individual wood decay processes. Therefore the scope of the presented work is to determine the relation between the holocellulose and lignin content of wood and the absorbance IR spectrum band  $1515$  ( $1510$ )  $\text{cm}^{-1}$ , using various base lines. As the inside standard the  $1378$   $\text{cm}^{-1}$  band was chosen, which is the least changing IR spectrum band at the wood degradation processes (Vodnansky, Slabina, Schneider 1963, Dziurzyński, Supiński, Surmiński 1988).

## MATERIAL AND METHODS

### EXPERIMENTS

Experiments were made on the pine (*Pinus silvestris*) and beech (*Fagus silvatica*), which was previously degraded by: alkaline cooking in NaOH, acid hydrolysis in  $\text{H}_2\text{SO}_4$ , and fungal decay by *Polystictus versicolor* and *Coniophora puteana*. In the degraded wood there were determined: solubles in NaOH, lignin, holocellulose, heat of combustion (Dziurzyński, Supiński 1986).

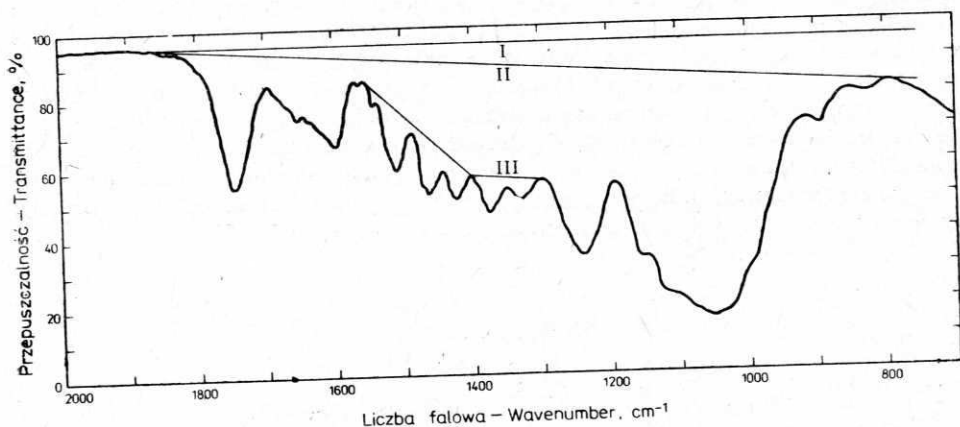


Fig. 1. Kinds of applied base-lines: I — parallel to the spectrum shift going through absorption minimum at  $1880$   $\text{cm}^{-1}$ , II — line joining absorption minima at  $1880$  and  $780$   $\text{cm}^{-1}$ , III — line joining absorption minima at  $1555$ ,  $1402$  and  $1295$   $\text{cm}^{-1}$

Rys. 1. Rodzaje stosowanych linii bazowych: I — równoległa do linii przesuwu widma przechodząca przez minimum absorpcji przy  $1880$   $\text{cm}^{-1}$ , II — linia łącząca minima absorpcji przy  $1880$  i  $780$   $\text{cm}^{-1}$ , III — linia łącząca minima absorpcji przy  $1555$ ,  $1402$  i  $1295$   $\text{cm}^{-1}$

Method of obtaining the IR spectra: A 400.0 mg batch of KBr and 2.0 mg of wood was homogenized, and then 200 mg of the obtained mixture was tableted. The spectra were recorded on the Spectrometer UR-20 (Dziurzyński, Supiński, Surmiński 1988). On each of the obtained spectra three base lines were drawn: I – parallel to the spectrum shift going through an absorption minimum at 1880 cm<sup>-1</sup> (Vodnansky, Slabina, Schneider 1963); II – line connecting absorption minimum at 1880 and 780 cm<sup>-1</sup> (Karklin, Erinsch 1971); III – line connecting absorption minima at 1555, 1402 and 1295 cm<sup>-1</sup>. Kinds of base lines are illustrated by Fig. 1.

