

DOI: 10.18721/JPM.11301

UDC 53.082.63

THE WOOD IN THE INHOMOGENEOUS TEMPERATURE FIELD: ESTIMATION OF CELLULOSE STRUCTURE PARAMETER FLUCTUATIONS

**N.N. Matveev¹, Hoai Thuong Nguyen²,
N.S. Kamalova¹, N.Yu. Evsikova¹, A.S. Chernykh¹**

¹Voronezh State University of Forestry and Technologies named after G.F. Morozov,
Voronezh, Russian Federation;

²Industrial University of Ho Chi Minh City, Vietnam

In the paper, the cellulose as a fiber-forming component of wood (natural composite) has been studied. The authors put forward a technique for estimating fluctuations of cellulose microstructure in the wood through monitoring the potential difference of the thermal polarization that arises in the samples placed into an inhomogeneous temperature field with a constant temperature gradient. Formalized simulation was used for an analysis of experimental results. The proposed technique made it possible to establish that the percent of the large-sized cellulose crystallites in the wood grew with increasing smoothly temperature gradient. Similar dynamics is not typical of linear crystalline polymers whose polarization decreases with growing temperature. The obtained effect can be assigned to the fact that natural wood exhibits heterogeneous structure.

Key words: microstructure, crystallite, composite, cellulose macromolecule, synthesized material

Citation: N.N. Matveev, H.T. Nguyen, N.S. Kamalova, N.Yu. Evsikova, A.S. Chernykh, The wood in the inhomogeneous temperature field: Estimation of cellulose structure parameter fluctuations, St. Petersburg Polytechnical State University Journal. Physics and Mathematics. 11 (3) (2018) 9–16. DOI: 10.18721/JPM.11301

ОЦЕНКА ФЛУКТУАЦИИ СТРУКТУРНЫХ ПАРАМЕТРОВ ЦЕЛЛЮЛОЗЫ В ДРЕВЕСИНЕ, ПОМЕЩЕННОЙ В НЕОДНОРОДНОЕ ТЕМПЕРАТУРНОЕ ПОЛЕ

**Н.Н. Матвеев¹, Х.Т. Нгуен², Н.С. Камалова¹,
Н.Ю. Евсикова¹, А.С. Черных¹**

¹Воронежский государственный лесотехнический университет имени Г.Ф. Морозова,
г. Воронеж, Российская Федерация;

²Индустриальный университет Хошимина, г. Хошимин, Вьетнам

В работе исследован волокнообразующий компонент древесины (природный композит) – целлюлоза. С целью оценки флуктуации микроструктуры целлюлозы в древесине авторы предлагают использовать мониторинг разности потенциалов термической поляризации объекта, которая возникает в образцах,

помещенных в неоднородное температурное поле с постоянным градиентом температуры. Для анализа результатов эксперимента использовалось формализованное моделирование. Предложенный метод анализа позволил установить, что в целлюлозе доля кристаллитов большого размера растет с плавным увеличением градиента температуры. Подобная динамика не характерна для линейных кристаллизующихся полимеров, поляризация которых снижается с повышением температуры. Полученный эффект авторы связывают с разнородной структурой дерева.

Ключевые слова: микроструктура, кристаллит, композит, макромолекула целлюлозы, синтезированный материал

Ссылка при цитировании: Матвеев Н.Н., Нгуен Х.Т., Камалова Н.С., Евсикова Н.Ю., Черных А.С. Оценка флуктуации структурных параметров целлюлозы в древесине, помещенной в неоднородное температурное поле // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2018. Т. 11. № 3. С. 9–16. DOI: 10.18721/JPM.11301

Introduction

Creating synthesized bioplastics with highly resistant physical properties such as strength, surface hardness and permissible hydrophobicity is one of the most urgent tasks in technology [1 – 8]. The arboform exemplifies these materials; it can be obtained through the synthesis from natural cellulose and “sulphate soap” released during the paper production process. The physical characteristics of these synthesized materials are determined by the orderliness of their fiber-forming component microstructure, as cellulose microstructure in our case. In this regard, the development of nondestructive methods for estimating microstructure fluctuations in the fiber-forming component of composite materials always attracts attention of the scientific community.

