

POLYAMIDAMINEPICHLOHYDRIN APPLICATION FOR ECO-SAFE WATERFAST AND WATERPROOF FOOD PACKAGING PAPER PRODUCTION

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Abstract. The paper presents the research results on the properties of the pulp coniferous and deciduous wood composition in its original state and paper made from it, proposes a mechanism to increase the waterfast and waterproof food packaging paper by surface treatment with a composition based on polyamidaminepichlorohydrin with polyvinyl alcohol and urea. The study was conducted in order to ensure an increase in the consumer properties of packaging paper, since when packaging materials encounter food products, their structure can change under the influence of moisture, steam, and gas. Polyamidaminepichlorohydrin was used as the main component of the composition for paper processing, as functional additives: polyvinyl alcohol and urea. The above-mentioned starting materials are environmentally friendly, since foreign inclusions in food packaging materials would pose a serious danger to human health and life, as well as to the brand image of the product in which they would be detected. It was proved that high waterfastness and waterproofness, as well as the necessary level of barrier, protective and operational properties of packaging material for food products cannot always be obtained by introducing a significant amount of polyamidaminepichlorohydrin, so the paper investigated the mechanism of interacting cellulose fibers of paper with polyamidaminepichlorohydrin, and also proved the possibility of its use to obtain packaging paper with a given set of properties. It was found that the consumption of up to 4–6% polyamidaminepichlorohydrin provides the main increase in the mechanical strength of packaging paper, both in wet and dry conditions. The resulting waterfast and waterproof material can be used for food packaging.

Keywords: packaging paper, polyamidaminepichlorohydrin, mechanical strength, waterfastness, waterproofness, porosity, food products.

Introduction. Formulation of the problem

Increasing the competitiveness of domestic food products in the domestic and foreign markets is impossible without the manufacture and introduction of high-quality packaging materials, which are characterized by an appropriate level of consumer properties, safety, and environmental friendliness.

It is known that in the process of food storage, complex biochemical processes of interaction between products, packaging, and the environment occur. Therefore, ensuring an increase in the consumer properties of packaging material is a very urgent problem, since during contact with food products, changes in their structure can occur under the influence of various media (moisture, steam, gas) [1-4].

Analysis of recent research and publications

When developing packaging for food products, it is advisable to take into account not only ensuring the commercial appearance of products, but also the operational properties of the packaging material, its ability to maintain high mechanical strength in dry and wet conditions to ensure the reliability of packaging and protect the properties of packaged food products from environmental influences [5-7].

The results of numerous studies show that the mechanical strength of paper in the dry state can be adjusted by changing the degree of cellulose fiber grinding and the paper density during its manufacturing [8-14]. A number of authors explain this by increasing the intensity of interweaving of

fibrillated fibers, which contributes to the establishment of a larger number of inter-fiber connections [15-18]. However, this method of increasing the strength of a dry paper web does not ensure its strength in the wet state [19-21], since the strength of the bands remains at the same level.

In food packaging, water-soluble thermosetting resins are used to increase the operational strength of paper in the wet state, in particular, an aqueous solution of polyamidamine modified with epichlorohydrin (PAECH) [22-27]. To ensure better penetration of PAECH into the structure of the paper web, it is proposed to use urea [28, 29]. However, the disadvantage of processed PAECH paper, which makes it difficult to use it for food packaging, is its low level of barrier properties.

To improve the barrier properties and increase the resistance of paper to various factors, polymer coatings based on polyvinyl alcohol are used due to its ability to form impermeable films. Thus, it is known that with a composite base of polyvinyl alcohol, it was possible to significantly increase the resistance of packing paper to water vapor transmission (from 533 to 1.3 g / m²/24h) and waterproofness (wetting angle $\geq 100^\circ$) [30], mechanical strength of packaging paper in dry and wet conditions [31, 32].

Therefore, to obtain waterfast food packaging paper with a given set of barrier properties, it is proposed to process it PAECH in a composition with urea and PVA.

Purpose and objectives

The research purpose is to substantiate the feasibility of using PAECH for eco-safe waterfast and waterproof food packaging paper production.

To achieve this goal, the following tasks should be performed:

- to describe and justify the choice of materials used for food packaging materials production;
- to determine the potential reactivity of cellulose and paper made from it;
- to investigate the mechanism of chemical interaction of PAECH with cellulose fibers in paper composition;
- to identify patterns of changes in paper properties during processing with PAECH solutions;
- to investigate the possibility of using PAECH together with urea to regulate the paper porosity;
- to investigate the effectiveness of using PAECH together with PVA to regulate the paper porosity;
- to evaluate the mechanical and barrier properties of paper treated with PAECH with urea and PVA compositions.

Research materials and methods

Research materials

The sulphate unbleached softwood pulp of brand HC-2 produced by JSC "Baltiyskaya cellulose" (Russia) and hardwood of brand HC-2 produced by JSC "Svetlogorsk Pulp and Cardboard Mill" (Belarus) were used in the research. These types of raw materials are imported to Ukraine, as they have a competitive price advantage in comparison with domestic

analogues, and Ukraine is not able fully to meet its own needs with raw materials of domestic production.

