

This paper reports the analysis of the biological destruction of timber and the use of protective materials, which established that the scarcity of data to explain and describe the process of bioprotection, neglect of environmentally friendly agents lead to the biodegradation of timber structures under the action of microorganisms. Devising reliable methods for studying the conditions of timber protection leads to designing new types of protective materials and application technologies. Therefore, it becomes necessary to determine the conditions for the formation of a barrier for bacteria permeability and to establish a mechanism for inhibiting material biodegradation. Given this, the dependence has been derived to determine the proportion of destroyed material under the effect of microorganisms when using an antiseptic-hydrophobicizer, which makes it possible to evaluate biopenetration. Based on the experimental data and theoretical dependences, the share of destroyed timber was determined under the effect of microorganisms, which is equal to 1 for natural timber. At the same time, this value for thermally modified timber is 0.033, and, when it is protected with oil – 0.009, respectively, exposed to the action of microorganisms for 60 days. It should be noted that the presence of oil, wax, and azure leads to blocking the timber surface from penetration. Such a mechanism underlying the effect of protective coating is likely the factor in the process adjustment, due to which the integrity of the object is preserved. Thus, a polymer shell was created on the surface of the sample, significantly reducing the penetration of microorganisms inside the timber, while the loss of timber mass during biodestruction did not exceed 2.5 %. Therefore, there are grounds to assert the possibility of targeted control over the processes of timber bio-penetration by using coatings capable of forming a protective film on the surface of the material

Keywords: protective agents, timber, penetration of microorganisms, weight loss, timber surface treatment

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DETERMINING PATTERNS IN REDUCING THE LEVEL OF BIO-DESTRUCTION OF THERMALLY MODIFIED TIMBER AFTER APPLYING PROTECTIVE COATINGS

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1. Introduction

In construction, the search for new highly effective means of protecting the timber from destruction is intensifying. This is important because timber utilization, especially outdoors, makes it vulnerable to environmental conditions that reduce its natural durability and eventually lead to

destruction. The main factors of timber destruction include biological destruction, which can act alone or in combination with other types of degradation, such as moisture.

The effect of high temperatures on timber over a certain time not only improves its dimensional stability and durability but also provides an attractive dark color. However, the achieved modification is not stable and needs protection.

Therefore, at present, the most effective method for improving the set of properties of thermally modified timber (increasing resistance to microorganisms and ultraviolet light, water resistance, and durability) is its protection with special antiseptic hydrophobicizers.

The main application area of thermally modified timber, in particular, are structures that operate under conditions of high humidity and biological exposure and ultraviolet light: the elements of buildings, pavilions, entertainment centers, as well as facilities hosting many people.

Existing protective coatings that are used to treat timber structures, in particular, drying oil, during operation under the action of ultraviolet light, moist air are washed out of the timber, which limits its service life. The use of environmentally friendly oil-based substances requires research into both changes in the surface structure of thermally modified timber during treatment and the impact on the resistance of products to operating conditions. Moreover, the mechanism of timber destruction due to biological action is insufficiently studied, which makes it impossible to obtain objective information about the nature of the processes that occur during operation. In addition, the lack of theoretical ideas about the kinetics of destruction in operating environments and the impact exerted on their stability by mixtures of antiseptic hydrophobicizers significantly limits the scope and prospects for the use of these materials.

Therefore, it is a relevant task to conduct a study aimed at determining the patterns in the inhibition of processes of timber biological penetration through mixtures of antiseptic hydrophobicizers.

2. Literature review and problem statement

In paper [1], it is noted that the most common defects of structural elements are biological damage to the support zones of the coating and the structures of the floor beams. The use of impregnation with polymer mixtures in the zones of destruction allows restoring the physical and mechanical timber properties and preserves the appearance of the architectural structure as a whole [1]. The cited paper reports the results of X-ray tomography of reconstructed samples of destroyed timber, as well as the technique of testing samples for crushing and cutting along the fibers. It was found that the increase in the strength of the reconstructed timber samples when crushed along the fibers was 77 % compared to the samples of destroyed timber, and 83 % when chipped. However, the viability of such a coating has not been determined.