It is well known that wood is naturally occurring composite material, and its main components are partially crystalline cellulose and lignin. Cellulose is a stereoregular syndiotactic polymer [9 – 12]. The macromolecules of the fiber-forming wood component (cellulose) are schematically arranged in the form of a coiled tape with a cross-section of 0.39×0.83 nm. Molecular chains of cellulose are packed in a mean length of 15 – 17 nm with a «loosening» section of 2.5 – 3.0 nm in length following. In addition, hollows of 0.5 – 1.0 nm are always located inside amorphous regions [13]. Thus, the packaging process of cellulose macromolecules is characterized by the alternation of crystalline and amorphous phases and the presence of pores in microfibrils in the wood. The peculiarities of this structure allow us to assume that the

response of biocomposite such as the wood substance to the change in external factors depends on the concentration of crystallites in the fiber-forming cellulose and their physical properties.

In the present work, a formalized model is proposed for estimating the fluctuations in the microstructure of cellulose in the wood on exposure to external nonuniform temperature fields. For this purpose, the concentration of cellulose crystallites has been chosen as the fluctuation parameter.

Experimental results

The temperature-scanning method was used for experimental investigation as described in detail in Refs. [14, 15]. In this method, an inhomogeneous temperature field providing a constant temperature gradient ∇T was applied to a thin-layer composite sample, and a thermal-origin electric field evolving as a result. The origin of this electric field in the wood can be bound up with the structural difference between cellulose and lignin and with pyroelectric and piezoelectric properties of fiber-cellulose crystallites as well [15]. The potential difference (PD) across this field depends on the degree of crystallinity of cellulose and is measured with controlled accuracy using electrical measuring instruments.

To determine the response of cellulose in the wood to the applied inhomogeneous temperature field, studies in fluctuations of the PD in the samples were carried out. The samples were prepared from birch wood containing up to 40 % moisture. The sample thickness l_0 was

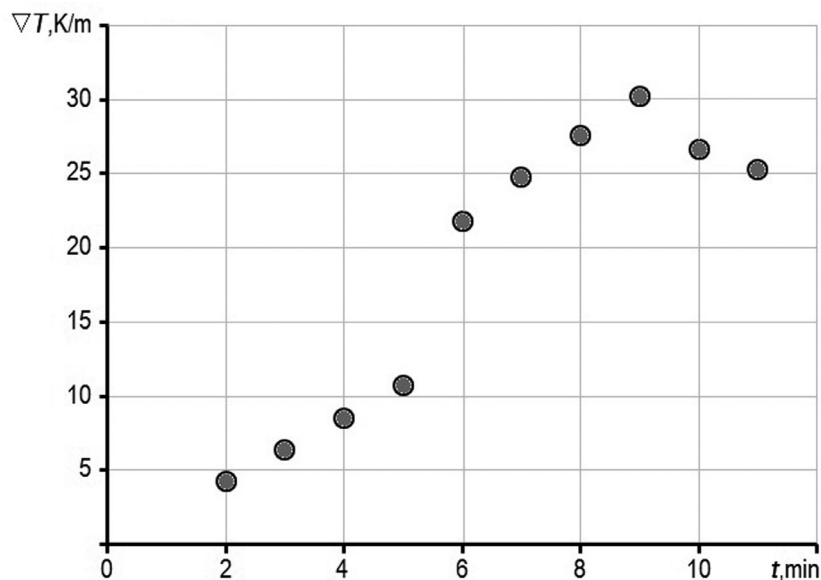


Fig. 1. The thermal-gradient dynamics for a wood thin layer during the test process