Paper samples were made from a composition of coniferous and deciduous pulp at a ratio of 80:20, ground to a grinding degree of 65°SHR. The fibrous semi-finished products were dissolved and ground in the presence of water in the Valley laboratory at a drum speed 500 r/min. The degree of grinding was monitored on a Shopper-Rigler device. Prototype paper samples were produced with using a sheet-forming laboratory device with a RapidKothen combined drying chamber in accordance with ISO 5269-2:2004. paper of various densities (650 kg/m³, 700kg / m³ and 750kg/m³), which in the future will expand the range of packaging materials for different food groups. The control samples for packaging paper were samples of the appropriate density raw paper.

Polyamidaminepichlorohydrin (PAECH) is used as the main component of the paper processing composition, polyvinyl alcohol (PVA) and urea are used as functional additives, and distilled water is used as a solvent.

We used PAECH manufactured by EkaChemicals AB (Sweden) of brand Eka WS 325 (dynamic viscosity (Brookfield) – 76.2 MPa*s; mass fraction of dry substances – 19.8%, density-1060 kg / m³ PH-3.5), PVA grade 7/18 (mass fraction of acetate groups – 19.8%; pH 4% of aqueous solution – 4.5), and urea Grade B (mass fraction of nitrogen in terms of dry matter – 52.3%; mass fraction of biuret – 0.55%; mass fraction of water – 0.6%) produced by PJSC "Severodonetsk Azot Association" (Ukraine.)

Urea is physiologically safe for humans and is officially approved for use in food production in most countries, including Ukraine and the European Union. The absolute advantage of using urea for food packaging paper production is not too high its production cost. If used correctly, it does not have any significant harmful effects on the environment.

In turn, polyvinyl alcohol (PVA) does not have a negative effect on the human body, is widely used in the food industry, including for the production of Edible Packaging Films, and is allowed for use in the food industry in Ukraine and the EU. The advantage of using polyvinyl alcohol for food packaging paper production, in comparison with natural (starch-based) materials, is its increased biological resistance. PVA – based compositions are environmentally friendly, have high adhesive properties, and films have high cohesive and mechanical strength [33]. Many scientists recognized PVA as one of the few water-soluble vinyl polymers that is also susceptible to biodegradation in the presence of appropriate acclimatized microorganisms. The materials were chosen based on their environmental safety, since foreign harmful inclusions in food packaging materials pose a danger to human health and the environment.

Taking into account the properties of these substances and effectively combining them, the preparation of a composition for surface treatment of food packaging paper was carried out according to the scheme shown in Fig. 1.

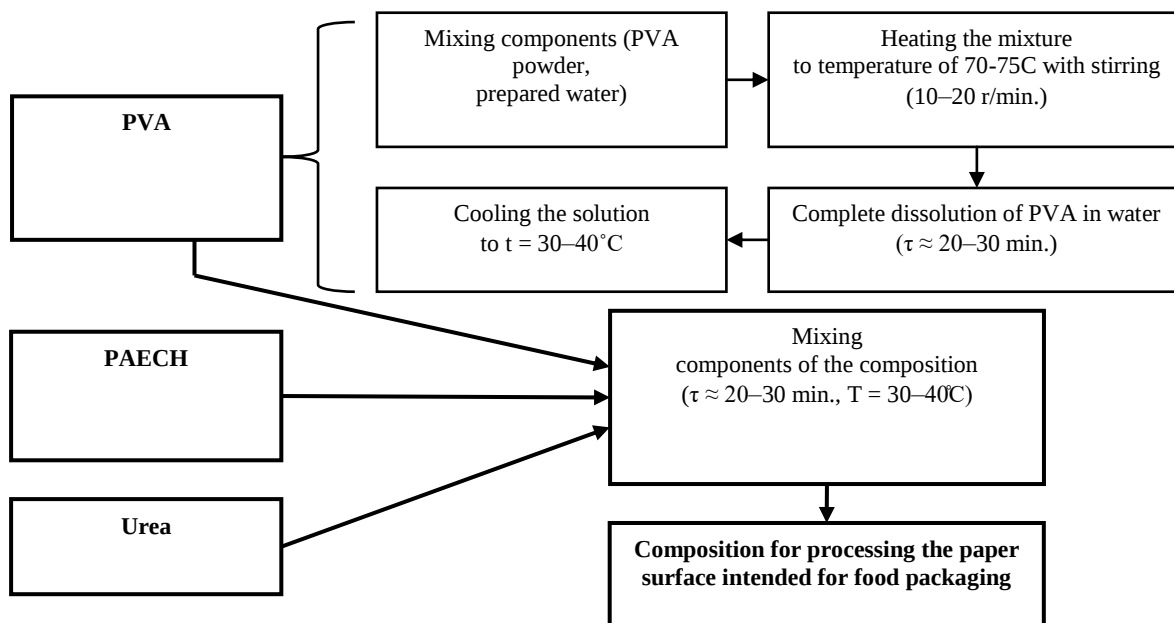


Fig. 1. Scheme for obtaining compositions for surface treatment of paper intended for food packaging

Processing paper with substances to give waterfastness and waterproofness and their compositions was carried out by one-way wetting, followed by drying with a gradual increase from 50 to 80°C to a constant mass. The processed paper was kept for 10-12 days to stabilize the properties of the manufactured material.