#### CALCULATIONS

Holocellulose ( $x_h$ ) and lignin ( $x_l$ ) content in wood was calculated from the straight line equation:

$$x_h = \frac{100 - x_h^0}{a_h^0 - A^0} (A - A^0) + x_h^0 \quad (\%) \quad (1a)$$

$$x_l = \frac{100 - x_l^0}{a_l^0 - A^0} (A - A^0) + x_l^0 \quad (\%) \quad (1b)$$

where

- $A, x_h, x_l$  – absorbance ( $A$ ) and percentage of holocellulose ( $x_h$ ) or lignin ( $x_l$ ) in the analysed sample of degraded wood;
- $A^0, x_h^0, x_l^0$  – absorbance ( $A^0$ ) and percentage of holocellulose ( $x_h^0$ ) or lignin ( $x_l^0$ ) in the sample of natural wood after extraction in ethanol-benzene mixture;
- $a_h^0, a_l^0, 100$  – absorbance of holocellulose ( $a_h^0$ ) or lignin ( $a_l^0$ ) and percentages of those constituents (100) isolated from natural wood *in vitro*.

The mentioned relation is a straight line equation going through two points. Their coordinates are ( $A^0, x_h^0$ ) and ( $a_h^0, 100$ ) in the case of calculation of holocellulose percentages – equation (1a) or ( $A^0, x_l^0$ ) and ( $a_l^0, 100$ ) in the case of calculation of lignin percentages – equation (1b). This dependence is based on an assumption that absorbances of wood constituents *in situ* form a total in an additive way. This assumption is compatible with Beer's law. The numerical data of values  $A^0, a_h^0, a_l^0$  which are necessary for calculation with the aid of equations (1a), (1b) are tabulated in three first lines of tables 1 and 2. Values  $x_h^0, x_l^0$  are tabulated in article in this issue (Dziurzyński, Supiński 1986).

#### RESULTS AND DISCUSSION

Absorbances of the 1515 cm<sup>-1</sup> band in pine wood and of 1510 cm<sup>-1</sup> in beech wood degraded by chemical and biotical agent are tabulated in tables 1 and 2. Separate tables for pine and beech wood are due to the significant differences between

Table 1

Absorbance of IR spectra bands  $1378\text{ cm}^{-1}$  and  $1515\text{ cm}^{-1}$  of pine wood decomposed by chemical and biotical agents in dependence on the kind of base line

Absorbancja pasm  $1378\text{ cm}^{-1}$  i  $1515\text{ cm}^{-1}$  widm IR drewna sosny rozłożonego przez czynniki chemiczne i biotyczne w zależności od rodzaju linii bazowej

Sample – Próbką		Mass loss Ubytek masy $\Delta m$ (%)	$A_{1378}$			$A_{1515}$			$A_{1515}/A_{1378}$		
			base line – linia bazowa								
			I	II	III	I	II	III	I	II	III
Holocellulose – Holoceluloza		–	0.279	0.242	0.049	0.091	0.063	0.000	0.326	0.260	0.000
Lignin – Lignina		–	0.258	0.199	0.008	0.531	0.488	0.427	2.058	2.452	53.375
Original wood – Drewno wyjściowe		0	0.283	0.237	0.051	0.225	0.192	0.143	0.795	0.810	2.804
Degraded wood – Drewno zdegradowane	NaOH	21.0	0.325	0.271	0.037	0.283	0.246	0.143	0.871	0.908	3.865
		33.3	0.359	0.297	0.040	0.255	0.212	0.112	0.710	0.713	2.800
		47.8	0.373	0.320	0.043	0.193	0.155	0.060	0.517	0.484	1.395
	H <sub>2</sub> SO <sub>4</sub>	10.2	0.312	0.240	0.054	0.256	0.217	0.160	0.820	0.904	2.963
		22.6	0.296	0.243	0.045	0.287	0.248	0.185	0.970	1.021	4.111
		31.6	0.336	0.277	0.046	0.346	0.306	0.231	1.030	1.105	5.022
	<i>Polystictus versicolor</i>	6.0	0.302	0.263	0.046	0.217	0.190	0.109	0.719	0.722	2.370
		14.0	0.357	0.302	0.063	0.257	0.219	0.123	0.725	0.725	1.952
		28.7	0.302	0.255	0.043	0.234	0.202	0.109	0.775	0.792	2.535
	<i>Coniophora puteana</i>	12.0	0.293	0.241	0.053	0.253	0.220	0.145	0.863	0.913	2.736
		23.0	0.328	0.283	0.053	0.305	0.273	0.192	0.930	0.965	3.623
		38.0	0.307	0.263	0.043	0.315	0.285	0.198	1.026	1.084	4.605
		63.0	0.371	0.311	0.031	0.580	0.527	0.418	1.563	1.727	13.484