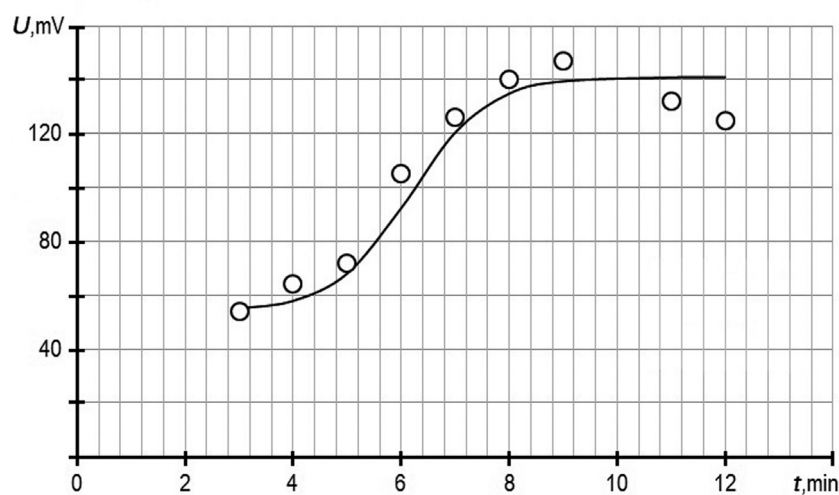


Fig. 2. The experimental (circles) and simulated (the solid line) PD-time relation for a wood thin layer

about 100 μm . A special measuring cell was used to change the temperature gradient in the wood layer as given in Ref. [15]. Thin sections of the wood were placed between massive brass rodes with the lower one heated. Therefore, the temperature gradient in the wood layer was controlled by the heating rate of the heated lower electrode. The PD was initially removed from the electrodes.

Fig. 1 shows the dynamics of the temperature gradient in a thin layer of wood during the

tests. Fig. 2 shows the experimental data for the measurement of the corresponding PD presented in the form of circles. Comparing the two figures, we can affirm that the PD correlates with the changes in the temperature gradient in the layer as established in various studies [14 – 16]. Thus, the temperature-scanning method makes it possible to control the value of the temperature gradient in the layer using electrical measuring instruments. In this regard, we propose to estimate the average

size of cellulose crystallites by analyzing the obtained data on the basis of a formalized model [17–20].

Justification of the formalized model

It is known that the relative change in the concentration n of cellulose crystallites depends on the relative rate of a crystal growth under smoothly changing external conditions and characterized by the rate G [16]:

$$\frac{dn}{n} = Gdt. \quad (1)$$

However, the crystal growth causes the diffusion of non-crystallizing fragments. This process is characterized by the coefficient k_D [16]:

$$\frac{dn}{dt} = -k_D \frac{dn}{dx}. \quad (2)$$

These two processes (1) and (2) balance each other in a stationary state. Therefore, the equations can be transformed to the form:

$$\frac{dn}{dx} = (-G/k_D)n. \quad (3)$$

The exponential function

$$n = n_0 \exp(-\Delta x/x_k)$$

is a solution of Eq. (3), where n_0 is the concentration of crystallites near crystallization centers, $x_k = k_D/G$ is the average size of the fiber-forming component crystallite.

This average size is determined when the concentration of crystallites located at a distance equal to crystallite size decreases by e times as compared to n_0 .

It should be noted that these concepts of crystallites growth do not take into account the peculiarity of experimental conditions. The constant temperature gradient creates inhomogeneous growth conditions along the thickness of a sample. According to the obtained experimental results we can assume that the average size of the cellulose crystallite x_k depends on the increment of the crystallite concentration as follows:

$$x_k(n) = x_{k0}(1 + \chi \Delta n), \quad (4)$$

where χ is a coefficient that characterizes the crystallinity degree of the cellulose in a sample,

x_{k0} is the initial value of x_k .

The solution of differential Eq. (3) taking Eq. (4) into account is transformed to the following form:

$$\frac{\Delta n}{n_0} = \frac{\exp(-\Delta x/x_k)}{(1 + \chi \exp(-\Delta x/x_k))n_0}, \quad (5)$$

where $\Delta x = \alpha l_0^2 \nabla T(t)$ is the value of the total compression of cellulose crystallites in a sample with the thickness l_0 during the expansion of lignin, α is the coefficient of thermal expansion of lignin.

According to Ref. [21] the ratio $\Delta n/n_0$ equals the relative change of crystallinity degree of cellulose in the wood. As reported in Ref. [22], the PD appeared in the wood on exposure to an inhomogeneous temperature field is directly proportional to crystallinity degree of cellulose. Thus, the relative change in PD in the sample within the framework of this approach is simulated by the following relationship:

$$\frac{U - U_0}{U_0} = k_U \frac{\Delta n}{n_0} = \frac{k_U \exp(-\Delta x/x_k)}{(1 + \chi \exp(-\Delta x/x_k))n_0}, \quad (6)$$

where k_U is a parameter that depends on the percolation features of thermal polarization processes occurred in the composite, U_0 is the PD initial value.

