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PERFORMANCE CHARACTERISTICS OF COATINGS CREATED WITH ALKYD AND OIL-BASED MATERIALS IN WOODEN HOUSE CONSTRUCTION

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Abstract: *The paper deals with the issues and study of the properties of varnish-and-paint materials which are used to create protective-and-decorative coatings for joinery and building structures. The article provides an examination of comparative studies on the qualitative characteristics of alkyd varnish (PF-283) and drying linseed. Changes in the drying time of linseed oil and alkyd (pentaphthalic) varnish are determined depending on the material consumption and drying temperature. The studies have shown that the drying rate of films at the same material consumption at temperatures of 50 and 80°C is practically the same and ranges from 80 to 114 minutes. The article also presents the results of studies on the performance properties of finishing materials (coating thickness, water and heat resistance). It was found that alkyd varnish-and-paint materials form a coating of greater film thickness and hardness. In terms of water-resistance and heat-resistance, coatings based on drying oils have higher performance indicators. Recommendations are given for the use of alkyd and oil-based varnish-and-paint materials for finishing joinery and building structures made of oak wood which are used in wooden house construction.*

Key words: *European oak, linseed oil, alkyd varnish, varnish consumption, coating thickness, hardness.*

1. Introduction

Wood is a material created by Nature itself for humans to use in their life. Wood accompanies a human from the cradle throughout their life path. In recent decades, the world has seen a rapid increase in demand for wooden houses. A wooden house "breathes", accumulates, and retains warmth well, as well as coolness in the hot weather. The thermal insulation of a wooden wall is several times higher than that of a brick or concrete wall of the same thickness. Wooden walls constantly maintain optimal humidity conditions, natural ventilation, and air exchange. Therefore, it is easy and pleasant to breathe in the atmosphere of

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a wooden house, and the resinous materials and other essential oils contained in the composition of wood have a positive effect on the human body and saturate the air with pleasant aromas. The relative humidity of the air inside a wooden house varies between 45-57% and does not depend on changes in external factors. If a house is professionally designed and built, then the indoor relative humidity is constantly within the optimal range [18, 22, 25, 31]. Studies have shown that during the spring heating season, energy consumption in a wooden house is 46% lower compared to a panel house. Houses made of wooden structural materials are environmentally friendly, save energy, and meet the high quality indicators of comfortable housing.

Wood is a natural material that has a beautiful color and texture, and sufficient density. However, the composition of wood, and especially its capillary-porous structure, has a significant interaction with liquids [4, 5]. The capillary-porous structure of wood significantly affects its ability to absorb moisture, which leads to its destruction. It is known that the composition of wood includes about 50% cellulose which is subject to destruction under the influence of atmospheric conditions.

In order to ensure the protection of wood and increase the service life of woodwork, wood must be treated to create a protective-and-decorative coating on the surface. To create protective-and-decorative coatings on the surface of wood products, various varnish-and-paint materials (VPM) are used [29].

Over the past decades, requirements for environmental protection and control over gas emissions from industrial enterprises have become more strict, which has necessitated a change in the range of varnish-and-paint products in order to expand the production of economical and less environmentally harmful paints and varnishes [1, 19, 26]. These include, in particular, oil-based or oil-modified film-forming systems. Manufacturers are faced with the difficult task of choosing quality products from a variety of offered materials presented by various trading companies – manufacturers of paints and varnishes. Today, every manufacturer of wood products knows that the future belongs to environmentally friendly paints and varnishes in the creation of protective-and-decorative films. However, which of them will satisfy the consumers' requirements is an important task for manufacturers. This task is particularly acute for those manufacturers who make products that are operated in open atmospheric conditions (wooden houses, joinery, etc.). Based on the above, the purpose of this work is to analyze the operational characteristics of finishing materials as well as protective-and-decorative coatings created with oil-based and alkyd materials during the operation of joinery and wooden house structures.