Conventional methods of timber protective treatment have significant weaknesses regarding the use of toxic chemicals [2]. In the cited study, a method of protection against the biological deterioration of timber was tested using the technique of carbonization. The results also showed that the local microflora, as well as favorable conditions for their growth, have been eliminated, and further protection can be extended for the life of timber from fungal colonization. However, such compositions can be washed away during operation because they are water-based.

Environmental concerns about organic chemicals used to protect timber and timber products against biological degradation have led to the development of natural timber preservatives with lower health risks and long-term efficacy [3]. In the cited study, mixing chitosan and cinnamic aldehyde to form an emulsion as a natural timber preserva-

tive may enhance the ability to resist destructive fungi. The results showed that the emulsion of chitosan with cinnamic aldehyde seriously affected the normal growth of destructive fungi and changed the morphology of the fungus rot. The study shows that a chitosan emulsion with brown aldehyde can be effectively used as an environmentally friendly timber preservative but the questions related to the resistance of given coatings to atmospheric fluctuations when applied outdoors remained unanswered.

Wetland archeological timber is at high risk of biological degradation during storage and recovery after excavation [4]. For this reason, biocides are often used to preserve timber residues. In the cited work, three essential oils (cinnamon, wild and garden thyme) were tested as possible alternative biocides for use in the conservation of wetland archeological timber. The oils were first tested to establish the minimum inhibitory concentration and to assess biocidal activity in selected fungal strains. Then the established result was applied to samples of wetland archeological timber. The results showed that the oils significantly reduced the viability of the fungal mycelium grown in the timber and the microbiota contained in the treated timber and water for storage. However, nothing was said about the degradation of the coating during operation.

When used in construction, wood-based materials are mainly affected by moisture and subsequent biological attacks [5]. One of the natural substances potentially used as an agent against wood-destroying pests is caffeine. In the cited study, an aqueous solution of caffeine (20 g/dm³) was applied onto 7 selected tree species (pine, spruce, beech, English oak, red oak, walnut, and sapele). The treated timber was then exposed to fungi (*Serpula lacrymans* and *Coniophora puteana*) and air mold for 28 days. The results showed that all species were covered with mold and fungi except walnut. The absorption of caffeine solution decreased in beech, red oak, pine, sapele, English oak, and spruce. The resistance of wood to biological degradation increased in the following order: oak, walnut, sapele, English oak, spruce, pine, beech. However, to confirm the effectiveness, one needs data on the leaching of caffeine during operation.

Timber is prone to degradation during operation, mainly due to rot [6]. Because several traditional preservatives for timber were banned because of their detrimental effects on humans and the environment, extending the service life of timber products using the new-generation natural preservatives is imperative in terms of human health and environmental protection. Some natural compounds of plant and animal origin were tested for their fungicidal properties, including essential oils, tannins, timber extracts, alkaloids, propolis or chitosan; their enormous potential in timber protection was shown. Although they are not without limitations, potential methods of overcoming their weaknesses and increasing bioactivity already exist, such as co-impregnation with various polymers, crosslinkers, metal chelators or antioxidants. However, the existence of discrepancies between laboratory tests and field characteristics, as well as problems related to the lack of standards that determine the quality and effectiveness of natural protective mixtures, create an urgent need for further careful research and arrangements.

Paper [7] demonstrated an effective and environmentally friendly method that significantly improves the durability of a composite product from a timber composition based on wool by including a natural system of timber protection. In particular, allyl isothiocyanate, a natural biocide based on

mustard oil, was encapsulated in the β -cyclodextrin cavity. Before applying the polymer resin of methylene diphenyl diisocyanate and hot pressing, the complex of preservatives was mixed with the wool of the southern pine. The use of a preservative system has significantly improved the resistance to rot against brown rot fungi, keeping the average weight loss of treated panels below 7 %. However, it is not known how this change in the additive affected the bonding process.

Timber can be prone to biological degradation even in a dry condition [8]. In the cited work, samples of two types of wood, namely pine (*Pinus sylvestris*) and refractory spruce (*Picea abies*), were impregnated with three types of commercially-available emulsion gels on a biological base containing insecticides and fungicides. The effect of the method of treatment by immersion, surface spraying, and vacuum impregnation on the content of active substances was analyzed. Visual evaluation and qualitative and quantitative analysis of cypermethrin, permethrin, and propiconazole by gas-liquid chromatography in combination with mass spectroscopy showed increased penetration of active substances and revealed differences in the penetration of each agent. Appropriate combinations of solvents and surfactants used in biologically based mixtures allowed rapid penetration into the timber. However, the vital functions of biosecurity and the mechanism of isolation are uncertain.