Table 2

Absorbance of IR spectra bands  $1378$  and  $1510\text{ cm}^{-1}$  of beech wood decomposed by chemical and biotical agents in dependence on the kind of base line

Absorbancja pasm  $1378$  i  $1510\text{ cm}^{-1}$  widm IR drewna buka rozłożonego przez czynniki chemiczne i biotyczne w zależności od rodzaju linii bazowej

Sample – Próbką		Mass loss Ubytek masy $\Delta m$ (%)	$A_{1378}$			$A_{1510}$			$A_{1510}/A_{1378}$		
			base line – linia bazowa								
			I	II	III	I	II	III	I	II	III
Holocellulose – Holoceluloza		–	0.302	0.300	0.086	0.094	0.080	0.000	0.311	0.267	0.000
Lignin – Lignina		–	0.325	0.268	0.037	0.575	0.534	0.433	1.769	1.993	11.703
Original wood – Drewno wyjściowe		0	0.320	0.291	0.092	0.211	0.191	0.117	0.659	0.656	1.272
Degraded wood – Drewno zdegradowane	NaOH	25.5	0.314	0.278	0.045	0.278	0.252	0.142	0.885	0.906	3.156
		52.0	0.359	0.324	0.068	0.173	0.148	0.038	0.482	0.457	0.559
		58.5	0.340	0.313	0.049	0.172	0.154	0.028	0.506	0.492	0.571
	H <sub>2</sub> SO <sub>4</sub>	13.8	0.316	0.277	0.060	0.263	0.235	0.150	0.832	0.848	2.500
		24.0	0.312	0.282	0.055	0.268	0.247	0.148	0.859	0.876	2.691
		42.7	0.350	0.303	0.057	0.328	0.295	0.200	0.937	0.973	3.509
	<i>Polystictus versicolor</i>	3.0	0.288	0.260	0.073	0.203	0.183	0.099	0.705	0.704	1.356
		24.0	0.375	0.341	0.092	0.250	0.227	0.121	0.667	0.666	1.315
		33.0	0.358	0.323	0.093	0.243	0.218	0.110	0.679	0.675	1.183
		63.0	0.418	0.379	0.096	0.270	0.242	0.115	0.646	0.638	1.198
	<i>Coniophora puteana</i>	2.5	0.353	0.321	0.090	0.258	0.235	0.125	0.731	0.732	1.389
		16.0	0.319	0.287	0.070	0.266	0.241	0.130	0.834	0.840	1.857
		23.0	0.407	0.370	0.091	0.311	0.284	0.170	0.764	0.767	1.868
		36.0	0.349	0.316	0.073	0.316	0.292	0.176	0.905	0.924	2.411
		57.0	0.397	0.347	0.052	0.431	0.395	0.252	1.086	1.138	4.846

the IR spectra of coniferous and broadleaved wood species (Kawamura, Higuchi 1964) caused mostly by the differences in the lignin methoxyl groups content (Sarkanen, Chang, Allan 1967b).

Absorbances of the 1515 and 1510 cm<sup>-1</sup> bands differ amongselves in dependence on the base line kind. Greatest absorbances are observed for base line I, slightly smaller for base line II and the smallest for base line III. Main cause of that are different distances of the base line I, II and III from the spectrum base. An additional reason of differences is that the base line II and III are situated at an angle to the line of spectrum shift. Value of this angle for base line II depends on the absorbance in the 780 cm<sup>-1</sup> band caused by various lignin contents (Dziurzyński, Supiński, Surmiński 1988). The angle of inclination of base line III is also changing. Especially intensive is changing the angle of the auxiliary section of base line III within the range 1402–1295 cm<sup>-1</sup>. The minimum absorbance at 1295 cm<sup>-1</sup> is caused mainly by the lignin content. In lignin preparation this absorbance is 2-times greater than in holocellulose (table 1 and 2). It was calculated with the aid of equations 1a, 1b the percentages of holocellulose and lignin. Those results are compared with arithmetic means of holocellulose and lignin contents presented in part I of this issue (Dziurzyński, Supiński, Surmiński 1988).