Oil has been known for a long time as a film-former for creating a protective-and-decorative coating on a wooden substrate [6]. Our ancestors used vegetable drying oils together with natural resins to protect wood products from various pests, fungi, moisture, sunlight, etc. As time passed, synthetic substitutes for these finishing materials began to appear which had better physico-chemical and protective-decorative properties [23].

Synthetic film-formers are distinguished by good adhesion and the ability to wet various substrates, they have durability, strength, elasticity, resistance to abrasion and various environmental influences, as well as high decorative properties, but they all belong to materials that pollute the environment [38].

Unlike synthetic varnish-and-paint materials, oil-based materials are environmentally friendly, but they dry slowly, they form thin-layer coatings because they penetrate deeply into the wood pores, and they form films of low hardness and reduced wear resistance. Such characteristics reduce their popularity as a varnish-and-paint material for finishing wood [2, 35, 38].

However, oil-based coating feels soft and, warm to be touch, and mimics the feeling of wood, unlike synthetic polymer films. In addition, oil-based coatings stabilize wood against shrinkage and swelling caused by water vapor exchange. In fact, oil modifies wood by filling its pores while creating a coating [2, 35, 37].

It is a well-known fact that coatings based on linseed oil have long been used in finishing joinery and wooden buildings, as moisture vapours easily penetrate through them. These films make it possible for moisture to pass through the film which, as a result, does not swell, and accordingly, the protective-and-decorative coating is not destroyed. Modern alkyd VPMs, which are often used for finishing joinery, are not resistant to water vapour exchange, which causes the rapid destruction of coatings based on them. Therefore, it is recommended to use water-soluble, latex or oil-based materials that are considered breathable for finishing surfaces that are used outdoors [18, 27, 37].

It is known that not all VPMs can provide adhesive strength when humidity changes, therefore they are not used for finishing products which are operated in an open atmospheric environment. As for oil-based materials, they are increasingly used every year to create coatings that are used outdoors [36].

Varnish-and-paint materials based on natural oils are environmentally friendly materials. They can, without reserve, be used not only in wooden housing construction, but also for finishing wooden toys, kitchen and household products made of wood, as well as natural-wood flooring [17, 22].

The use of linseed oil is appropriate for wood coatings and Ukraine has a sufficient capacity of raw material for linseed oil production.

Oak wood is most often used in house building, in manufacturing structural parts, millwork, interior design, and furniture making. The strength, high durability, and decorative properties of oak wood ensure its wide use in woodworking, furniture and other industries, therefore, this article investigated coatings created on substrates made of oak wood.

2. Materials and Methods

To conduct the experimental studies, methodological support for the work was developed before performing the experiments, consisting in the preparation of materials, devices, and measuring equipment, as well as methods for conducting experimental tests.

The following materials were used for the studies:

- oak specimens, size 30×40×8 mm (European oak - *Quercus robur* L.), with a moisture content of 12% and an average density of 690 kg/m^3;

- alkyd (pentaphthalic) varnish PF-283 (TU 6-10-612-76. Semi-finished alkyd varnishes [33]) intended to create protective- and-decorative coatings on wood products (wooden houses, windows, doors, flooring, also suitable for covering metals). Mass fraction of non-volatile substances (DSTU ISO 3251:2015 Paints, varnishes, and plastics – Determination of non-volatile-matter content (ISO 3251:2008, IDT – [13]) – 50-51%; density (DSTU ISO 2811-1:2019 Paints and varnishes – Determination of density – Part 1: Pycnometer method (ISO 2811-1:2016, IDT – [11])) – 0.91 g/cm^3; lustre (DSTU ISO 2813:2015 Paints and varnishes – Determination of gloss value at 20, 60 and 85° (ISO 2813:2014, IDT – [12])) – 120-130 GU; drying time (23°C) – 24 hours;
- linseed oil (DSTU ISO 150-2002 Raw, refined and boiled linseed oil for paints and varnishes [7]. Specifications and methods of test (ISO 150:1980, IDT – [7])) is used for finishing and preserving wood; density 0.930-0.938 (at 15°), solidification temperature from -8 to -27°C, iodine number – 165-192, acid number – 0.55-3.5. It belongs to drying oils, is used mainly for the production of waterproof varnish;
- solvent – white spirit (TU U 20.3-37168244-002:2014 Organic solvents [34]);
- abrasive paper No.280, No. 320 (DK 021:2015:14810000-2 Abrasive products – [21]).