Finally, we obtain the relation for estimating the PD:

$$U = U_0 \left\{ 1 + \frac{k_U \exp(-\alpha l_0^2 \nabla T/x_k)}{[1 + \chi \exp(-\alpha l_0^2 \nabla T/x_k)]n_0} \right\}. \quad (7)$$

Eq. (7) connects the PD in the sample on exposure to an inhomogeneous temperature field with the fluctuations in external conditions such as the changes in $\nabla T(t)$ and the features of fiber-forming microstructure (x_k, χ) and filler (α).

Furthermore, Eq. (7) is the basic axiom of the formalized model for the method of estimating the response of natural component-containing microstructure to fluctuations of external conditions in general and temperature in particular. The model experiment was implemented by the linear regression method using Excel spreadsheets. The results are presented by the solid line in Fig. 2. Comparing the results of the real and simulated experiments (see



Fig. 2) we can conclude that it is possible to estimate the values of χ , x_k and k_U parameters from the results of physical and simulated experiments with controlled accuracy.

Summary

Thus, it has been shown that the temperature-scanning method using elements of formalized simulation makes it possible to estimate the fluctuations of supramolecular structure of the fiber-forming component in a composite when changing the external conditions. Consequently, it can also be used to study the microstructure of arboforms and synthesized plastics.

Furthermore, analysis of the PD dynamics with a smoothly increasing temperature gradient suggests that the fraction of cellulose crystallites with a large size in the wood grows

with increasing the temperature gradient value. It should be noted that similar dynamics do not characterize linear crystallizing polymers, in which polarization decreases with increasing temperature. Perhaps, the considered effect is due to interaction between wood components and the cellulose characterized by the complexity of supramolecular structure.

The work was supported by the grant «Development of Innovative Ideas “Growth Points – 2017”» of the Federal State Budgetary Educational Institution of Higher Education «Voronezh State University of Forestry and Technologies named after G.F. Morozov».

Работа выполнена при финансовой поддержке Воронежского государственного лесотехнического университета имени Г.Ф. Морозова (грант “Развитие инновационных идей «Точки роста – 2017»”).