There are some differences between the holocellulose and lignin contents calculated from the equations 1a, 1b and contents of those constituents established on the basis of chemical methods and heat of combustion measurements. Values of those differences are illustrated by the following statistics:

$$\text{arithmetic mean } \Delta\bar{x} = \frac{1}{n} \sum_{i=1}^n (x_{\text{IR}} - \bar{x})_i$$

$$\text{standard deviation } \bar{\rho} = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_{\text{IR}} - \bar{x})_i^2}$$

$$\text{statistics } \chi^2 = \sum_{i=1}^n \frac{(x_{\text{IR}} - \bar{x})_i^2}{(x_{\text{IR}})_i}$$

where

$x_{\text{IR}}$  – percentages of lignin ( $x_l$ ) or holocellulose ( $x_h$ ) determined on the basis of IR spectroscopy (equations (1a), (1b));

$\bar{x}$  – arithmetic means of lignin ( $x_l$ ) or holocellulose ( $x_h$ ) percentages of chemical determinations and calculations on the basis of heat of combustion measurements;

$l$  – index of sample of wood degraded by chemical or biotic agent – mass losses (tab. 1 and 2);

$n$  – sum of samples of wood degraded by chemical or biotic agent.

The mentioned statistical data are tabulated in table 3. It results, that the highest compatibility between the calculated and experimental percentages of holocellulose

Table 3

Statistical values of differences between calculated and experimental percentages of lignin and holocellulose of tested samples\*  
 Wielkości statystyczne różnic między obliczonymi i eksperymentalnymi zawartościami ligniny i holocelulozy w badanych próbkach\*

Wood species Gatunek drewna	Statistics Statystyka	Base line I — Linia bazowa I						Base line II — Linia bazowa II						Base line III — Linia bazowa III											
		without standard bez standardu			with standard ze standardem			without standard bez standardu			with standard ze standardem			without standard bez standardu			with standard ze standardem								
		lignin lignina	holocellu- lose holocelu- loza	lignin lignina	holocellu- lose holocelu- loza	lignin lignina	holocellu- lose holocelu- loza	lignin lignina	holocellu- lose holocelu- loza	lignin lignina	holocellu- lose holocelu- loza	lignin lignina	holocellu- lose holocelu- loza	lignin lignina	holocellu- lose holocelu- loza	lignin lignina	holocellu- lose holocelu- loza	lignin lignina	holocellu- lose holocelu- loza						
Pine	$\overline{dx}$	11.47	-8.86	3.58	-1.13	11.15	-8.59	3.86	-2.14	2.69	0.31	2.12	-2.91	11.47	-8.86	3.58	-1.13	11.15	-8.59	3.86	-2.14	2.69	0.31	2.12	-2.91
Sosna	$\rho$	11.47	0.04	3.74	3.16	11.15	8.72	3.86	3.61	4.80	3.97	4.38	5.96	11.47	0.04	3.74	3.16	11.15	8.72	3.86	3.61	4.80	3.97	4.38	5.96
	$\chi^2$	45.87	27.65	7.09	2.78	44.36	23.14	7.13	4.43	13.99	5.04	15.25	15.10	45.87	27.65	7.09	2.78	44.36	23.14	7.13	4.43	13.99	5.04	15.25	15.10
Beech	$\overline{dx}$	12.95	-8.66	9.19	-4.19	13.19	-6.07	8.62	-4.33	5.23	1.74	7.31	-9.93	12.95	-8.66	9.19	-4.19	13.19	-6.07	8.62	-4.33	5.23	1.74	7.31	-9.93
	$\rho$	19.97	9.28	9.19	6.19	13.19	8.70	8.62	6.14	5.95	4.56	7.31	12.20	19.97	9.28	9.19	6.19	13.19	8.70	8.62	6.14	5.95	4.56	7.31	12.20
Buk	$\chi^2$	86.18	30.96	52.50	16.89	89.29	26.53	48.89	17.18	27.58	8.05	39.59	231.32	86.18	30.96	52.50	16.89	89.29	26.53	48.89	17.18	27.58	8.05	39.59	231.32