Study [9] aimed to evaluate the effectiveness of saline solutions (sodium chloride, lithium chloride, sodium carbonate, magnesium sulfate, zinc sulfate, and copper sulfate II). They impregnated the wood of *Corymbia torelliana* and *Eucalyptus cloeziana* to determine the biological resistance to brown rot (*Postia placenta*) [9]. Test samples of wood with a size of 20×20×30 mm were taken from the boards obtained in the core part in the direction "base-top". The samples were impregnated with a 5 % concentration of solutions and exposed for 16 weeks to the fungus *P. placenta* under laboratory conditions. *E. cloeziana* wood was more resistant to rot than *C. Torelliana*. It was found that the treatment of wood with saline solutions was satisfactory in terms of resistance to destruction, and they can be used as a parameter to assess the biostability of wood, but the issue of their resistance to leaching remains unresolved.

Impregnation of dry timber with pure oligomers of lactic acid (OLA) followed by heat treatment renders timber promising properties due to good diffusion of OLA, polymerization, and stability in cell walls [10]. The treatment provides a sharp reduction in the equilibrium moisture content, high dimensional stability, and good strength. The treatment of dry timber with a solution of lactic acid reduces the level of polymerization but provides good properties. However, it is not known how this additive affected biostability.

In order to elucidate the relationship between photo- and biological degradation, wood samples treated with a translucent coating were degraded under a xenon lamp over different periods [11]. The samples were then inoculated with one of two black spotted fungi (*Aureobasidium pullulans* and *Epicoccum nigrum*). Colonization was monitored visually and by colorimetric analysis. The degree and nature of degradation were assessed using various procedures. The chemical composition was studied by Fourier infrared spectroscopy (FTIR), and the physical changes by both microscopic analysis and adhesion tests. It was found that the coating thickness and adhesion decrease with increasing photodegradation. Observations under a microscope revealed numerous bubbles trapped in the coating films. It was found that these

bubbles become holes after photodegradation and reduction of the coating thickness. It was found that stronger photodegradation led to wider colonization of samples. The fungi used a transgressor to pass through the protective layer and take advantage of the organic matter present at the wood interface. It has also been found that fungal colonization reduces the adhesion of the coating in the early stages of exposure.

During timber operation, its constituent biopolymers are subjected to intensive and progressive processes of oxidative degradation under the effect of the environment [12]. And this affects the natural strength of wood and causes significant structural and color changes, as well as a gradual decrease in its resistance to biological agents. One of the effective ways to prevent wood degradation is to apply protective coating layers by chemically modifying the surface. Recent trends in this area include the use of biologically based natural products – extractives, oils, waxes, resins, biopolymers, biological control agents, for which the main classification criterion is represented by the type of protection. But there are unresolved issues related to the resistance of these coatings to atmospheric fluctuations when used outdoors.

Thus, it has been determined that during timber operation, there is a gradual degradation of components, which requires effective protection with environmentally friendly substances. Besides, no parameters have been identified that provide resistance to loss of protective properties. The limited number of mathematical models to explain and describe the process of timber bioprotection, as well as the neglect of the use of organic substances for the formation of elastic coatings, leads to inefficient utilization of protective means. Therefore, the unsolved part of the problem of biosafety of timber products is the establishment of resistance parameters of the material to biodegradation and the impact of coatings on this process, which necessitated research in this area.

3. The aim and objectives of the study

The study aims to identify destruction patterns under the effect of microbiological factors on the protective coating of a timber article used in construction. This would make it possible to justify the application of protective coatings at facilities where thermally modified timber is used.

To achieve this goal, the following tasks were set:

- to model the destruction process under the action of microorganisms on the
- protective coating of timber and determine the proportion of destroyed material;
- to establish the level of timber weight loss reduction under the effect of mycobacteria during thermal modification and protection with a coating made from antiseptic hydrophobicizer.