Five samples were used for research in each experiment.

The experimental studies were performed in the following main lines:

a. determining film polymerization time;
b. dependence of the penetration of the varnish-and-paint materials into the wood and the thickness of the film on the drying time and consumption of the composition;
c. determining the main performance characteristics of the protective-and-decorative coatings.

The experimental studies were conducted in accordance with the methodology described in the State standards, using instruments and measuring equipment. The following instruments were used for measurement: the 2124 TML pendulum hardness tester, the MIS-11 tool-room (instrumental) microscope, the SNOL 24/200 laboratory drying cabinet, a mercury thermometer, the JD-110-4 laboratory-analytical scales, as well as laboratory glassware, brushes, and glass plates. The following methodologies were used to conduct the studies in accordance with the goal set in the work: DSTU ISO 9117-1:2015 Paints and varnishes – Drying tests – Part 1: Determination of through-dry state and through-dry time (ISO 9117-1:2009, IDT – [14]); DSTU ISO 2808: 2019 Paints and varnishes. Determination of film thickness (ISO 2808:2019, IDT – [9]); DSTU ISO 1522:2015 Paints and varnishes – Pendulum damping test (ISO 1522:2006, IDT – [8]); DSTU ISO 2810:2015 Paints and varnishes – Natural weathering of coatings – Exposure and assessment (ISO 2810:2004, IDT – 10]).

To realize the above goal, two types of finishing materials (alkyd (pentaphthalic) varnish PF-283 and, linseed oil with consumption of 80, 100, 120 g/m^2) were applied with the help of an applicator to create a uniform coating layer to previously prepared samples of European oak wood (*Quercus robur* L.) measuring 30×40×8 mm.

To control the drying of the coatings, the samples with applied finishing materials were placed in a SNOL 24/200 drying laboratory cabinet at temperatures of 50 and 80°C. Also, some of the samples were dried at a temperature of 20°C. The duration of drying was determined by the stabilization of the coating.

The thickness of the films was determined on the coatings obtained after drying using a MIS-11 tool-room microscope.

To determine the hardness of the coatings, the finishing materials under study were applied to glass plates with the above-mentioned material consumption, and dried according to the above parameters. The hardness was determined with a 2124 TML pendulum hardness tester.

The study of the influence of atmospheric conditions on the protective-and- decorative coatings was carried out in accordance with the standards of exposure to temperature and humidity.

To determine water resistance, metal foil specimens were coated with oil and alkyd varnish PF-283 with the specified consumption. After drying, the specimens were immersed in a container with water for 1/3 of the total length and kept for 8 hours, with visual observation every 2 hours.

When determining the heat resistance of the protective-and-decorative coatings created with linseed oil and alkyd varnish PF-283, the studies were conducted on oak wood specimens. The varnish-and-paint materials were applied and dried according to the operating parameters. On the coating, after drying and conditioning, which lasted 24 hours, a container with water was installed through filter paper, in which a temperature of 90±5°C was constantly maintained. After drying and conditioning, which lasted for 24 hours, a container with water was placed on the coating through filter paper, in which a temperature of 90±5°C was constantly maintained. The action of the temperature on the coating lasted for 20 minutes. After that, a visual inspection of the surface and an assessment of the coating were performed.

During the experimental studies, the temperature in the laboratory was 20±2°C and, the relative humidity was 65-70%. The conditioning time of the samples was 48 hours.