Research methods

IR spectroscopy of cellulose and paper intended for food packaging

Comparative analysis of cellulose and paper samples for potential reactivity, as well as the processes of interaction of paper with PAECH, was studied by IR spectroscopy. The intensity of radiation absorption by the studied substances in the range of wave numbers 400-4000 CM was determined⁻¹. The spectra were obtained by a Fourier transform IR spectrophotometer-Avatar 370 PT – TRTermoNicolet. Dehydrated potassium bromide was used as the carrier.

The presence and degree of interaction were evaluated by shifting the characteristic oscillation bands corresponding to the hydroxyl, carboxyl, aryl, and alkyl groups in the paper composition. The offset magnitude of the maximum position a of the characteristic absorption bands towards lower or higher frequencies (ΔU , CM⁻¹) is used to quantify the increase or decrease in the strength of the corresponding functional groups or bands. Changes in paper composition were quantified by the ratio of intensities and ϕ . And for characteristic absorption bands (where a_0 – intensity of the absorption band, and b_0 – background intensity of the band at the maximum absorption). The degree of energy uniformity of functional groups and bands in the composition of the studied materials and its possible changes were estimated by the width of the

corresponding characteristic bands at the level of 50% absorption ($\Delta U_{1/2}$, CM⁻¹).

Investigation of mechanical and barrier properties of paper intended for food packaging

Indicators of the destructive force of paper materials for food packaging were determined in dry and wet conditions in accordance with DSTU 2334-94 and DSTU ISO 3781:2005. The tests were performed on a vertical breaking machine RMB-30-2m. The waterfastness of paper materials was defined as the ratio of their strength indicators in wet and dry states. Determination of strength in the wet state was carried out after holding it in water for 1 hour.

Determination of the paper materials porosity was carried out on the BIITM.M MT-160 device. The essence of the method is to measure the volume of air passing through a certain area of the sample per unit time at a given level of air rarefaction. The surface water absorption was determined by the Cobb method according to DSTU 3549-97. The essence of the method is to determine the mass of water that is absorbed by the surface of the material at wetting on one side for 60 seconds. The indicator is defined as the difference in weighing before and after wetting. Water permeability was determined in accordance with DSTU 2711-94 "Paper and cardboard. Method for determining waterproofness." The essence of the method is to measure the time after which water penetrates through a sample of paper packaging material to the other side under set conditions.

Results of the research and their discussion

Comparative evaluation of the chemical activity of the composition of cellulose and paper made from it.

The composition of cellulose macromolecules is characterized by the content of a significant number of reactive hydroxyl groups. In the production process of paper intended for food packaging, hydroxyl groups can undergo various transformations.

A comparative analysis of the initial composition of cellulose and paper made from it is carried out. IR spectra (Fig. 2) these materials have significant differences in the composition and structure of the characteristic absorption bands.

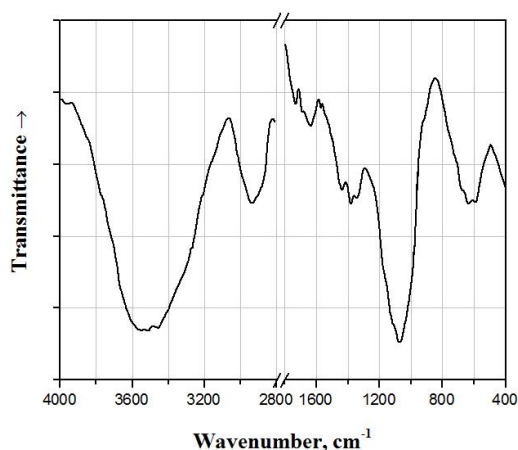


Fig. 2. IR spectrum of cellulose composition

The IR spectrum of the coniferous and deciduous cellulose composition is characterized by intense absorption bands at 1420, 1320, 1160, and 666 CM^{-1} (Table. 1).

Table 1. Characteristics of absorption bands of the IR spectrum of cellulose

Maximum position, CM^{-1}	I_0/I	$\Delta\nu_{1/2}$, sm^{-1}
3413	4.38	492.0
2913	0.66	512.0
2880	0.60	—
1720	0.18	—
1633	0.38	—
1420	0.97	40.0
1373	1.18	80.0
1320	1.03	
1160	3.57	
1073	7.93	253.0
891	0.38	—
666	0.69	20.0
573	0.73	93.0

By indicator I_0/I the characteristic bands available for the specified sample can be divided into three groups. The first one is characteristic at the level I_0/I 3.57 (1160 cm^{-1} , C–O–C band fluctuations), 4.38 (3413 cm^{-1} , OH groups) and 7.93 (1073 cm^{-1} , fluctuations of C–C, C–OH, C–H bands). The second group in terms of intensity ratio includes the following limits: 0.6–0.66 (2880 and 2913 cm^{-1} , bands C–H), 0.69 (666 cm^{-1} , C–OH), 0.97 (1420 cm^{-1} , H–CH, O–CH) and 1.03–1.18 (1320 and 1373 cm^{-1} , CH). The third one is

characterized by a lower value of the ratio I_0/I , which is at the level of 0.38 (1633 cm^{-1} , OH bundles) and 0.18 (1720 cm^{-1} , C=O).