4. The study materials and methods

4.1. Examined materials and equipment used in the experiment

The study was performed using samples of untreated pine timber, 20×20×20 mm (Fig. 1).

The thermal timber modification was performed at temperatures of 190 °C and

220 °C for 10 hours. Both the activation energy [13] and the end of phase transitions were taken into consider-

ation [14]. The samples were then treated with oil-wax and azure by immersion method with re-treatment after drying of the first layer in 24 hours [15].



Fig. 1. Timber model sample: I – unmodified; thermally modified: II – at a temperature of 190 °C during 10 hours; III – at a temperature of 220 °C during 10 hours

To determine the degree of timber biological destruction, the samples of untreated timber, thermally modified timber, and timber protected by coatings were used.

4. 2. Procedure for determining the sample's parameters

We determined the biological destruction of timber according to a working procedure, which includes the planning of the experiment and processing of research results. The essence was to experimentally determine the loss of timber mass under the effect of soil microflora (soil destroyers) under certain air-humidity conditions and during the pre-defined time. Wood is considered biostable if the average weight loss of the samples is not more than 5 %.

The tests were performed as follows. Timber samples were placed on the ground in the box marked upwards (sample numbers) so that the distance from the walls of the box and the partition to the samples was (40 ± 2) mm, and the distance between the samples (30 ± 2) mm. The timber test period for biodegradation was 60 days. Every 15 days, the box was removed from the plastic wrap, opened, the surface was inspected, and the box was weighed. When reducing the weight of the box, the soil between the samples was moistened to restore the initial weight of the box. After that, the box was closed, wrapped in plastic, and installed in the chamber. After completion of the tests, the samples were carefully cleaned from the soil with a soft brush, dried, and weighed.

Studies on modeling the process of permeability of microorganisms to wood through a protective coating were performed using the basic principles of mathematical physics [16].

5. Results of studying the destruction process of timber exposed to destroying fungi

5. 1. Modeling the process of formation of the proportion of destroyed timber under the microbiological effect of destructive fungi

We assume that the proportion of the timber volume involved in the biochemical metabolic process depends on the size of the population of the microorganisms and can be determined from the following system of differential equations:

$$\left. \begin{aligned} \frac{dN}{dt} &= (\alpha - \beta \cdot R) \cdot N, \\ \frac{dR}{dt} &= \gamma \cdot N, \\ \frac{dX}{dt} &= k \cdot (a - X) \cdot N, \end{aligned} \right\} \quad (1)$$

where N is the number (size) of the active (living) microorganisms' population in the volume of the material V (m^3);

X is the part of the volume involved in the biochemical metabolic process;

R is the function of bioprotective substances, the value of which is equal to the proportion of microorganisms that have ceased to function as a result of adverse conditions: the accumulation of decomposition products of enzymatic activity; excretion of toxic substances during metabolic processes; increase of insulating ability;

α is the boundary maximum specific growth rate of microorganisms;

β is the specific rate of decrease in the number of microorganisms;

γ is the coefficient of a decrease in population;

k is the coefficient of microorganism penetration into the material;

a is the total share of organic matter.

It is known that the function of the number of active microorganisms in the organic mass at the initial time is $N(0)=N_0$, and according to experiments, this function necessarily has a point of global maximum (maximum of the possible number of microorganisms) $t=t_m$, where $N(t_m)=N_m$ [17]. In addition, the values α , β , γ are the integration constants, k , N_m , and t_m must be determined experimentally, which is a difficult task. However, in physical terms, some of them do not depend on boundary conditions.

For example, in the third equation of system (1), it is consciously necessary to take $a=1$ because the X value cannot exceed 1 or take negative values. The solution to the problem of population size dynamics of microorganisms is given below.

As a result of solving system (1), considering that the proportion of destroyed material cannot exceed 1 or take negative values, and after substituting the right-hand side instead of N and integration, we obtain the following equation:

$$X = 1 - e^{-2kN_m \frac{t_m}{\Delta} \left[\text{th} \frac{\Delta}{2} - \text{th} \left[\left(1 - \frac{t}{t_m} \right) \frac{\Delta}{2} \right] \right]} \quad (2)$$

The process of biological destruction of timber is characterized by an incubation period – the duration of time after which intensive destruction begins. Studies suggest that the duration of this period coincides with the time t_m , during which the population of microorganisms reaches a critical size.