3. Results and Discussion

The determination of the polymerization time of alkyd varnish PF-283 and linseed oil was carried out according to the methodology on oak wood specimens with a change in the consumption of the finishing materials and the drying temperature of the coatings. The drying time of linseed oil at a consumption of 80 g/m^2 at a temperature of 20°C was from 1,426 to 1,481 min, at a temperature of 50°C – from 79 to 82 min, and at a temperature of 80°C – from 86 to 89 min. The drying time of alkyd varnish at a consumption of 80 g/m^2 at a temperature of 20°C was from 1,379 to 1,425 min, at a temperature of 50 °C – from 68 to 72 min, and at a temperature of 80°C – from 63 to 67 min. Statistical processing of the results of the experimental studies yielded average values of the drying time of the coatings at different material consumptions and temperature regimes. The obtained data of the experimental studies are presented in Figures 1 and 2.

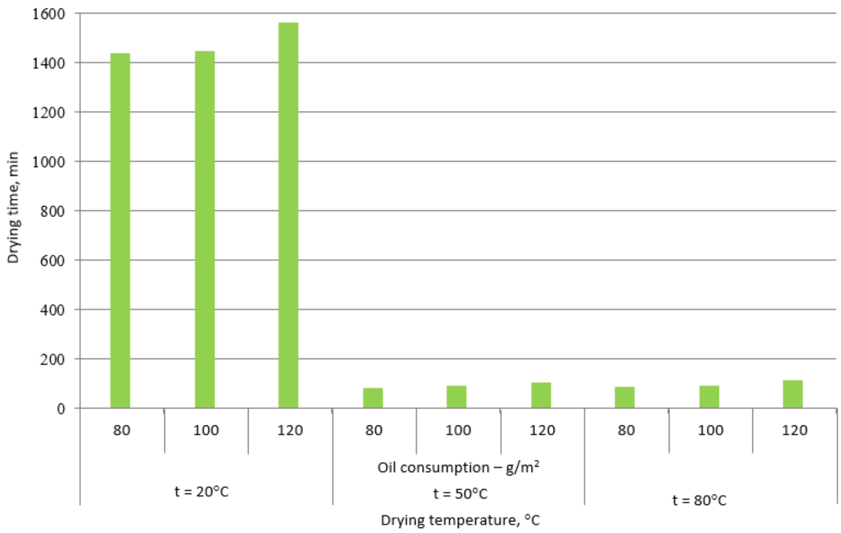

Fig.1. *Drying time of linseed oil depending on temperature and material consumption*

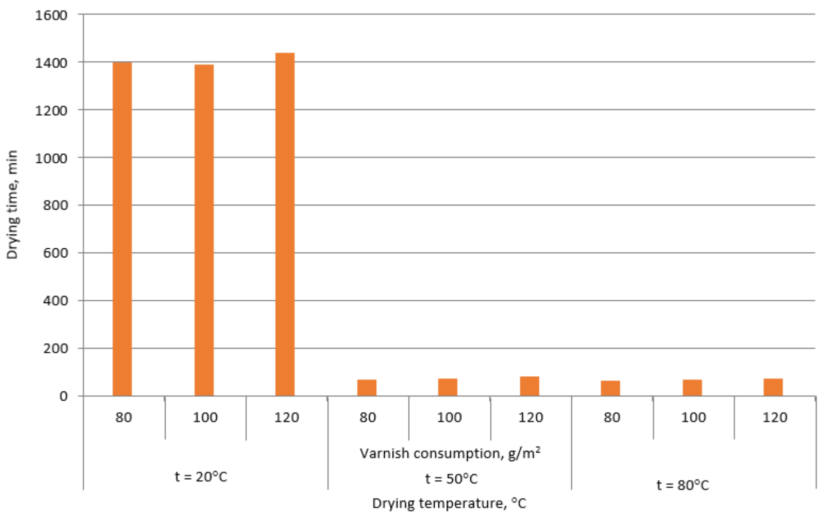

Fig. 2. *Drying time of alkyd varnish depending on temperature and consumption of material*

The results of the study show that oil-based coatings do not significantly differ in terms of drying time from film formation based on alkyd varnish, but the oil-based coating takes longer to dry. This is due to the fact that alkyd varnish includes modifiers based on drying oils. However, alkyd varnishes are based on products made from polyatomic alcohols and polybasic acids (polyester resins) which dry faster than oil materials and form a coating of greater thickness [3, 15, 20, 28, 32].