The highest width values at half the height of the absorption bands were recorded for the positions of the highs of 2913 (512 cm^{-1}) and 3413 cm^{-1} (492 cm^{-1}), which quantify the hydroxyl functional groups in cellulose.

The IR spectrum of paper has a slightly smaller number of characteristic absorption bands compared to the studied cellulose (Fig. 3).

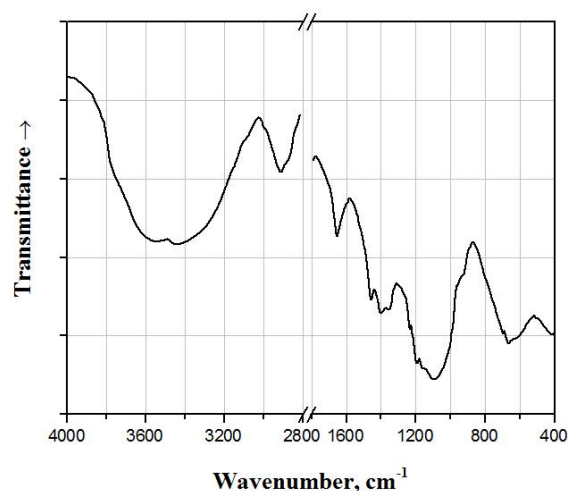


Fig. 3. IR spectrum of paper made from cellulose composition

Comparison of the position of the main Maxima of the original pulp and paper intended for food packaging showed that the largest deviations for the Strip were at 3362, 2900 and 1644 cm^{-1} they can reach up to 11 cm downwards⁻¹ and magnification up to 44 cm^{-1} . Moreover, such a difference is observed only in the case of the last band, which is responsible for the valence vibrations of OH groups with adsorbed water (Table. 2).

Table 2. Characteristics of the absorption bands of the IR spectrum of paper intended for food packaging

Maximum position, CM^{-1}	I_0/I	$\Delta\nu_{1/2}$, sm^{-1}
3362	2.89	611.8
2900	0.68	1064.4
1644	0.56	—
1435	1.36	611.8
1370	1.42	
1305	1.28	
1052	6.92	
881	0.40	
620	1.06	—

Analysis of the IR spectra of cellulose and paper intended for food packaging was performed on the basis of three main characteristic absorption bands (3362–3614, 2900–2931 and 1600–1644 cm^{-1}). The choice of the latter is due to their presence in the composition of both studied materials. In addition, by

their chemical composition, compounds and functional groups (H_2O , OH, CH), which have characteristic valence and differential vibrations in the marked wave number ranges, among all other components of cellulose, have a determining effect on forming the reactivity of the surface of materials to interact with PAECH.

Position of high-frequency paper absorption bands ($3361\text{--}3400\text{ cm}^{-1}$) shows the presence of an offset in the low-frequency region up to 52 cm^{-1} . This fact can be considered as evidence of an increase in the strength of OH group bands between cellulose macromolecules. A similar pattern is observed for the absorption bands responsible for valence fluctuations of C–H bands, which provide a stronger band between cellulose macromolecules and create a water-repellent effect [34]. The strength bands of C–H paper (in terms of displacement towards low frequencies, it is 31 cm^{-1}) increases in comparison with the original cellulose.

An inverse relationship is observed to manufacture paper intended for food packaging in comparison with cellulose in relation to adsorbed water. The maximum position of the characteristic bands responsible for adsorbed moisture is shifted to the high-frequency region of the spectrum by 11 cm^{-1} , that is, the strength of the water band with the Matrix decreases slightly, its amount, according to the data on the ratio of the intensity of the characteristic absorption bands for paper ($I_0/I = 0.56$) is 1.5–2.2 times higher than the content of cellulose composition.

The studied materials, judging by the change in the attitude I_0/I , contain a different number of OH groups. The paper under study is characterized by the value of the indicator $I_0/I = 2.89$, which is less than in the original cellulose $I_0/I = 4.38$ for a strip of about 3413 cm^{-1} , that is, the bands concentration OH is higher.

The absorption bands of the OH groups of cellulose and paper differ quite significantly in energy terms. Deviation (according to the value data $\Delta V_{1/2}$) folds between pulp and paper up to 160 cm^{-1} . Moreover, the advantage in the strength of O–H bands is clearly fixed for paper. The absorption bands responsible for valence fluctuations of the C–H groups have the index $\Delta V_{1/2}$ for paper at the level of 106.4 against 512 cm^{-1} for the studied cellulose composition.

A comparative analysis of cellulose and paper made on its basis for food packaging made it possible to quantify and qualitatively assess the level of reactivity of these materials. It was found that paper has a slightly higher concentration of O–H and C–H groups compared to cellulose. In addition, it is characterized by a large amount of adsorbed water, but the strength of its band with the material is much lower. This gives grounds to assert that paper is not significantly available to the original cellulose in terms of chemical activity, and therefore allows effective use of the surface treatment method.

Investigation of the interaction mechanism between PAECH and paper

Analysis of the PAECH IR spectrum (Fig. 4) allows distinguishing the following characteristic absorption bands by the level of differentiation and lack of masking the main bonds: 1546 cm^{-1} – N–H bonds (deformation vibrations (against the background of C–O and C–H bonds); 1636 cm^{-1} – vibrations mainly C–O ligament against the background of deformation vibrations of N–H and possibly C–H bonds; 3270 cm^{-1} – vibrations of N–H bonds; 1256 cm^{-1} – fluctuations of C–O bonds against the background of N–H and CH_2 [35].

