УДК 674.048.5

Хвойные бореальной зоны. 2023. Т. XLI, № 7 (специальный). С. 616–622

ИССЛЕДОВАНИЕ ВЛИЯНИЯ СВЕРХВЫСОКОЧАСТОТНОГО ИЗЛУЧЕНИЯ НА ПРОНИЦАЕМОСТЬ ДРЕВЕСИНЫ ЛИСТВЕННИЦЫ СИБИРСКОЙ

С. Г. Елисеев, В. Н. Ермолин, С. С. Ступников

Сибирский государственный университет науки и технологий имени академика М. Ф. Решетнева
Российская Федерация, 660037, г. Красноярск, просп. им. газеты «Красноярский рабочий», 31
E-mail: serezha-stupnikov@mail.ru

Древесина лиственницы сибирской за счет имеющихся в сибирском регионе значительных запасов является перспективным объектом для модификации. Однако из-за низкой проницаемости древесины ее пропитка модифицирующими составами практически невозможна. В работе представлены результаты исследований направленных на повышение проницаемости ядровой древесины лиственницы сибирской за счет воздействия СВЧ-излучения.

Экспериментальные исследования проводились на образцах древесины размерами 50×50×150 мм (последний вдоль волокон) изготовленных из свежесрубленной ядровой древесины лиственницы сибирской с исходной влажностью 55 %. Обработка древесины СВЧ осуществлялась в микроволновой камере при частоте 2,45 ГГц с фиксированной мощностью 0,9 кВт. Продолжительность обработки СВЧ составляла 270 с и 330 с.

После обработки СВЧ древесина пропитывалась в автоклаве при давлении 0,5 МПа в течение 40 мин. Для моделирования процессов происходящих в сортиментах промышленных размеров, у части образцов производилась герметизация торцов. В качестве пропиточного состава использовался водный раствор FeSO4.

Полученные экспериментальные данные показывают, что СВЧ-обработка древесины лиственницы позволяет эффективно повышать проницаемость древесины как вдоль, так и поперек волокон. В ходе исследований установлено, что СВЧ-обработка обеспечивает увеличение поглощения древесиной пропиточного раствора в 2,5–2,6 раза, а глубины пропитки поперек волокон в 2,3 раза. При пропитке короткомерных сортиментов СВЧ-обработка позволяет добиться сквозного пропитывания древесины. Чрезмерная обработка СВЧ может приводить к образованию разрывов древесины вдоль волокон.

***Ключевые слова**: СВЧ, древесина, модификация, лиственница, проницаемость, повышение проницаемости, пропитка.*

*Conifers of the boreal area. 2*023, Vol. XL, No. 7 (special), P. 616–622

RESEARCH OF THE INFLUENCE OF MICROWAVE RADIATION ON THE PERMEABILITY OF SIBERIAN LARCH WOOD

S. G. Eliseev, V. N. Ermolin, S. S. Stupnikov

Reshetnev Siberian State University of Science and Technology
31, Krasnoyarskii rabochii prospekt, Krasnoyarsk, 660037, Russian Federation
E-mail: serezha-stupnikov@mail.ru

The wood of Siberian larch, due to the significant reserves available in the Siberian region, is a promising object for modification. However, because of the low permeability of wood, its impregnation with modifying compositions is practically impossible. The research presents the results of studies aimed at increasing the permeability of the heartwood of Siberian larch as a result of exposure to microwave radiation.

Experimental studies were carried out on wood samples with dimensions of 50×50×150 mm (the latter along the fibers) made from freshly cut heartwood of Siberian larch with an initial moisture content of 55 %. Microwave wood processing was carried out in a microwave chamber at a frequency of 2.45 GHz with the fixed power of 0.9 kW. The duration of microwave processing was 270 s and 330 s.

After microwave treatment, the wood was impregnated in an autoclave at a pressure of 0.5 MPa for 40 minutes. To simulate the processes occurring in assortment of industrial sizes, the ends of some samples were sealed. An aqueous solution of FeSO4 was used as the impregnating composition.