As the temperature rises, the hardening time of the coatings decreases. However, as the studies have shown, the drying rate of the films at temperatures of 50 and 80°C is almost the same, and even at a temperature of 50°C it is slightly lower. This confirms the fact that both oil-based and alkyd VPMs pass into a hard state due to the polymerization reaction, and not due to the volatilization of solvents. In order to reduce energy costs when finishing wood with oil-based and alkyd materials, it is advisable to use a temperature regime within 50°C.

According to the task of this work, it is advisable to check how the thickness of varnish-and-paint coatings created by alkyd and oil-based compositions on an oak wood substrate changes. It is known that the thickness of the protective-and-decorative film is responsible for the performance characteristics of coatings and the product as a whole. Therefore, it is very important for wooden products, especially building structures that operate in an open atmospheric environment, to ensure the required thickness of the protective film [18, 36].

After conducting the experimental studies to determine the thickness of the protective-and-decorative coating formed with alkyd varnish and linseed oil on oak wood, the following results were obtained. The thickness of the linseed oil coating at a consumption of 80 g/m^2 at a temperature of 20°C was from 43 to 45 µm, at a temperature of 50°C – from 38 to 41 µm, and at a temperature of 80°C – from 38 to 41 µm. The coating thickness of alkyd varnish at a consumption of 80 g/m^2 at a temperature of 20°C was from 52 to 56 µm, at a temperature of 50°C – from 51 to 54 µm, and at a temperature of 80°C – from 51 to 56 µm. When statistically processing the results of the experimental studies, average values of the thickness of the coating films were obtained for different material consumption and temperature regimes. The results of the experimental studies are shown in Figure 3.

The results show that the thickness of the coating practically does not change with temperature, but this pattern is observed during the film formation of alkyd varnish PF-283. However, during forced drying of linseed oil, the effect of temperature on film thickness is more significant. It is known that oils penetrate deeply into wood pores because the oil molecule is approximately 10-50 times smaller than wood pores. When heated, the viscosity of the oil decreases, and, accordingly, its penetration into the wood increases and the surface thickness of the film decreases. The dependence of the film thickness on temperature is insignificant; more significant is the change in the coating thickness depending on the consumption of VPM and on the film-former on which this product is based [16, 32].

As can be seen, alkyd varnishes form a thicker film compared to oils, which confirms previous conclusions that alkyd varnish has a modified polyester resin in its composition which does not penetrate as deeply into the wood pores as oil materials [25, 27].

Deep penetration of oil compositions into the wood pores cannot be considered a negative characteristic of the finishing material, because it is known that oil compositions are able to preserve wood and better protect it from negative atmospheric effects (humidity, temperature changes, exposure to ultraviolet radiation).

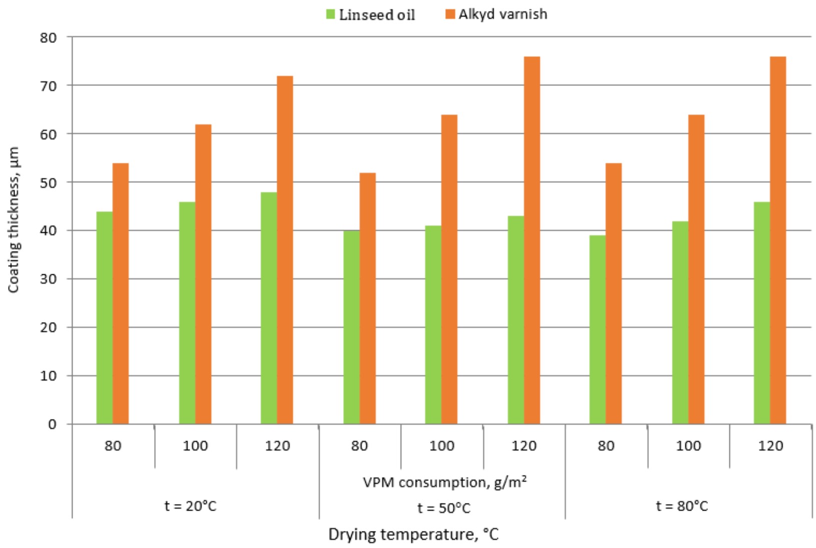

Fig. 3. *The thickness of the protective-and-decorative film formed with linseed oil and alkyd varnish on oak wood*