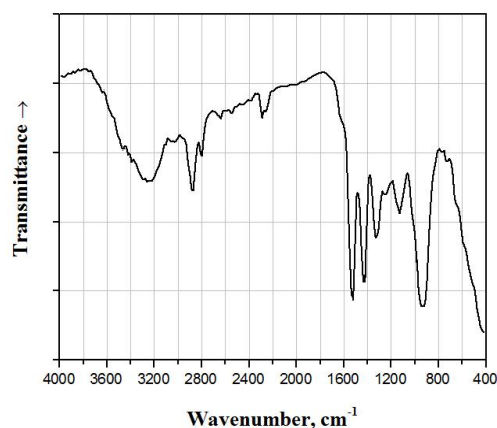


Fig. 4. PAECH IR spectrum

As a result of paper surface treatment with polyamidaminepiclorohydrin, a slight increase (up to 10%) in the intensity of the absorption bands is recorded at 1636 and 1546 cm^{-1} (Fig. 5).

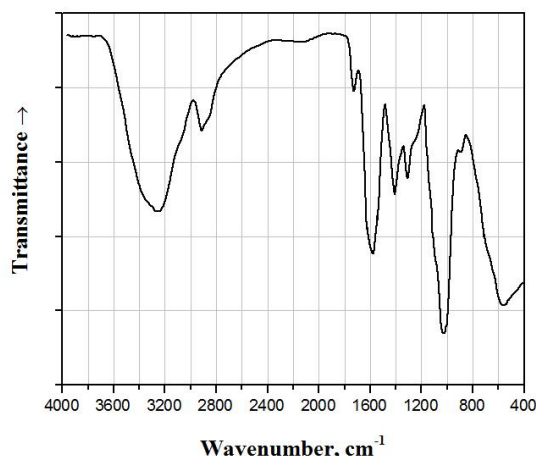


Fig. 5. IR spectrum of processed PAECH paper intended for food packaging

In addition to the above, a new absorption band appears (insignificant intensity at 3270 cm^{-1}). The intensity of the absorption band is significantly reduced with a maximum in the region of 3400 cm^{-1} . The recorded changes in the IR spectra of the original and processed paper allow concluding that the interaction of compositions based on PAECH and paper occurs with

the participation of hydroxyl groups of cellulose and PAECH: $\text{PAECH} - \text{OH} + \text{HO-cellulose} + \text{H}_2\text{O} \rightarrow \text{PAECH} - \text{cellulose} + \text{N}_2\text{OH}$. In this case, the C-OH ring bands in the paper composition predominate. At the same time, the participation of N-H and C-O groups in PAECH with hydroxyl groups of paper pulp is not excluded. Thus, the results indicate the presence and formation of relationships between the functional groups of PAECH and cellulose in the paper composition, and therefore the feasibility of surface treatment of paper with appropriate compositions.

Properties of paper treated with PAECH and its compositions with urea and PVA

The waterproofness of paper is the degree to which it retains its strength and resistance to tearing in the wet state. The waterproof paper is considered to be paper that, when completely saturated with water, retains from 15 to 50% of its strength in a dry state. Usually, paper has a low waterproofness, and breaks due to the weakening of the hydrogen bonds of the fibers under the influence of water. When completely saturated with water, the test paper retains 5–10% of its strength in a dry state (Fig. 6) depending on density. The effect of the PAECH solution concentration on the mechanical properties, as well as the surface absorbency, water porosity, and paper breathability is studied.

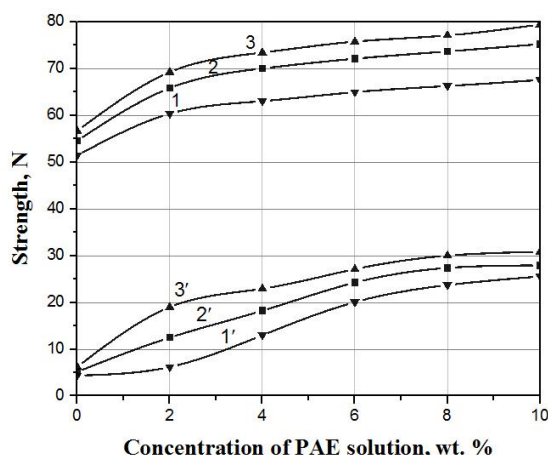


Fig. 6. Effect of PAECH solution concentration on breaking force in dry (1, 2, 3) and wet (1', 2', 3') states of processed paper of different densities: 1 – 650kg/m³; 2 – 700kg/m³; 3 – 750kg/m³

It was found that the resin consumption of up to 4-6% provides the main increase in the strength properties of packaging paper in both wet and dry conditions. When using 4% PAECH, the increase in breaking force for the sample (1) with the lowest density is 23%, for thicker paper (2, 3) – 29 and 30%, respectively. A further increase in resin consumption has little effect on the breaking force in the dry state. The breaking force of the paper increases to the level of 67.6–79.5H with an increase in the concentration of PAECH solution from 4 max.% up to 10 max.%. In the wet state, the destructive force of the paper when using

a PAECH solution with a concentration of 6 max. % increases by 4.4–4.8 times relative to the initial values of 4.3–6.2H, depending on the base paper density. At the same time, the level of moisture resistance for paper with a density of 650 kg/m³, 700kg/m³, 750kg/m³ it is 31%, 34%, and 36%, respectively, which indicates the high efficiency of using PAECH to give waterproofness to paper.