The obtained experimental data show that microwave processing of larch wood can effectively increase the permeability of wood both along and across fibers. In the course of research, it was found that microwave treatment provides an 2.5–2.6 times increase in the absorption of the impregnating solution by wood, and the depth of impregnation across the fibers by 2.3 times. When impregnating short assortments, microwave processing allows achieving thorough impregnation of wood. Excessive microwave processing may cause the wood to break along the fibers.

Keywords*: microwave, wood, modification, larch, permeability, increased permeability, impregnation.*

INTRODUCTION

Annual consumption of natural wood is constantly growing in the world. This is facilitated by the unique properties of wood, such as relatively high specific strength, environmental friendliness, decorative appearance, renewable resource, etc.

The range of wood on the world market is represented by a very extensive list of different types of tree species. At the same time, wood of certain species is in high demand due to its attractive color, texture or high physical and mechanical properties. This negatively affects the size of populations of this species, contributes to the formation of a supply shortage and, consequently, an increase in the price of such wood.

One of the ways to meet the demand for wood with sought-after properties may be the targeted modification of wood with less valuable species growing in northern latitudes.

A promising species for targeted modification of wood is Siberian larch, widespread in the Siberian region [1]. Larch wood has fairly high physical and mechanical properties, comparable to such species as oak, ash, and beech [2]. And its modification can provide high bio- and fire resistance, increasing physical, mechanical and decorative properties.

Most technologies for direct changing the properties of wood are based on deep or even through impregnation with modifying compounds. At the same time, the permeability of wood to liquids is a prerequisite for the implementation of such technologies. Larch wood is a hard-to-impregnate species. Almost the entire volume of the larch trunk is occupied by heartwood, which has low permeability to liquids and gases [3]. Therefore, without increasing the permeability of wood, it is almost impossible to impregnate it.

A large number of works have been devoted to the study of the reasons for the low permeability of the core part of a coniferous tree trunk in comparison with the sapwood. Low permeability of heartwood is explained by a change in the position of the tori in the pores of vertical tracheids [6], deposition of extractives in the cell walls [3] and clogging of the marginal zones of the pores of ray tracheids with extractives [7].

To date, a wide range of methods have been developed to increase the permeability of wood raw materials: by pricking [4], using variable pressure [7], pre-infection with wood-coloring fungi [8], by burning with a laser beam [9; 10], temperature increases [3], etc. The listed methods have serious disadvantages: they violate the integrity of the wood, are energy-consuming, and technically difficult to implement in industrial conditions, have an unacceptably long process duration, etc.

Recently, methods for increasing the permeability of wood through microwave treatment have been actively developed all over the world. Studies [12; 13; 14; 15; 16; 17; 18; 19] have noted the high efficiency of microwave processing of wood in order to increase permeability with an acceptable decrease in mechanical properties. In the study [12], due to microwave treatment, the absorption of Chinese fir wood increased by 156 % compared to the control untreated wood, and in the work [13] this value was increased to 308 %. An increase in the permeability of hardwood also indicates the effectiveness of microwave exposure. It has been established that microwave treatment of European beech wood provides an increase in permeability along the fibers up to 159 % [15].

In the cited works [20; 21; 22; 23; 24] the mechanism of increasing the permeability of wood when exposed to microwaves is explained primarily by the heating and evaporation of the water contained in it, as a result of which vapor-gas pressure arises and partial destruction of the cell walls of anatomical elements occurs. Moreover, in most of the sources reviewed, the authors focus on increasing permeability along the fibers. While it is the transverse permeability of wood that is decisive when impregnating assortments longer than 0.5 meters [6]. In this regard, the possibility of increasing transverse permeability due to microwave exposure is of no less interest.

Taking into account the available scientific data on the high potential of microwave treatment to increase the permeability of wood and taking into account the preliminary results obtained [11], it was decided to investigate the possibility of increasing the permeability of heartwood of Siberian larch, taking into account structural directions.

MATERIALS AND METHODS OF RESEARCH

For research purposes from freshly cut 120 samples of larch heartwood were made with an oriented arrangement of annual layers relative to the layers, dimensions 50×50×150 mm (the latter along the fibers). The initial humidity of the samples was 55 %.