Another important indicator of the film formation process is the hardness of the coating. To determine the hardness of protective-and-decorative films, specimens were created with formed coatings on a glass substrate, with different consumptions of oil and alkyd varnish [25, 28, 29].

The hardness was determined using the M-3 pendulum hardness tester in accordance with the standard 1522:2015 Paints and varnishes – Pendulum damping test (ISO 1522:2006, IDT – [8]).

The data on the measurement of conventional hardness after drying of films at different temperatures and technological conditioning of the coatings are listed in Table 1. Comparative hardness indicators of oil and alkyd varnish are presented in Figure 4.

The results of determining conditional hardness by the M-3 device Table 1

Type of VPM	VPM consumption [g/m^2]	Average value of the pendulum damping time, according to M-3	Glass number, according to M-3 [s]	Minimum hardness value [c.u]	Maximum hardness value [c.u]	Conditional hardness [c.u.]
Linseed oil	80	86	441±5	0.1914	0.2020	0.1950
	100	74		0.1603	0.1700	0.1678
	120	67		0.1443	0.1557	0.1519
Varnish PF-283	80	104		0.2264	0.2431	0.2358
	100	102		0.2197	0.2373	0.2313
	120	96		0.2046	0.2233	0.2177

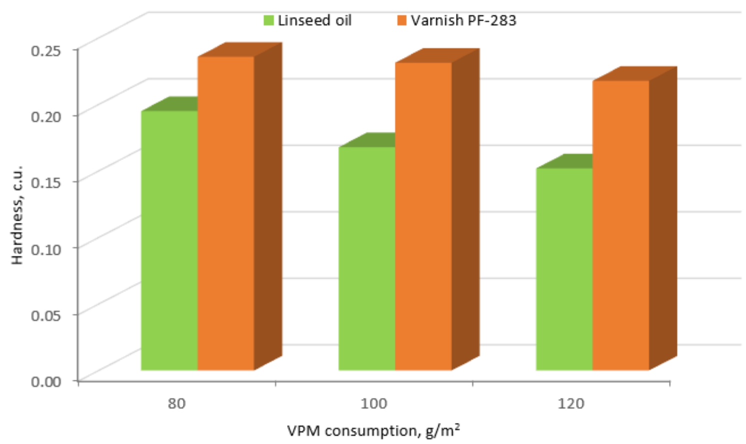

Fig. 4. *Conditional hardness of oil and alkyd varnish depending on VPM consumption*

Determining the hardness of the coatings confirmed that the films formed with oil-based materials have a reduced hardness compared to synthetic VPMs. Also, the hardness of the coating showed that for oil-based coatings, material consumption is of significant importance in comparison with alkyd materials. An increase in oil consumption leads to a significant decrease in the hardness of the protective-and- decorative film. These studies confirmed the schedule of wood finishing offered to manufacturers with regard to the consumption of oil-based materials – up to 100 g/m^2, which ensures a satisfactory drying time of the film and its hardness.

During the processing of the results of the experimental studies, the accuracy rate of the experiments exceeded 95%.

For wooden products that are operated in an open atmospheric environment, water resistance and heat resistance of the protective-and-decorative coatings are very important indicators of product quality.

The study of water resistance and heat resistance of coatings was carried out in accordance with DSTU ISO 2810: 2015 Paints and varnishes – Natural weathering of coatings – Exposure and assessment (ISO 2810:2004, IDT – [10]). The results of assessing the water resistance of the coatings on oak wood samples finished with oil and alkyd varnish PF-283 are shown in Table 2.