\* Results for samples of wood decomposed in all four investigated processes:  $n = 12$  for pine samples,  $n = 14$  for beech samples. There were disregarded: a) results for original wood ( $\Delta m = 0\%$ ) because they are used in the assumptions of the equations 1a and 1b; b) results for the wood maximally decayed by *C. puteana* fungus, because analysis of such wood was charged with to great anomalies — Wyniki dla próbek drewna rozłożonego we wszystkich czterech badanych procesach:  $n = 12$  dla próbek sosny,  $n = 14$  dla próbek buka. Pominięto: a) wyniki dla drewna wyjściowego ( $\Delta m = 0\%$ ), ponieważ są one zawarte w założeniach równań 1a i 1b; b) wyniki dla drewna maksymalnie rozłożonego przez grzyb *C. puteana*, ponieważ analiza tego drewna obarczona jest zbyt dużymi anomaliami.



and lignin could be obtained by using: for pine wood the base line I and II, with the inside standard  $1378 \text{ cm}^{-1}$ , and for Beech the base line III without the inside standard. Standard deviations ( $\bar{\rho}$ ) of those differences are for pine: holocellulose 3.16 and 3.61%, lignin 3.74 and 3.86%. For beech those deviations are: holocellulose 4.56%, lignin 5.95%. In case of base lines I and II the mentioned statistical data are even few times smaller if they are calculated from absorbance with the use of an inside standard. The use of base line III with an inside standard caused a rise of the investigated differences. The cause of that is a rather great variance of absorbance of the inside standard i.e. the  $1378 \text{ cm}^{-1}$  band, determined with the use of auxiliary section of the base line III. Summarizing the results of this investigation of pine and beech wood, it is to be stated, that the base line III without any inside standard suits for holocellulose and lignin determinations as well as the base lines I and II with an inside standard. It can be explained by the fact, that the base line III is drawn on the basis of the minimum  $1402 \text{ cm}^{-1}$ , which is in direct vicinity of bands  $1378 \text{ cm}^{-1}$  chosen as the inside standard.

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**BADANIA SKŁADU CHEMICZNEGO DREWNA  
NA PODSTAWIE SPEKTROSKOPII W PODCZERWIENI  
II. OZNACZANIE ZAWARTOŚCI HOLOCELULOZY I LIGNINY  
PRZY ZASTOSOWANIU RÓŻNYCH LINII BAZOWYCH PASMA 1515 (1510) CM<sup>-1</sup>**

Streszczenie

Obliczono zawartość holocelulozy i ligniny w drewnie zdegradowanym czynnikami chemicznymi i biotycznymi na podstawie absorpcji pasma 1515 cm<sup>-1</sup> (sosna) i 1510 cm<sup>-1</sup> (buk) przy użyciu trzech rodzajów linii bazowych: I — równoległej do linii przesuwu widma przechodzącej przez minimum absorpcji przy 1880 cm<sup>-1</sup>, II — linii łączącej minima absorpcji przy 1880 i 780 cm<sup>-1</sup>, III — linii łączącej minima absorpcji przy 1555, 1402 i 1295 cm<sup>-1</sup>. Obliczenia wykonano na podstawie równania linii prostej

$$x_h = \frac{100 - x_h^0}{a_h^0 - A^0} (A - A^0) + x_h^0 \quad (\%) \quad (1a)$$

$$x_l = \frac{100 - x_l^0}{a_l^0 - A^0} (A - A^0) + x_l^0 \quad (\%) \quad (1b)$$

gdzie

$A, x_h, x_l$  — absorbanca ( $A$ ) i zawartości procentowe holocelulozy ( $x_h$ ) lub ligniny ( $x_l$ ) w próbce drewna zdegradowanego;

$A^0, x_h^0, x_l^0$  — absorbanca ( $A^0$ ) i zawartości procentowe holocelulozy ( $x_h^0$ ) lub ligniny ( $x_l^0$ ) w próbce drewna wyjściowego wyekstrahowanego mieszaniną etanol-benzen;

$a_h^0, a_l^0, 100$  — absorbanca preparatu holocelulozy ( $a_h^0$ ) lub ligniny ( $a_l^0$ ) i zawartości procentowe tych składników wyizolowanych *in vitro* z drewna naturalnego (100%).