REFERENCES

- [1] **A.M. Kamalov, M.E. Borisova**, The influence of moisture on charge relaxation in modified polyimide films, *St. Petersburg Polytechnical University Journal. Physics and Mathematics*. (2) (2016) 188–192.
- [2] **A. Abdulkhani, J. Hosseinzadeh, S. Dadashi, M. Mousavi**, A study of morphological, thermal, mechanical and barrier properties of PLA based biocomposites prepared with micro and nano sized cellulosic fibers, *Cellulose Chemistry and Technology*. 49 (7–8) (2015) 597–605.
- [3] **Yu.M. Spivak, V.A. Moshnikov**, Features of photosensitive polycrystalline PbCdSe layers with a network-like structure, *Journal of Surface Investigation. X-Ray, Synchrotron and Neutron Techniques*. 4(1) (2010) 71–76.
- [4] **E.V. Maraeva, V.A. Moshnikov, Yu.M. Tairov**, Models of the formation of oxide phases in nanostructured materials based on lead chalcogenides subjected to treatment in oxygen and iodine vapors, *Semiconductors*. 47(10) (2013) 1422–1425.
- [5] **D. Lingam, A.R. Parikh, J. Huang, et al.**, Nano/microscale pyroelectric energy harvesting: challenges and opportunities, *International Journal of Smart and Nano Materials*. 4(4) (2013) 229–245.
- [6] **S.K.T. Ravindran, T. Huesgen, M. Kroener, P. Woias**, A self-sustaining micro thermomechanic-pyroelectric generator, *Applied Physics Letters*. 99 (10) (2011) 104102.
- [7] **T.C. Harman, P.J. Taylor, M.P. Walsh, B.E. LaForge**, Quantum dot superlattice thermoelectric materials and devices, *Science*. 5590 (297) (2002) 2229–2232.
- [8] **A.J. Boukai, Yu. Bunimovich, J. Tahir-Kheli, et al.**, Silicon nanowires as efficient thermoelectric materials, *Nature*. 451(10) (2008) 168–171.
- [9] **H.T. Nguyen, A.S. Sidorkin, S.D. Milovidova, O.V. Rogazinskaya**, Investigation of dielectric relaxation in ferroelectric composite nanocrystalline cellulose-triglycine sulfate, *Ferroelectrics*. 498 (1) (2016) 27–35.
- [10] **H.T. Nguyen, S.D. Milovidova, A.S. Sidorkin, O.V. Rogazinskaya**, Dielectric properties of composites based on nanocrystalline cellulose with triglycinesulfate, *Physics of the Solid State*. 57(3) (2015) 503–506.
- [11] **A.Yu. Milinskiy**, Dielectric properties of nanocrystalline cellulose-potassium iodide composites, *St. Petersburg Polytechnical University Journal. Physics and Mathematics*. 3 (2017) 57–62.
- [12] **B. Lindner, L. Petridis, J.C. Smith, P. Langan**, Determination of cellulose crystallinity from powder diffraction diagrams, *Biopolymers*. 103(2) (2015) 67–73.
- [13] **L. Mandelkern**, *Crystallization of polymers*, 2nd edition, Vol. 1, Cambridge University Press, Cambridge, 2004.
- [14] **N.N. Matveev, N.S. Kamalova, N.Yu. Evsikova, O. Farberovich**, Influence of structural inhomogeneities on the formation of the pyroelectric phase in polymers, *Physics of the Solid State*. 57(6) (2015) 1148–1150.
- [15] **N.N. Matveev, N.S. Kamalova, N.Yu. Evsikova, et al.**, Emergence of differences in potential in wood as a result of natural changes in temperature, *Bulletin of the Russian Academy of*

Sciences: Physics. 80(9) (2016) 1158–1160.

[16] **B. Wunderlich**, *Macromolecular Physics*, Vol. 3: Crystal Melting, Academic Press, New York, 1980.

[17] **V.I. Arnold**, «Zhestkie» i «myagkie» matematicheskie modeli [«Hard» and «soft» mathematical models], MCNMO, Moscow, 2004.

[18] **K. Chattopadhyay, A.K. Tiwari, D. Singh, et al.**, A systematic analytical study on lignocelluloses originated inhibitors in hydrolyzed biomass, *Cellulose Chemistry and Technology*. 49(1) (2015), 81–85.

[19] **D.A. Kozhanov**, The features of finite-element modeling of a structural element of flexible woven composites, *St. Petersburg Polytechnical University Journal. Physics and Mathematics*. 2 (2016) 1–6.

[20] **K.C. Cunha, V.H. Rusu, I.F.T. Viana, et al.**,

Assessing protein conformational sampling and structural stability via de novo design and molecular dynamics simulations, *Biopolymers*. 103(6) (2015) 351–361.

[21] **V.V. Postnikov, N.Yu. Evsikova, N.S. Kamalova, N.N. Matveev**, Stepen kristallichnosti tsellyulozy i termicheskoye skanirovaniye [The degree of cellulose crystallinity and the thermal scanning], *INTERMATIC-2009: Materials of the International Scientific and Technical Conference*, The Russian Academy of Sciences, Energoatomizdat, Moscow, 1 (2009) 197–199.

[22] **N.Y. Evsikova, N.S. Kamalova, N.N. Matveev, V.V. Postnikov**, A new approach to determining the degree of cellulose crystallinity in wood, *Bulletin of the Russian Academy of Sciences: Physics*. 74(9) (2010) 1317–1318.

Received 28.12.2017, accepted 20.06.2018.

THE AUTHORS

MATVEEV Nikolay N.

Voronezh State University of Forestry and Technologies named after G.F. Morozov
8 Timiryazev St., Voronezh, 394087, Russian Federation
nmtv@vglta.vrn.ru

NGUYEN Hoai Thuong

Industrial University of Ho Chi Minh City
12 Nguyen Van Bao, Ward 4, Go Vap, Ho Chi Minh, Vietnam
nguyenthuongfee@iuh.edu.vn

KAMALOVA Nina S.

