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STUDIES OF THE EFFECT OF VISCOSITY STABILIZERS OF FIRE RETARDANT ALUMINOSILICATE PAINTS FOR WOOD PRODUCTS AND STRUCTURES

Sergii Guzii*

Department of fire prevention in settlements National University of Civil Defense of Ukraine, Kharkiv, Ukraine

Abstract. The paper presents the results of studies on the effect of viscosity stabilizers on the rheological properties of fire-retardant paints for products and structures of their wood. Optimization of viscosity stabilizers was carried out using a two-factor three-level design of the Box-Benkin experiment. Using the method of superposition of the response surfaces of the output parameters, the optimal ranges of the concentrations of Betolin additives were determined, which satisfy the regulatory levels for fire retardant paints, namely: the first area limited by the concentrations of Betolin® A-11 (factor x1) from 0.5 to 0.54%, Betolin® Q 40 (factor x2) 0.62 to 0.68%; in the second area - the concentration of additives Betolin® A-11 (factor x1) from 0.72 to 0.88%, Betolin® Q 40 (factor x2) from 0.9 to 1.0%. The optimization results were implemented in the production of fire-retardant paints for products and structures of their wood in the conditions of Geofip LLC (Kropyvnytskyi, Ukraine) under the FD5 trademark.

Keywords: viscosity stabilizers, fire retardant paint, optimization, products and structures, wood.
AMS Subject Classification: 82D15.
Corresponding author: Sergii Guzii, Department of fire prevention in settlements, National University of Civil Defense of Ukraine, 94 Chernishevska str., Kharkiv 61023, Ukraine, Tel.: +380984033356,
e-mail: *guziy@nuczu.edu.ua*
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1 Introduction

In recent years, as a result of both climatic changes and the activities of mankind, man-made hazards have arisen, which are manifested in accidents or disasters at potentially dangerous facilities and facilities of increased danger, are the most dangerous and contain a threat to human life and activities, the environment or are capable of create it as a result of a possible explosion, fire, flooding, environmental pollution (Otrosh, 2019).

The problem of the deterioration of structures, structures and machines, which all countries face, is of particular importance for Ukraine due to the difficult economic and financial situation. Particular attention is paid to the issues of managing the operational reliability and durability of objects by determining their technical condition and residual resource.

Since 2018 and to date, more than 78,608 fires have been registered in Ukraine. Material losses from fires amounted to more than 8 billion 279 million 119 thousand UAH. On average, 215 fires broke out daily, destroying or damaging more than 70 buildings and structures. Daily material losses from fires, on average, amounted to 22.7 million UAH. With each fire, the state suffered direct losses amounting to more than 28.0 thousand UAH.

Reconstruction of objects of any purpose can be carried out only on the basis of a comprehensive analysis (Otrosh, 2018). In this case, the following should be taken into account: the real state of building structures; forecast of possible soil subsidence or exposure to high temperatures; the results of calculations of structures according to design schemes, most fully taking into account the specifics of their deformations, including temperature. This issue is relevant for fire protection of modern wooden structures, as well as the same structures during their reconstruction and restoration of architectural monuments. Modern innovative fire-retardant mineral-based materials (Krivenko et al., 2018; Berzins, 2017), which are characterized by their environmental friendliness (Krivenko et al., 2009; Guzii, 2011; Krivenko et al., 2019; Guzii, 2019), and computer systems make it possible to perform calculations of the fire resistance of wooden structures in the presence of information on the characteristics of materials (Rasev, et al., 2010).

Of particular interest are fire-retardant paints based on geopolymer (Guzii et al., 2020; Guzii et al., 2020) which, according to the author's recipe, are industrially produced at the production facilities of Geofip LLC (Kropyvnytskyi, Ukraine). However, as the experience of using these paints at objects for fire protection of wooden structures has shown, they also have their drawbacks. In addition to providing the first group of incombustibility, fire retardant aluminosilicate materials tend to change their viscosity after manufacture.

Therefore, the purpose of this work is to study the effect of viscosity stabilizers of fire-resistant aluminosilicate paints for wood products and structures.

2 Materials and research methods

For the manufacture of fire-retardant paints an alkaline aluminosilicate binder was used with the ratio of the main oxides Na2O/Al2O3=1, SiO2/Al2O3=6 and H2O/Al2O3=20. Functional fillers and pigments were introduced into the composition of the paints/ The dry matter content of the polymer did not exceed no more 1%. The paints were produced in an industrial dissolver under the conditions of the LLC Geofip (Kropyvnytskyi, Ukraine). To control the rheological characteristics of the aluminosilicate base of the fire-retardant paint, viscosity stabilizers Betolin® A-11 and Betolin®Q40, products of Woellner GmbH (Germany), were introduced into its composition. The calculation of the optimal ratio of oxides was carried out taking into account the recommendations (Kryvenko et al., 2016; Barrer, 1982; Kravchenko et al., 2015). The total sum of all components of the mixture was 100%/ Optimization of the compositions of fire-retardant paints was carried out using a two-factor three-level experiment plan of Box-Benkin in the mathematical environment STATISTICA 12. The adequacy of the regression equations was assessed by the Fisher criterion (Voznesensky et al., 1989) in the software 2F = plan developed by Excel at the Kyiv National University of Construction and Architecture. The response surfaces are identical in both software packages. The factors of variation and matrix of planning the experiment are given in table 1 a table 2.