Microwave processing of wood samples was carried out in a microwave chamber at a frequency of 2.45 GHz with a fixed power of 0.9 kW. Based on the duration of microwave treatment (taking into account the preliminary data obtained [11]), all samples were divided into two treatment groups: microwave 270 s and microwave 330 s. Control samples were not subjected to microwave treatment.

After microwave treatment, all samples were impregnated in an autoclave at a pressure of 0.5 MPa for 40 minutes. Since the permeability of wood along the fibers is many times greater than the transverse one [2], to simulate the processes occurring in industrial-sized assortments, the ends of some samples were sealed. Before impregnation, the samples of the first and second groups were divided into two subgroups. Samples of the first subgroup were impregnated without waterproofing the ends, the second to study transverse permeability with waterproofed ends to prevent longitudinal impregnation. The samples were waterproofed by applying three layers of PPH15 and one layer of silicone sealant. An aqueous solution of FeSO4 was used as an impregnating composition. This solution changes the color of larch heartwood, allowing you to record the depth of the impregnation front. To determine the absorption of the solution, the samples were weighed and the absorption was calculated in kg/m^3. The impregnation depth was determined after splitting the samples along the fibers into four parts.

RESULTS AND DISCUSSION

The results of studies of microwave treatment influence on the longitudinal permeability of heartwood for liquids are presented in Fig. 12.

The data obtained discovered that absorption of samples treated microwaves and impregnated without waterproofing the ends increased in comparison with control samples (Fig. 1) by 1.7–2 times. Moreover, the most significant increase in the absorption rate was observed in samples of the second group that underwent longer microwave treatment. A comparison of the absorption of microwave 270 s and microwave 330 s samples showed an 18 % superiority of the latter.

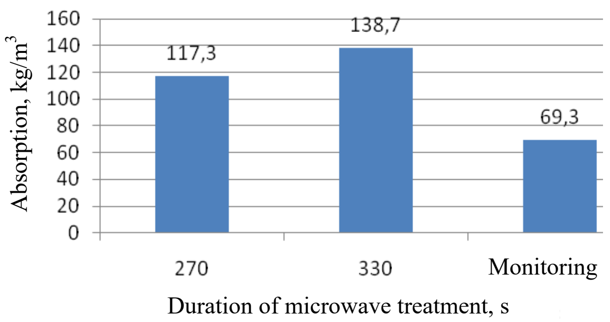

Fig. 1. The effect of microwave processing on the value absorption of samples without waterproofing the ends

When splitting the samples, the following features of the penetration of the impregnating solution were revealed (Fig. 2). All samples treated with microwaves and impregnated without waterproofing the ends showed through penetration of the impregnating solution with local unimpregnated areas (Fig. 2, *a*). While the average depth of penetration of the impregnating solution in the control samples was slightly more than 16 mm (Fig. 2, *b*). In the transverse direction, the depth of penetration of the impregnating solution for samples impregnated without waterproofing was not recorded, since the solution penetrated primarily along the fibers.

Impregnation of wood samples with sealed ends showed the following results (Table 1, Fig. 3). The absorption of the solution by such samples predictably turned out to be 4–6 times lower in comparison with samples impregnated without sealing the ends. At the same time, in the samples treated with microwaves, just as in the previous experiment, there was a significant increase in the absorption of the solution relative to the control samples. The absorption of microwave samples at 270 s exceeded the control by 38.1 %, and at microwave 330 s by 82.5 %. At the same time, the absorption of samples with a microwave treatment duration of 330 s turned out to be 44 % higher than those treated with 270 s.

Fig. 2. Samples of wood after impregnation without waterproofing the ends:
a – microwave-treated; *b* – untreated microwave (control)

After assessing absorption, all wood samples impregnated with closed ends were split into four parts to measure the depth of advance of the impregnation front. The measurement results are presented in Table 1 and in Fig. 4.