Along with this, the use of PAECH allows significantly reducing the absorbency of paper when it is unilaterally wetted with water (Fig. 7).

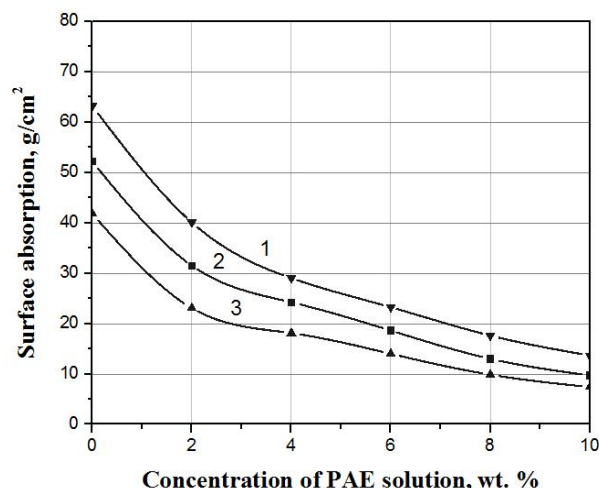


Fig. 7. The effect of the concentration of PAECH solution on the surface absorbency of the treated paper of different density: 1 – 650 kg/m³; 2 – 700 kg/m³; 3 – 750 kg/m³

With increasing the concentration of PAECH solution to 10 max., the surface absorbency of the studied paper samples of various densities is significantly reduced to 7.3–13.6 g/m², that is, it decreases by 4.7–5.7 times relative to the raw base paper. A significant decrease in the surface absorbency of paper intended for food packaging indicates partial closure of pores and capillaries in the paper structure, as well as an increase in the hydrophobicity of paper, as a result of the PAECH action. In this case, the complex action of the resin affects the water resistance of the paper (Fig. 8).

In general, it was found that the use of PAECH can significantly increase the water resistance of paper intended for food packaging. Water penetration resistance for the studied paper samples increases from 48–73 from 1800–2170 p. However, the paper sample with the lowest density of 650 has the maximum water resistance (2170c).kg/m³. The use of less concentrated PAECH solutions is more effective for paper with a denser structure. Whereas the higher PAECH content in solution (4–6 max.%) helps to increase the water resistance of less dense paper, which is explained by its better penetration into the more porous structure of the material. The results obtained indicate that an increase in density significantly reduces the effectiveness of PAECH with an increase in its concentration in solution.

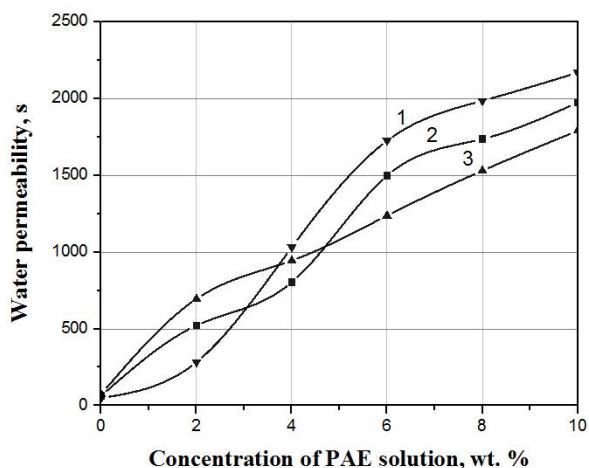


Fig. 8. Effect of the PAECH solution concentration on the water permeability of the treated paper-cutting density: 1 – 650 kg/m³; 2 – 700 kg/m³; 3 – 750 kg/m³

The possibility of increasing the penetration of PAECH into the paper structure using urea was studied on paper samples with an average density (700 kg/m³). At the same time, processing the paper with PAECH solution in a composition with urea makes it possible to obtain a material with a higher resistance to water penetration (Fig. 9), which is an important performance characteristic of food packaging paper.

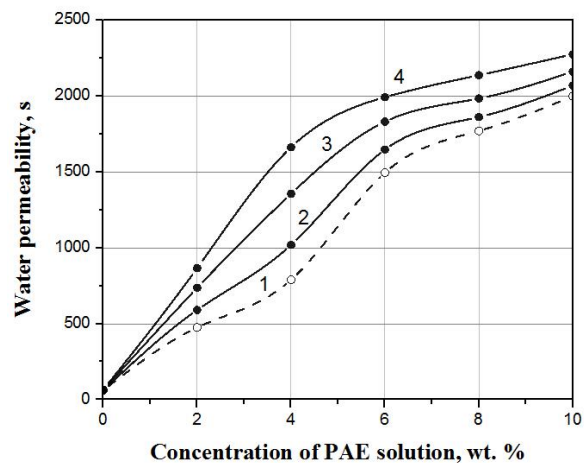


Fig. 9. Effect of PAECH solution concentration on the water permeability of processed paper (700 kg/m³) depending on the urea content: 1 – without urea; 2 – 2 max.%; 3 – 4 WT.%; 4 – 6 max.%

It was found that the use of PAECH together with urea contributes to a significant increase in the availability of cellulose fiber and provides a uniform increase in water resistance.