Wyniki obliczeń zestawiono w postaci różnic z wynikami analiz chemicznych i oznaczeń na podstawie ciepła spalania. Najmniejsze różnice zaobserwowano stosując: dla drewna sosny linie bazowe I i II ze standardem wewnętrznym, dla drewna buka linię bazową III bez standardu wewnętrznego. Odchylenia standardowe tych różnic ( $\rho$ ) wynoszą dla drewna sosny: holoceluloza 3,16 i 3,61%, lignina 3,74 i 3,86%. Dla drewna buka odchylenia te wynoszą: holoceluloza 4,56%, lignina 5,95%.

**ИССЛЕДОВАНИЯ ХИМИЧЕСКОГО СОСТАВА ДРЕВЕСИНЫ НА  
ОСНОВЕ ИНФРАКРАСНОЙ СПЕКТРОСКОПИИ  
II. ОПРЕДЕЛЕНИЕ СОДЕРЖАНИЯ ХОЛОЦЕЛЛЮЛОЗЫ И ЛИГНИНА  
С ПРИМЕНЕНИЕМ РАЗНЫХ БАЗИСНЫХ ЛИНИЙ ПОЛОСЫ 1515 (1510) CM<sup>-1</sup>**

Резюме

Исчислено содержание холоцеллюлозы и лигнина в древесине, подвергшейся деградации химическими и биотическими факторами, на основе поглощения полосы 1515 см<sup>-1</sup> (сосна) и 1510 см<sup>-1</sup> (бук), с применением трёх видов базисных линий: I — линии, параллель-



ной к линии перемещения спектра, переходящей через минимум поглощения при  $1880 \text{ cm}^{-1}$ , II — линии, соединяющей минимумы поглощения при  $1880$  и  $780 \text{ cm}^{-1}$ , III — линии, соединяющей минимумы поглощения при  $1555$ ,  $1402$  и  $1295 \text{ cm}^{-1}$ . Исчисления были сделаны на основе уравнения прямой линии:

$$x_h = \frac{100 - x_h^0}{a_h^0 - A^0} (A - A^0) + x_h^0 (\%) \quad (1a)$$

$$x_l = \frac{100 - x_l^0}{a_l^0 - A^0} (A - A^0) + x_l^0 (\%) \quad (1b)$$

где

$A$ ,  $x_h$ ,  $x_l$  — поглощение ( $A$ ) и процентные содержания холоцеллюлозы ( $x_h$ ) или лигнина ( $x_l$ ) в образце древесины, подвергшейся деградации,

$A^0$ ,  $x_h^0$ ,  $x_l^0$  — поглощение ( $A^0$ ) и процентные содержания холоцеллюлозы ( $x_h^0$ ) или лигнина ( $x_l^0$ ) в образце исходной древесины, экстрагированной смесью этанол-бензол,

$a_h^0$ ,  $a_l^0$ , 100 — поглощение препарата холоцеллюлозы ( $a_h^0$ ) или лигнина ( $a_l^0$ ) и процентные содержания этих компонентов, изолированных *in vitro* из натуральной древесины (100%).

Результаты исчислений сопоставлены в форме разниц с результатами химических анализов и определений на основе теплоты сгорания. Наименьшие различия были обнаружены, когда применялись: для сосновой древесины — базисные линии I и II с внутренним стандартом, для буковой древесины — базисная линия III без внутреннего стандарта. Стандартные отклонения этих разниц ( $\rho$ ) составляют для сосновой древесины: холоцеллюлоза — 3,16 и 3,61%, лигнин — 3,74 и 3,86%. Для буковой древесины эти отклонения составляют: холоцеллюлоза — 4,56%, лигнин — 5,95%.

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