From the histogram in Fig. 4 it follows that increasing the depth of penetration of the impregnating solution (compared to control samples) is observed only in the radial direction and only in samples treated with microwave 330 s (by 43.5 %). While samples treated with microwave 270 s show only a tendency to increase the depth of impregnation (within the limits of the accuracy of the experiment). In the tangential direction, on the contrary, there was a slight tendency towards a decrease in permeability in samples treated with microwaves. In general, when impregnating in the transverse direction, a greater depth of solution advancement in all cases was observed in the radial direction.

For samples of microwave 270 s, the radial direction exceeded the tangential direction by 2.3 times, and microwave 330 s by 3 times, in control samples the difference was 2-fold. Despite the significant increase in the relative depth of impregnation of samples of the microwave group 330 s in the radial direction, in fact, the depth of advance of the impregnation front was less than 2 mm, which cannot be called a significant result.

Table 1
Results of impregnation of wood with sealed ends

Duration of Microwave processing, s	Absorption, kg/m^3	Depth of impregnation in structural directions, mm	
		radial	tangential
270	22,1±0,86	1,20±0,04	0,52±0,02
330	29,2±1,16	1,65±0,05	0,55±0,02
Control	16,0±0,37	1,15±0,04	0,56±0,027

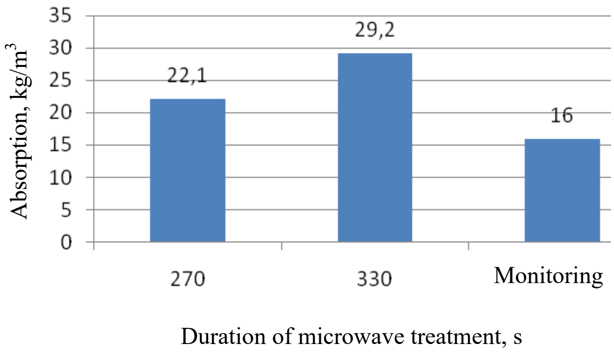

Fig. 3. Influence of microwave treatment on the value absorption of samples with waterproofing of ends

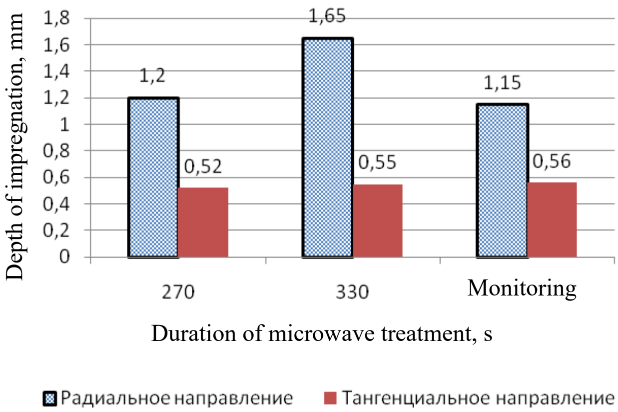

Fig. 4. The influence of microwave treatment on the depth of wood impregnation across the grain

The results obtained showed a significant increase in the permeability of larch heartwood along the fibers and a less significant increase across the fibers. Apparently, the excess pressure generated during microwave treatment (due to its active relaxation along the fibers) turned out to be insufficient to create transport paths across the fibers.

To confirm the hypothesis put forward. A batch of samples was produced in the amount of 60 pcs., similar dimensions and humidity (50×50×150 mm W – 55 %). In this case, unlike the previous experiment, before microwave treatment the samples underwent special preparation, which consisted of multilayer sealing of the end surfaces of the samples. Sealing was carried out to exclude pressure relaxation due to transfer along the fibers, which made it possible to simulate processes occurring in assortments of real sizes. The ends of the samples were covered with a layer of silicone sealant, then plastic plugs with inserted rubber gaskets were put on them. Before being placed in the microwave chamber, the plugs of opposite ends were tightened with a clamp made of heat-resistant plastic (Fig. 5).