The research results of the effect of processing paper with different densities with PAECH solutions at different concentrations on its breathability are shown in Fig. 10.

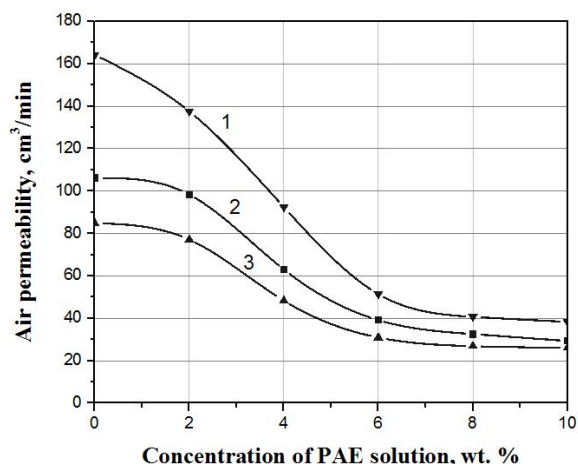


Fig. 10. Effect of PAECH solution concentration on the breathability of the treated paper-cutting density: 1 – 650 kg/m³; 2 – 700 kg/m³; 3 – 750 kg/m³

The breathability of raw paper of different densities varies significantly and ranges from 84 to 164 cm³/min. PAECH, due to its polymer nature and low degree of polymerization, has the ability to penetrate capillaries and pores between cellulose fibers, close them, reducing the overall porosity of paper. Treatment of the studied paper samples with PAECH solutions reduces their breathability to the level of 26–38 cm³/min. At the same time, the main decrease in the indicator occurs at concentrations of 2–6 max.% in solution. Further increase in the PAECH content is ineffective, and the achieved level of breathability is higher than optimal for packaging moisture-containing food products.

To determine the possibility of adjusting the level of air permeability of paper by using PAECH together with PVA, the most air-permeable samples (with a density of 650 kg/m³) were studied³) after treatment with solutions with different content of components (Fig. 11).

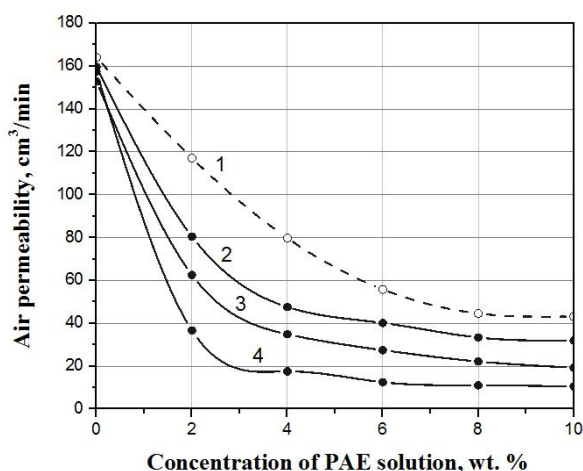


Fig. 11. Effect of PAECH solution concentration on the breathability of processed paper (650kg / m³) depending on the content of PVA: 1 – without PVA; 2 – 2 max.%; 3 – 4 max.%; 4 – 6 max.%

These dependences indicate that the high-molecular structure of PVA contributes to achieving a lower level of paper breathability. Using a solution containing 6–8 max.% PAECH and 4–6 max.% PVA allows providing the necessary level of breathability for a wide range of packaging materials. Thus, it is proved that the combined use of PAECH and PVA makes it possible to control the breathability of paper in a controlled way.

Properties of packaging paper obtained from using compositions based on PAECH.

The results of previous studies have shown the effectiveness of using PAECH together with urea and PVA. For further research, model three-component compositions were prepared, which were applied to the surface of paper weighing 50 g/m². The obtained results are shown in Table 3.

Table 3. Properties of packaging paper processed with model compositions based on PAECH

Option of model composition	Component content, max. %			Air permeability, cm ³ / min	Destructive effort, H	Wet-strength, %	Surface absorbency, g/m ²
	PAECH	Urea	PVA				
1	6	6	3	19	78	40	15
2	6	6	1	28	55	35	21
3	2	6	3	22	71	25	26
4	2	6	1	39	53	19	34
5	6	2	3	20	75	32	15
6	6	2	1	29	51	20	17
7	2	2	3	20	70	30	24
8	2	2	1	38	50	17	28
9	4	4	2	36	62	31	16

It was found that applying a composition containing 4–6 max. % PAECH, 4–6 max. % urea, 1–2 max.% PVA and water as a solvent gives the waterproofness to paper, and also increases the level of barrier properties and reduces its surface absorbency.

It should be noted that the introduction of PAECH in compositions with urea contributes not only to a decrease in permeability indicators, but also to an increase in the plasticity and mechanical strength of paper in dry and wet conditions. Analysis of the strength indicators of prototypes indicates that the urea content significantly affects the strength of paper. The main increase in mechanical strength, especially in the wet state, is provided by increasing the content of PAECH in the model composition, which shows optimal properties in the range of 4–6%.