Analytical studies of the process of timber biodegradation were performed using pine wood. Our analysis of the results of experiments on the biological destruction of timber showed that the biofouling of untreated samples took place at a rate of about $0.00004 \text{ m}^2/\text{day}$. The maximum weight loss in the case of biodegradation was 15.6 %, the depth of bacteria penetration – 0.5 mm at a rate of $0.0002 \text{ m}/\text{day}$ ($N_m=6 \%$, $k=0.5$). For the samples of thermally modified timber, biofouling took place at a rate of about $2 \cdot 10^{-5} \text{ m}^2/\text{day}$, penetration depth – to 0.1 mm at a rate of $0.000022 \text{ m}/\text{day}$ ($N_m=2 \%$, $k=0.2$). The weight loss of timber samples was 3.6 %. For the samples of thermally modified timber treated with antiseptic hydrophobicizer,

biofouling took place at a rate of about $4 \cdot 10^{-7} \text{ m}^2/\text{day}$. The penetration depth was up to 0.05 mm at a rate of 0.000001 m/day ($N_m=1\%$, $k=0.01$), and the weight loss of timber samples was less than 1.4%. For a given series of samples (untreated), the rate of biodegradation is 1.1 kg/($\text{m}^3 \cdot \text{day}$), for thermally modified timber – 0.55 kg/($\text{m}^3 \cdot \text{day}$), and for thermally modified timber treated with antiseptic hydrophobicizer was 0.1 kg/($\text{m}^3 \cdot \text{day}$), respectively.

Figure 2 shows the results of processing the duration of the period of biodegradation. Data were processed using the Microsoft Excel (USA) static function

$$t_m = a \cdot \psi^b, \tag{3}$$

where a and b are the empirical constants, day and $\text{m}^3, \text{day}/\text{kg}$.

Since in accordance with the condition $t=t_m$ for the destruction parameters t_m and $x=\Delta/2$, we obtain:

$$thx = \frac{\chi}{t} \cdot x, \tag{4}$$

where χ is a parameter that characterizes the time during which a unit of mass is lost per unit volume of timber under the action of microorganisms.

Based on equation (4), we determine the second parameter of the bio-destructive process x [18].

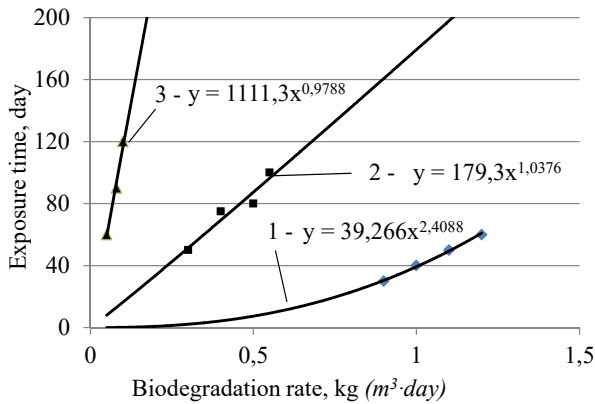


Fig. 2. Dependence of timber bio-destruction rate on incubation period: 1 – untreated timber, 2 – thermally modified timber, 3 – thermally modified timber treated with antiseptic hydrophobicizer

To begin with, calculate the biodegradable characteristic of the material χ . Pinewood was used for clarity. According to Fig. 3, the intensive biodegradation of untreated timber begins on day 30, and the specific density of the sample decreases to 510 kg/ m^3 at a biodegradation rate of 1.1 kg/($\text{m}^3 \cdot \text{day}$). Accordingly, the value of the parameter χ ($\chi=\Delta\rho/\psi$) is 36.7 days. The plot in Fig. 3 shows that the approximation for untreated timber gives the value $a=0.1822$; $b=0.4543$, then, from, equation (3), the value of the parameter t_m is 48.6 days.

Let us calculate parameter A :

$$A = \frac{\chi}{t_m}, \tag{5}$$

and solve equation (4) graphically; we obtain the value $x=\Delta/2=0.9$ for unmodified timber, for thermally modified timber – 6, and for thermally modified timber treated with antiseptic hydrophobicizer – 8, respectively (Fig. 3).