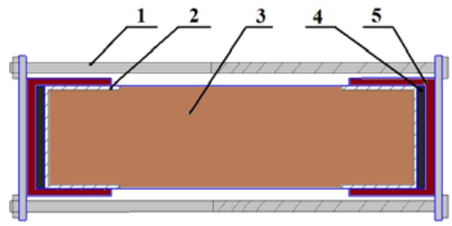

Fig. 5. Sealing the ends of the samples for microwave processing:
1 – plastic clamp; 2 – heat resistant silicone sealant;
3 – wood sample; 4 – rubber gasket; 5 – plastic plug

As in the previous experiment, the samples were divided according to the duration of microwave treatment: 270 s and microwave 330 s. After microwave treatment, the sealing layer was restored at the ends of the samples and then impregnated for 40 min with an aqueous solution of $FeSO_4$ at an excess pressure of 0.5 MPa. After impregnation, the magnitude of absorption and the depth of advance of the impregnation front were assessed. The research results are given in table 2 and in Fig. 6 and 7.

The results obtained show (Fig. 6) that the treatment of samples with microwave 270 s with closed ends made it possible to increase the absorption of wood by 2.1 times and by 2.6 times when treated with microwave 330 s. At the same time, the group that underwent longer microwave treatment had absorption 1.25 times higher than that of the 270 s microwave samples. In comparison with samples processed by microwave without sealing the ends (Fig. 3), the absorption rate increased by 1.6 times for samples of microwave 270 s and by 1.5 times for microwave 330 s.

The difference in solution absorption between samples with different durations of microwave treatment, in the case of sealing the ends during processing, was not as significant – 25 %, as without sealing – more than 44 % (Fig. 3).

Separately, it should be noted that some of the samples that underwent microwave treatment for 330 s were found to have closed cracks that formed during the treatment process. This indicates excessive processing time. The absorption values obtained for cracked samples were not taken into account in the calculation of the average absorption value.

The results of measuring the depth of impregnation of samples treated with microwaves with sealed ends revealed the following features (Fig. 7). The depth of advance of the impregnation front increased for all samples that underwent microwave treatment, both in the radial and tangential directions. Compared to the control, the increase in the depth of impregnation in the radial direction ranged from 74 to 131 %, and in tangential 122–127 %.

The greatest value of the advance of the impregnation front (as in the previous experiment) was noted in the radial direction for samples that underwent a longer microwave treatment of 330 s. 33 % higher than for samples treated with microwave 270 s. In the tangential direction, no significant difference in the depth of impregnation between samples of different treatment durations was established. In general, under the same microwave processing conditions in the radial direction, the depth of advance of the impregnation front exceeded the tangential direction by 59–107 %.

A comparison of the impregnation depth of samples treated with microwaves with open and closed ends showed the following. Under the same processing conditions, samples with ends sealed during microwave treatment showed a depth of impregnation higher than those with unsealed ends. In the radial direction the difference was 65–71 %, in the tangential direction 140–148 %. Typical examples of the advancement of the impregnation front in the radial and tangential directions for microwave samples at 330 s and 270 s are presented in Fig. 8.

Table 2
Indicators of impregnation of wood treated with microwaves with sealed ends

Duration of microwave treatment, s	Absorption, kg/m^3	Depth of impregnation in structural directions, mm	
		radial	tangential
270	34,7±1,08	2,05±0,08	1,29±0,04
330	43,4±1,78	2.73±0,11	1,32±0,05
Monitoring	16,4±0,39	1,18±0,02	0,58±0,015

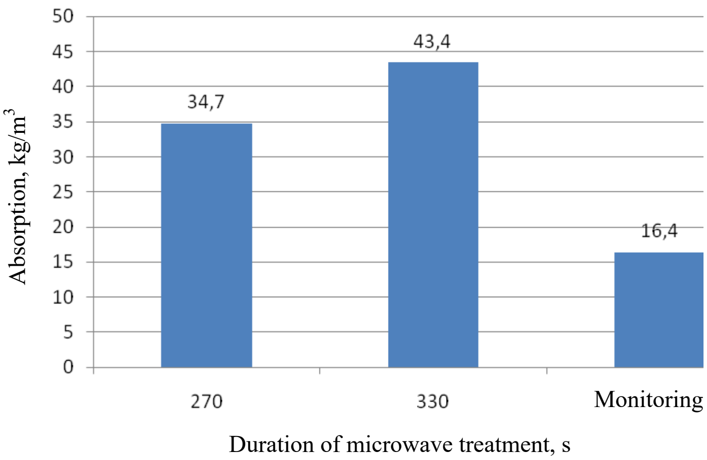

Fig. 6. Influence of microwave treatment on the absorption value of samples with sealed ends during microwave processing and impregnation