Using a composition with a PVA content of more than 3% is impractical, since an increase in the viscosity leads to its weak penetration into the inter-fiber space of paper, requires an increase in the impregnation time, can cause the coating to stick to the drying cylinders of the paper machine during drying, and reduces the quality of paper intended for food packaging.

The obtained results can be explained by the fact that the use of PVA in model compositions, even with a small content (1–2 max.%) in combination with PAECH contributes to the creation of a more closed microporous structure [36], which is consistent with a decrease in the surface selectivity of the treated samples.

Analyzing the permeability indicators of experimental paper samples, it can be argued that the use of compositions with a PVA content above 4 max.% significantly reduces the breathability of the

material, which is undesirable for packaging materials for moisture-containing food products. At equal concentrations of PVA the increased quality indicators have paper samples treated with compositions containing urea and PAECH in the range 4–6 max.%. Increasing the content of these substances in the composition for processing paper above-mentioned level is impractical, as it leads to a slight increase in the values of the barrier indicators.

Conclusions

1. To obtain eco-safe waterfast waterproof food packaging paper, it is proposed to use compositions based on PAECH together with urea and PVA.

2. It is established that paper in comparison with the initial cellulose is characterized by a large amount of adsorbed water, but the strength of its band with the material is significantly lower, which makes it possible to consider surface processing of paper no less effective compared to the introduction of compositions based on PAECH directly into the paper pulp.

3. Processing paper with a composition based on PAECH is accompanied by the formation of a significant number of bands between the hydroxyl groups of PAECH and cellulose fibers mainly due to the C–OH ring in the cellulose, but interaction with the participation of N–H and C–O groups in the composition of PAECH is not excluded. At the same time, increasing the contact points of cellulose fibers and increasing the number of hydrogen inter-fiber bands provides food packaging paper high resistance to water and maintaining strength in the wet state.

4. Usage of PAECH can significantly increase the waterfastness, mechanical strength of paper in dry and wet conditions, as well as reduce its surface absorbency, but it is ineffective for achieving the

required level of breathability. In addition, as the density of the processed paper increases, the effectiveness of PAECH solutions decreases.

5. To ensure more efficient penetration of PAECH into the paper structure, urea was used, which provided a more uniform increase in waterfastness and made it possible to obtain a material with a higher resistance to water penetration.

6. Processing paper PAECH together with PVA allows controlling the breathability of paper and get the material with a denser and more closed structure.

7. It was found that surface treatment of paper with solutions containing 4-6 max.% PAECH, 4-6 max. urea%, 1-2 max.% PVA allows obtaining paper packaging materials with increased mechanical strength and waterfastness and provide the necessary level of breathability and surface absorbency.

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ЗАСТОСУВАННЯ ПОЛІАМІДАМІНЕПІХЛОРГІДРИНУ ДЛЯ ОТРИМАННЯ ЕКОБЕЗПЕЧНОГО ВОЛОГОМІЩНОГО ВОДОНЕПРОНИКНОГО ПАКУВАЛЬНОГО ПАПЕРУ ДЛЯ ХАРЧОВИХ ПРОДУКТІВ

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Анотація. У статті наведено результати досліджень властивостей композиції целюлози хвойних і листяних порід деревини у вихідному стані та паперу виготовленого із неї, запропоновано механізм підвищення вологомощності та водонепроникності паперу, призначеного для упакування харчових продуктів, шляхом його поверхневого оброблення композицією на основі поліамідамінепіхлоргідрину з полівініловим спиртом та карбамідом. Дослідження проводили з метою забезпечення підвищення споживних властивостей пакувального паперу оскільки при контакті пакувальних матеріалів з харчовими продуктами можуть відбуватися зміни їх структури під дією вологи, пари, газу. В якості основного компонента композиції для обробки паперу застосовували поліамідамінепіхлоргідрин, в якості функціональних добавок: полівініловий спирт та карбамід. Перераховані вище вихідні матеріали є екологічно безпечні, оскільки сторонні включення в пакувальних матеріалах для харчових продуктів становили б серйозну небезпеку для здоров'я і життя людини, а також для іміджу торгової марки продукту, в якому вони були б виявлені. Доведено, що високу вологомощність та водонепроникність, а також необхідний рівень бар'єрних, захисних та експлуатаційних властивостей пакувального матеріалу для харчових продуктів не завжди можна одержати введенням значної кількості поліамідамінепіхлоргідрину, тому у роботі досліджено механізм взаємодії целюлозних волокон паперу з поліамідамінепіхлоргідрину, а також доведено можливість її застосування для отримання пакувального паперу із заданим комплексом властивостей. Встановлено, що витрата до 4–6% поліамідамінепіхлоргідрину забезпечує основний приріст механічної міцності пакувального паперу, як у вологому так і в сухому станах. Одержаний вологомощний та водонепроникний матеріал можна застосовувати для упакування харчових продуктів.

Ключові слова: пакувальний папір, поліамідамінепіхлоргідрин, механічна міцність, вологомощність, водонепроникність, повітропроникність, харчові продукти.

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