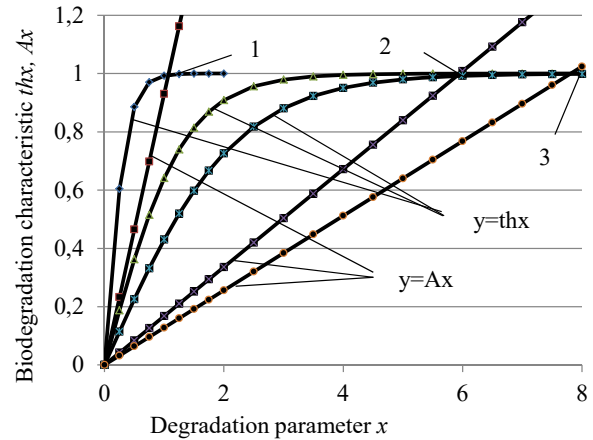


Fig. 3. Determining biodegradation parameters: 1 – untreated timber, 2 – thermally modified timber, 3 – thermally modified timber treated by antiseptic hydrophobicizer

For thermally modified timber, intensive biodegradation begins on day 40; the specific density of the sample decreases to 530 kg/ m^3 ; the parameter χ ($\chi=\Delta\rho/\psi$) value is 36.3 days; the approximation for treated timber $a=159.33$; $b=0.8855$, t_m is 93.8 days. The value $x=\Delta/2=6.0$. For the thermally modified timber treated with an antiseptic hydrophobicizer, intensive biodegradation begins on day 60; the specific density of the sample decreases to 540 kg/ m^3 . The parameter χ ($\chi=\Delta\rho/\psi$) value is 100.1 days; the approximation for the treated timber $a=1111.3$; $b=0.9788$, t_m is 116.7 days. The value $x=\Delta/2=8.0$.

According to equation (2), using the results of experimental studies above, in particular, the incubation period t_m , the exchange process parameter Δ , the penetration coefficient k , and the number of microorganisms N_m , the proportion of destroyed material was calculated (Fig. 4).

Fig. 4 shows that the presence of the antiseptic hydrophobicizer on the surface effectively protects the thermally modified timber from the action of microorganisms.

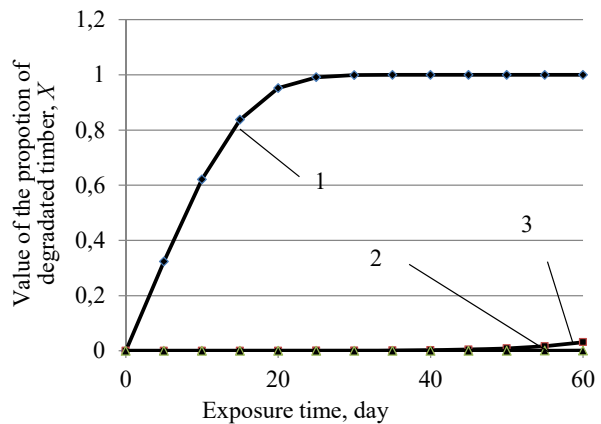


Fig. 4. Value of the proportion of destroyed timber (X) under the effect of microorganisms: 1 – untreated timber, 2 – thermally modified timber, 3 – thermally modified timber treated with antiseptic hydrophobicizer

Thus, as a result of our research, the mathematical model has been built of the timber biodegradation process involving microorganisms; the proportion of the destroyed material has

been determined; the dynamics of biodegradation have been modeled, considering the thermal modification of timber and the effect of bioprotective substances.

5. 2. Determining timber bio-resistance experimentally

It is also necessary to consider that when thermally-treated timber is applied, its destruction under the effect of bacteria is possible. Taking into consideration the research reported in [13], it is proposed to use oil-wax and azure to protect materials against biological destruction.

Our studies to determine the biostability of thermally modified timber were performed according to a working procedure. Namely, by determining the biological resistance to the action of the microflora in the forest soil affected by timber-destroying fungi *Hericium erinaccus*, aged for two calendar months in the laboratory at National University of Life and Environmental Sciences of Ukraine (Fig. 5).



a



b

Fig. 5. Determining timber resistance to bio-destruction: *a* – *Hericiu merinaccus* fungi; *b* – studied timber samples under laboratory conditions

Table 1 gives the results regarding the weight loss by a sample after exposure to micro-bacteria for 60 days, as well as the proportion of destroyed timber.