When studying the water resistance of protective-and-decorative coatings, it was found that pentaphthalic varnish-based films are more susceptible to water damage than oil-based films. This confirms the high resistance of oil-based coatings to atmospheric conditions [18, 24, 25].

After conducting the studies of the water resistance of the coatings based on alkyd and oil materials, it is possible to draw conclusions about the possibility of using these coatings in atmospheric conditions. However, oil-based coatings have a higher resistance to moisture and water.

After conducting a visual inspection and an assessment of the surface, the results of the heat resistance of the coatings were obtained (Table 3).

Results of determining the water resistance of the coatings Table 2

Type of VPM	VPM consumption [g/m^2]	Duration of exposure of specimens in water [h]	Water temperature [°C]	Changes in the surface of the coating (visually)
Linseed oil	80	12	20±2	Very slight blooming
	100	12		Coating is unchanged
	120	12		Coating is unchanged
Varnish PF-283	80	12		Blooming, micro peeling
	100	12		Slight blooming
	120	12		Blooming

Determining the resistance of the coatings to temperature confirmed that films based on linseed oil and alkyd varnish have satisfactory resistance to high temperatures. However, an increase in the film thickness leads to a decrease in the resistance of both materials. As for oil-based materials, it can be noted that an increase in material consumption leads to a long polymerization period of the coating, and, accordingly, to an increase in the stickiness of the film [3, 17, 30, 36]. In alkyd varnish coatings, with an increase in the film thickness, destruction processes can occur due to the action of elevated temperatures, which leads to a loss of adhesion.

The study data confirmed the need to comply with technological finishing schedules in order to obtain satisfactory performance characteristics of protective-and-decorative coatings.

Results of determining the heat resistance of the coatings Table 3

Type of VPM	VPM consumption [g/m^2]	Duration of specimens exposure under temperature [min]	Water temperature in the container [°C]	Changes in the surface of the coating (visually)
Linseed oil	80	20	90±5	Coating is unchanged
	100	20		Coating is unchanged
	120	20		Sticking of paper lints to the film
Varnish PF-283	80	20		Coating is unchanged
	100	20		Coating is unchanged
	120	20		Changes in the lustre of the film

Finishing of wooden houses and joinery that are part of the overall structure in housing construction is very important in terms of service life and ensuring the operability of individual elements and the house as a whole. Therefore, it is necessary to set high technological requirements for the choice of finishing materials for creating protective-and-decorative coatings on structures in wooden house construction.

It is known that oil-based and alkyd film-formers have the best characteristics of coating resistance to atmospheric conditions. Among the above-mentioned materials, alkyd VPMs and drying oils are most widely used in house construction which, in addition to good resistance to weather conditions, belong to conditionally environmentally friendly systems. The study of the qualitative characteristics of oil-based and alkyd materials showed that the drying time of alkyd VPMs is somewhat shorter than that of linseed oil, but not significantly, and alkyd varnishes form a film of greater thickness at the same consumption as oil materials. Alkyd VPMs form a coating of higher hardness. However, oil-based materials have high water and heat resistance, and, accordingly, this corresponds to good adhesion of the protective-and- decorative film to wood. In addition, high indicators of water and heat resistance for products that are operated outdoors, under increased atmospheric load, are very important for the durability of the protective-and-decorative coating, and, accordingly, of the product as a whole.

3. Conclusions

Despite the fact that many new paint and varnish materials for wood finishing have recently appeared on the market, alkyd varnishes remain popular due to their versatility and low cost. Therefore, the study of their properties for use in atmospheric operating conditions is extremely important.

The results of studies on the operational characteristics of protective and decorative coatings created for carpentry and building structures made of oak wood indicate that alkyd (pentaphthalic) varnish (PF-283) and drying oil (linseed oil) form high-quality films and can be used for finishing wooden houses, carpentry, and building structures (windows, doors, floors, attics, stairs, etc.). Therefore, they can be classified as weather-resistant paint-and-varnish materials. However, coatings based on drying oils are more resistant to atmospheric effects and, thus, will ensure a longer service life of wood products and will not create a negative impact on the environment.

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