Voronezh State University of Forestry and Technologies named after G.F. Morozov
8 Timiryazev St., Voronezh, 394087, Russian Federation
rc@icmail.ru

EVSIKOVA Nataliya Yu.

Voronezh State University of Forestry and Technologies named after G.F. Morozov
8 Timiryazev St., Voronezh, 394087, Russian Federation
natalyaevsikova@mail.ru

CHERNYKH Alexander S.

Voronezh State University of Forestry and Technologies named after G.F. Morozov
8 Timiryazev St., Voronezh, 394087, Russian Federation
edu-ltu@vglta.vrn.ru

СПИСОК ЛИТЕРАТУРЫ

1. **Камалов А.М., Борисова М.Э.** Влияние влаги на релаксацию электрического заряда в модифицированных пленках на основе полиимида // *Научно-технические ведомости СПбГПУ. Физико-математические науки*. 2016. № 3 (248). С. 33 – 38.

2. **Abdulkhani A., Hosseinzadeh J., Dadashi S., Mousavi M.** A study of morphological, thermal,

mechanical and barrier properties of PLA based biocomposites prepared with micro and nano sized cellulosic fibers // *Cellulose Chemistry and Technology*. 2015. Vol. 49. No. 7–8. Pp. 597–605.

3. **Спивак Ю.М., Мошников В.А.** Особенности строения фоточувствительных поликристаллических слоев сетчатого типа на основе PbCdSe(I) // *Поверхность. Рентгеновские, син-*

хротронные и нейтронные исследования. 2010. № 1. С. 97–102.

4. **Мараева Е.В., Мошников В.А., Таиров Ю.М.** Модели формирования оксидных слоев в наноструктурированных материалах на основе халькогенидов свинца при обработке в парах кислорода и иода // Физика и техника полупроводников. 2013. Т. 47. № 10. С. 1431–1434.

5. **Lingam D., Parikh A.R., Huang J., Jain A., Minary-Jolandan M.** Nano/microscale pyroelectric energy harvesting: challenges and opportunities // International Journal of Smart and Nano Materials. 2013. Vol. 4. No. 4. Pp. 229–245.

6. **Ravindran S.K.T., Huesgen T., Kroener M., Woias P.** A self-sustaining micro thermomechanic-pyroelectric generator // Applied Physics Letters. 2011. Vol. 99. No. 10. P. 104102.

7. **Harman T.C., Taylor P.J., Walsh M.P., LaForge B.E.** Quantum dot superlattice thermoelectric materials and devices // Science. 2002. Vol. 5590. No. 297. Pp. 2229–2232.

8. **Boukai A.J., Bunimovich Yu., Tahir-Kheli J., Yu J.-K., Goddard III W.A., Heath J.R.** Silicon nanowires as efficient thermoelectric materials // Nature. 2008. Vol. 451. No. 10. Pp. 168–171.

9. **Nguyen H.T., Sidorkin A.S., Milovidova S.D., Rogazinskaya O.V.** Investigation of dielectric relaxation in ferroelectric composite nanocrystalline cellulose-triglycine sulfate // Ferroelectrics. 2016. Vol. 498. No. 1. Pp. 27–35.

10. **Нгуен Х.Т., Миловидова С.Д., Сидоркин А.С., Рогазинская О.В.** Диэлектрические свойства композитов на основе нанокристаллической целлюлозы с триглицинсульфатом // Физика твердого тела. 2015. Т. 57. № 3. С. 491–494.

11. **Милинский А.Ю.** Диэлектрические свойства композитов нанокристаллическая целлюлоза – иодат калия // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2017. Т. 10. № 1. С. 93–99.

12. **Lindner B., Petridis L., Smith J.C., Langan P.** Determination of cellulose crystallinity from powder diffraction diagrams // Biopolymers. 2015. Vol. 103. No. 2. Pp. 67–73.

13. **Mandelkern L.** Crystallization of polymers. 2nd Ed. Vol. 1. Cambridge: Cambridge University

Press, 2004.