During the test, the development of fungal lesions on the surface of the sample was monitored. After 6 days, a white fluffy mycelium of the fungus was found in all boxes on the soil surface, which later spread to the surface of the timber (Fig. 6).



a

b

Fig. 6. The general view of pine timber samples on the sixth day of exposure in a box with soil: *a* – untreated; *b* – the surface that was treated with oil-wax

Table 1

Results of studying the effect of oil-wax and azure on timber resistance to bio-degradation

Test object	Sample weight, g		Timber weight loss, %	Timber degraded proportion
	before test	after test		
Pine, untreated	4.9	4.1	16.33	0.195122
Pine, untreated + wax	4.33	4.12	4.85	0.053528
Pine, untreated + azure	4.7	4.5	4.25	0.044444
Pine, thermally modified at 190 °C	4.86	4.7	3.29	0.034043
Pine, thermally modified at 190 °C + wax	5.65	5.51	2.48	0.025408
Pine, thermally modified at 190 °C + azure	4.46	4.36	2.24	0.022936
Pine, thermally modified at 220 °C	4.49	4.36	2.89	0.029817
Pine, thermally modified at 220 °C + wax	5.45	5.35	1.83	0.018692
Pine, thermally modified at 220 °C+ azure	3.87	3.8	1.81	0.018421

Analysis of experimental studies (Table 1) shows that the maximum weight loss in the case of biodegradation of untreated timber samples was up to 16 %, and is to be considered biodegradable. The weight loss by the thermally modified timber samples did not exceed 3 %; treated with oil-wax and azure, less than 2.5 %.

Fig. 7 shows the regression dependences of timber weight loss.

It was found that oil-wax and azure in the treatment of thermally modified timber reduce (compared to untreated) weight loss by more than by 4 times in terms of biodegradation, and additional treatment with antiseptic hydrophobizer – by more than 8 times.

6. Discussion of results of studying the process of timber biodestruction

When studying the process of reducing the level of biodegradation in thermally modified timber while applying a protective coating, it is natural, as follows from the results in Table 1, Fig. 2, 4, to extend the time of penetration of microorganisms through the protective coating. This is due to the formation of a protective shell at the surface of timber during the polymerization of antiseptic hydrophobicizer, which slows down the penetration of microorganisms into the timber and its destruction.

It should be noted that the presence of oil-wax and azure leads to the formation of an elastic film at the surface of the timber, resistant to the penetration of microorganisms. Such a mechanism of action of the elastic film is likely the factor that regulates the process, due to which the biostability of timber is preserved. In this sense, there is an interpretation of the results from determining the biodegradation of timber after exposure to microorganisms, namely the loss of mass of samples under the biological influence. The weight loss of the coated and thermally modified timber did not exceed 2.5 %; and, for the sample of ordinary wood, was about 16 %. This indicates the formation of a barrier to the penetration of microorganisms, which can be identified by the method of biological influence on the studied samples.

This means that considering this fact opens the possibility for effective regulation of the properties of thermally modified timber directly under the conditions of industrial production.

The comparison of the experimental study on the biodegradation of timber during the application of a protective coating and the theoretical study to determine the proportion of destroyed material reveals the inhibition of the penetration of microorganisms. The weight loss of the protected thermally modified timber did not exceed 2.5 %.

This does not differ from the practical data reported in works [6, 7], the authors of which, by the way, also link the effectiveness of biosafety with the formation of a protective shell on the timber surface. But, in contrast to the results reported in [8, 9], our data on the effect of antiseptics on the process of inhibiting the penetration of micro-bacteria suggest the following:

- the main regulator of the process is not so much the formation of a significant number of antiseptics that inhibit microorganisms, as some protective coatings are destroyed under the influence of atmospheric action;
- a significant impact on the process of timber protection when using a protective coating is exerted in terms of the formation of an antiseptic hydrophobicizer shell from an elastic film on the surface of the material resistant to destruction under the action of temperature-humidity fields.