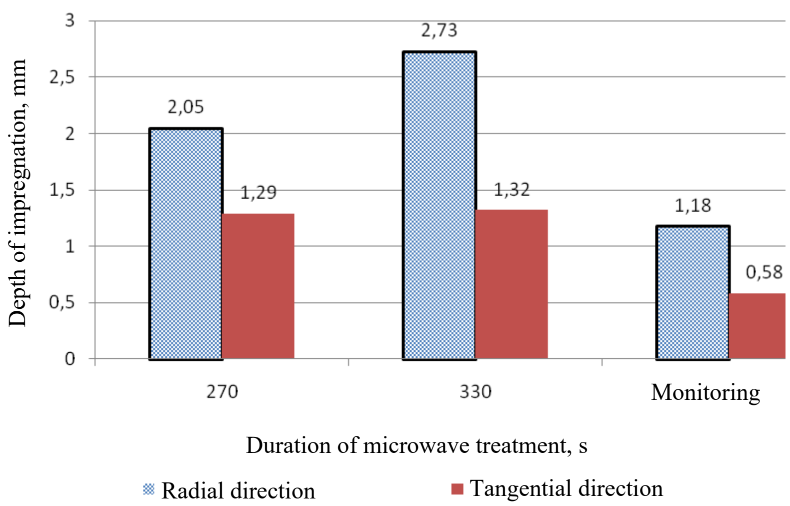

Fig. 7. The influence of microwave treatment on the depth of wood impregnation across the grain with closed ends for microwave processing and impregnation

Fig. 8. Fragments of wood samples treated with microwaves and impregnated with closed ends:
a – radial direction; *b* – tangential direction

CONCLUSIONS

Based on the results of the research, the following conclusions can be drawn:

– Microwave exposure to the heartwood of Siberian larch allows you to increase its permeability, both longitudinally and transversely.

– This is confirmed by a significant increase in absorption and depth of wood impregnation.

– Since microwave treatment allows for end-to-end impregnation of wood along the fibers and a 2.5-fold increase in the absorption of impregnating liquid, this creates good prospects for using microwaves to prepare for impregnation of short-length assortments.

– Increasing the duration of microwave treatment has a positive effect on the results of increasing the permeability of larch heartwood. But excessive microwave treatment can lead to wood ruptures along the grain. Their formation is most likely associated with high vapor-gas pressure arising in the wood.

– When impregnating long assortments, the modeling of which was carried out by sealing the ends of the samples, there is a significant increase in the permeability of larch wood across the fibers. The depth of impregnation increased by 2.3 times, and absorption by more than 2.6 times. This indicates that microwave treatment of long assortments before impregnation also has good prospects for increasing their permeability.

REFERENCES

1. Utkin A. I., Zamolodchikov D. G., Chestnykh O. V. Organic carbon in larch forests of Russia // Coniferous boreal zones. 2003. Vol. 21, No. 1. P. 66–76.

2. Ugolev B. N. Wood science and forest commodity science : Textbook. Moscow, GOU VPO MGUL, 2007, 351 p.

3. Kharuk E. V. Permeability of wood to gases and liquids. Novosibirsk, Science, 1976, 197 p.

4. Baraks A. M., Nikifirov Yu. N. Deep impregnation of wood by applying pricks. Moscow, Timber industry, 1969, 156 p.

5. Bazhenov V. A., Moskaleva V. E. On the permeability of sapwood and pine kernels by liquids and the possibility of its regulation // Tr. Institute of forests of the USSR Academy of Sciences. 1953, Vol. 9. P. 205–216.

6. Dzhaparidze L. I., Bregadze N. N. Features in the displacement of tori during the emergence of ripe wood // Botanical Journal of the USSR. 1940. Vol. 25, No. 4-5. P. 310–317.