14. **Матвеев Н.Н., Камалова Н.С., Евсикова Н.Ю., Фарберович О.** Влияние структурных неоднородностей на формирование пироэлектрической фазы в полимерах // Физика твердого тела. 2015. Т. 57. № 6. С. 1131–1133.

15. **Матвеев Н.Н., Сидоркин А.С., Камалова Н.С., Евсикова Н.Ю., Лисицын В.И.** Разность потенциалов, возникающая в древесине при естественных перепадах температуры // Известия РАН. Серия физическая. 2016. Т. 80. № 9. С. 1272–1274.

16. **Вундерлих Б.** Физика макромолекул. Т. 3. Плавление кристаллов. М.: Мир, 1984. 488 с.

17. **Арнольд В.И.** «Жесткие» и «мягкие» математические модели. М.: Изд-во МЦНМО, 2004. 32 с.

18. **Chattopadhyay K., Tiwari A.K., Singh D., Patel M.B., Basu B.** A systematic analytical study on lignocelluloses originated inhibitors in hydrolyzed biomass // Cellulose Chemistry and Technology. 2015. Vol. 49. No. 1. Pp. 81–85.

19. **Кожанов Д.А.** Особенности конечно-элементного моделирования вида структурного элемента гибких тканых композитов // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2016. № 1 (237). С. 7–15.

20. **Cunha K.C., Rusu V.H., Viana I.F.T., Marques E.T.A., Dhalia R., Lins R.D.** Assessing protein conformational sampling and structural stability via de novo design and molecular dynamics simulations // Biopolymers. 2015. Vol. 103. No. 6. Pp. 351–361.

21. **Постников В.В., Евсикова Н.Ю., Камалова Н.С., Матвеев Н.Н.** Степень кристалличности целлюлозы и термическое сканирование // Фундаментальные проблемы радиоэлектронного приборостроения (INTERMATIC-2009). Матер. 7-й Междунар. научно-техн. конф. Москва, 7–11 декабря 2009 г. /под ред. А.С. Сигова. Ч. 1. М.: Энергоатомиздат, 2009. С. 197–199.

22. **Евсикова Н.Ю., Камалова Н.С., Матвеев Н.Н., Постников В.В.** Новый подход к определению степени кристалличности целлюлозы в древесине // Известия РАН. Серия физическая. 2010. Т. 74. № 9. С. 1317–1318.

Статья поступила в редакцию 28.12.2017, принята к публикации 20.06.2018.

СВЕДЕНИЯ ОБ АВТОРАХ

МАТВЕЕВ Николай Николаевич — доктор физико-математических наук, заведующий кафедрой общей и прикладной физики Воронежского государственного лесотехнического университета имени Г.Ф. Морозова, г. Воронеж, Российская Федерация.

394087, Российская Федерация, г. Воронеж, ул. Тимирязева, 8.
nmtv@vglta.vrn.ru

НГУЕН Хоай Тхьонг — кандидат физико-математических наук, доцент *Промышленного университета Хошмина, г. Хошимин, Вьетнам.*

12 Nguyen Van Bao, Ward 4, Go Vap, Ho Chi Minh, Vietnam

nguyenthuongfee@iuh.edu.vn

КАМАЛОВА Нина Сергеевна — кандидат физико-математических наук, доцент кафедры общей и прикладной физики *Воронежского государственного лесотехнического университета имени Г.Ф. Морозова, г. Воронеж, Российская Федерация.*

394087, Российская Федерация, г. Воронеж, ул. Тимирязева, 8

nc@icmail.ru

ЕВСИКОВА Наталья Юрьевна — кандидат физико-математических наук, доцент кафедры общей и прикладной физики *Воронежского государственного лесотехнического университета имени Г.Ф. Морозова, г. Воронеж, Российская Федерация.*

394087, Российская Федерация, г. Воронеж, ул. Тимирязева, 8

natalyaevsikova@mail.ru

ЧЕРНЫХ Александр Сергеевич — кандидат технических наук, проректор по учебной и воспитательной работе *Воронежского государственного лесотехнического университета имени Г.Ф. Морозова, г. Воронеж, Российская Федерация.*

394087, г. Воронеж, ул. Тимирязева, 8

edu-ltu@vglta.vrn.ru