Such conclusions can be considered appropriate from a practical point of view because they allow for a reasonable approach to determining the required amount of protective agents. From a theoretical point of view, this allows us to argue about determining the mechanism of processes of inhibition of permeability of microorganisms, which is a certain advantage of this study.

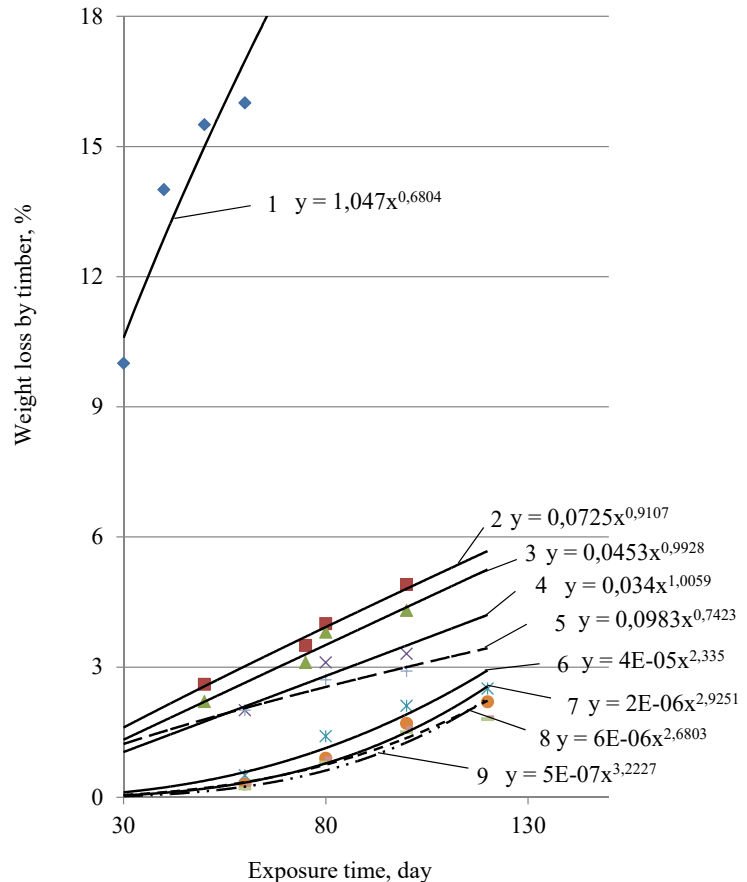


Fig. 7. Regression dependences of weight loss by pine timber: untreated timber: 1 – untreated; 2 – treated with oil-wax; 3 – treated with azure at 190 °C; 4 – thermally modified timber; 6 – treated with oil-wax; 7 – treated with azure; timber at 220 °C: 5 – thermally modified timber; 8 – treated with oil-wax; 9 – treated with azure

However, it is impossible not to note that the results of determination (Fig. 4) indicate an ambiguous effect of the antiseptic on the change in protective effectiveness. This is manifested primarily in the loss of mass by a sample when testing protected timber. Such uncertainty imposes certain restrictions on the use of the obtained results, which can be interpreted as shortcomings of this study. The inability to remove these limitations in the current study creates a potentially interesting direction for further research. In particular, it can be focused on detecting the point in time from which the reduction of protective properties to the destruction of timber under the influence of microorganisms begins. This detection could allow us to investigate the structural transformations of the elastic film that begin to occur at this time and to identify the input process variables that significantly affect the onset of such a transformation.

7. Conclusions

1. We have modeled the process of biological destruction of timber protected by thermal modification and protective coating based on antiseptic hydrophobicizer, and determined the parameters of biodegradation, as well as dependences that make it possible to change the proportion of destroyed material. According to the analytical data and established dependences, the share of destroyed timber was calculated, which was 1 for natural wood, 0.033 for thermally modified timber, and 0.009

when protected with oil, respectively, under the action of microorganisms over 60 days.

2. Features of inhibition of the process of penetration of microorganisms into the material treated with a composition based on oil-wax and azure are the formation of a protective layer on the timber surface. Thus, a polymeric shell formed at the surface of the sample, which significantly reduced the penetration of microorganisms into the timber, and the weight loss of timber during bio-destruction did not exceed 2.5 %.

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