7. Ermolin V. N. Fundamentals of increasing the permeability of coniferous wood liquids : Monograph ; Siberian State Technical University. Krasnoyarsk, 1999. T. 100.

8. Gorshin S. N. Wood preservation. Moscow, Timber industry, 1977, 336 p.

9. Wang Y., Ando K., Hattori N. Changes in the anatomy of surface and liquid uptake of wood after laser incising // Wood Sci Technol. 2013, Vol. 47, No. 3, P. 447–455.

10. Islam M. N., Ando K., Yamauchi H., Kobayashi Y., Hattori N. Comparative study between full cell and passive impregnation method of wood preservation for laser incised Douglas fir lumber // Wood Sci Technol. 2008, Vol. 42, No. 4. P. 343–350.

11. Stupnikov S. S. Increasing longitudinal permeability of siberian larch wood // Young people. Society. Modern science, technology and innovation. 2019, Vol. 18, P. 390–391.

12. He S., Lin L., Fu F., Zhou Y., Fan M. Microwave Treatment for Enhancing the Liquid Permeability of Chinese Fir // BioResources. 2014, Vol. 9, No. 2, P. 1924–1938.

13. Li X. J., Lu K. Y., Lin L. Y., Zhou Y. D., Cai Z. Y., Fu F. Fundamental characteristics of microwave explosion pretreatment of wood I. Properties of temperature development // Forestry Studies in China. 2010, Vol. 12, No. 1, P. 9–13.

14. Dashti H., Shahverdi M., Taghiyari H., Salehpur S. and Heshmati S. Effects of steaming and microwave pretreatments on mass transfer characteristics of aleppe oak (Quercus infectoria) // BioResources. 2012, Vol. 7, No. 3, P. 3262–3273.

15. Dömény J., Koiš V., Dejmal A. Microwave radiation effect on axial fluid permeability in false heartwood of beech (Fagus sylvatica L.) // BioResources. 2014, Vol. 9, No. 1, P. 372–380.

16. Hong-Hai L., Qing-Wen W., Lin Y., Tao J., Ying-Chun C. A. I. Modification of larch wood by intensive microwave irradiation //Journal of Forestry Research. 2005, Vol. 16, No. 3, P. 237–240.

17. Terziev N., Daniel G., Torgovnikov G., Vinden P. Effect of Microwave Treatment on the Wood Structure of Norway Spruce and Radiata Pine // BioResources. 2020. Vol. 15, No. 3, P. 5616–5626.

18. Daian G. Delamination in Timber Induced by Microwave Energy // Delamination in Wood, Wood Products and Wood-Based Composites. Springer, Dord-recht, 2010, P. 159–172.

19. Vrublevskaya V. I., Matusevich V. O., Nevzorova A. B. Interaction of microwave radiation with hygroscopic moisture in wood // Bulletin of F. Skorina Gomel State University. 2006, No. 6, P. 42–48.

20. Torgovnikov G., Vinden P. Microwave wood modification technology and its applications // Forest Products Journal. 2010, Vol. 60, No. 2, P. 173–182.

21. Torgovnikov G., Vinden P. New wood based materials “Torgvin” and “Vintorg” // Proceedings of 5th Pacific Rim Bio-based Composites Symposium, Canberra, Australia. 2000, P. 756–764.

22. Torgovnikov G., Vinden P. Microwave modification of wood properties: improvements in wood permeability // The International Research Group on Wood Preservation, Kona, Hawaii, IRG/WP 00-40181, 2000.

23. Vinden P., Torgovnikov G. The physical manipulation of wood properties using microwave // Proceedings, International Conference of IUFRO, The Future of Eucalypts for wood production, March 19–24, Tasmania, Australia, 2000, P. 240–247.

24. Yang L. Modification on the permeability of larch wood by microwave // Thesis of master degree, Northeast Forestry University, Harbin, China, 2004.

Поступила в редакцию 26.11.2020
Хвойные бореальной зоны. 2021. Т. XXXIX, № 2
Переводная версия принята к публикации 01.12.2023