The numerical values of the output parameters are given in table. 3. Their values were obtained on devices according to the methods and calculations adopted in assessing the properties of paints and varnishes (Guzii, 2017; Guzii et al., 2019).

The minimum/maximum values of the output parameters were chosen as the criteria for evaluating the properties: $\nu\to$ min; $\rho\to$min; cosΘav$\to$1; $\gamma\to$min; Wa, Wk, Ww$\to$max; s$\to$1; f$\to$0. The error in measuring the values of surface tension and contact angle using the devices and devices described in (Glazacheva et al., 2015; Ershov, 2013) did not exceed 10%.

Table 1: Factors of variation

Factors, view	Natural	Codes	Varying levels			Interval of variation
			-1	0	1	
A-11	%	X1	0.5	0.75	1	0.25
Q-40	%	X2	0.5	0.75	1	0.25

Table 2: Experiment planning matrix

No	Matrix plan codes		Matrix plan in full size	
	X1	X2	A-11	Q-40
1	1	1	1	1
2	1	-1	1	0.5
3	-1	1	0.5	1
4	-1	-1	0.5	0.5
5	1	0	1	0.75
6	-1	0	0.5	0.75
7	0	1	0.75	1
8	0	-1	0.75	0.5
9	0	0	0.75	0.75

Table 3: Experiment results

No	ν, sec	ρ, g/?m^3	cosθ	γ, mN/m	Wa, mN/m	Wk, mN/m	Ww, mN/m	s	f, mN/m
1	70	1.399	0.76638	77.6	137.07	155.2	59.47	0.8832	-18.13
2	75	1.385	0.59763	75.6	120.78	151.2	45.18	0.7988	-30.42
3	59	1.389	0.68455	96.3	162.22	192,6	65.92	0.8423	-30.38
4	66	1.346	0.72741	85,6	147.87	171.2	62.27	0.8637	-23.33
5	52	1.374	0.77307	82.1	145.57	164.2	63.47	0.8865	-18.63
6	51	1.374	0.8335	77.6	142,28	155.2	64.68	0.9168	-12.92
7	71	1.395	0.79441	82.3	147.68	164.6	65.38	0.8972	-16.92
8	65	1.383	0.75172	80,6	141.19	161.2	60.59	0.8759	-19.01
9	53	1,372	0.766	84.8	149.76	169,6	64.96	0.883	-19.84
Control	42	1.368	0,81765	74.1	134.69	148.2	60.59	0.9088	-13.51

Note: ν - technological viscosity, sec; ρ - suspension density, g/cm^3; γ - value of surface tension, mN/m; $cos\Theta$av - the average value of the cosine of the angle of wetting of the substrate with paint; Wa, Wk, Ww - work of forces of adhesion, cohesion and wetting, mN/m; s, f - coefficients of wetting and spreading of paint over the surface of the substrate, mN/m.

3 Analysis of experimental results

As a result of optimization of compositions of fire-retardant paint, mathematical models (1-8) and surfaces of response functions (Fig. 1 - Fig. 8) were obtained from the influence of variable factors - viscosity stabilizers on the physical and rheokinetic properties of fire-retardant aluminosilicate paints.

Density, ρ, g/cm^3 (the equation is adequate, F$_{calculated}$=1.12 < F$_{tabular}$=19.3 by Fisher's criterion):

$$\rho = 1.378 + 0.008x_1 + 0.012x_2 - 0.006x_{11} + 0.009x_{22} - 0.007x_1x_2 \quad (1)$$

Technological viscosity, ν, s (the equation is adequate, F$_{calculated}$=9.17 < F$_{tabular}$=19.3 by Fisher's criterion):

$$\nu = 53.481 + 3.5x_1 - x_2 - 1.389x_{11} + 15.111x_{22} + 0.5x_1x_2 \quad (2)$$

Value of surface tension, γ, mN/m (the equation is adequate, $F_{calculated}$=6.04 < $F_{tabular}$=19.3 by Fisher's criterion):

$$\gamma = 80.396 - 4.033x_1 + 2.4x_2 + 0.422x_{11} + 2.022x_{22} - 2.175x_1x_2 \quad (3)$$

Work of forces of adhesion, Wa, mN/m (the equation is adequate, $F_{calculated}$=5.83 < $F_{tabular}$=19.3 by Fisher's criterion):

$$Wa = 146.474 - 8.158x_1 + 6.188x_2 - 2.509x_{11} - 1.999x_{22} + 0.485x_1x_2 \quad (4)$$

Work of forces of cohesion, Wk, mN/m (the equation is adequate, $F_{calculated}$=2.13 < $F_{tabular}$=19.3 by Fisher's criterion):

$$Wk = 159.152 - 8.067x_1 + 4.8x_2 + 2.189x_{11} + 5.389x_{22} - 4.35x_1x_2 \quad (5)$$

Work of forces of wetting, Ww, mN/m (the equation is adequate, $F_{calculated}$=5.71 < $F_{tabular}$=19.3 by Fisher's criterion):

$$Ww = 66.204 - 4.125x_1 + 3.788x_2 - 3.187x_{11} - 4.277x_{22} + 2.66x_1x_2 \quad (6)$$

Coefficients of wetting, s (the equation is adequate, $F_{calculated}$=6.24 < $F_{tabular}$=19.3 by Fisher's criterion):

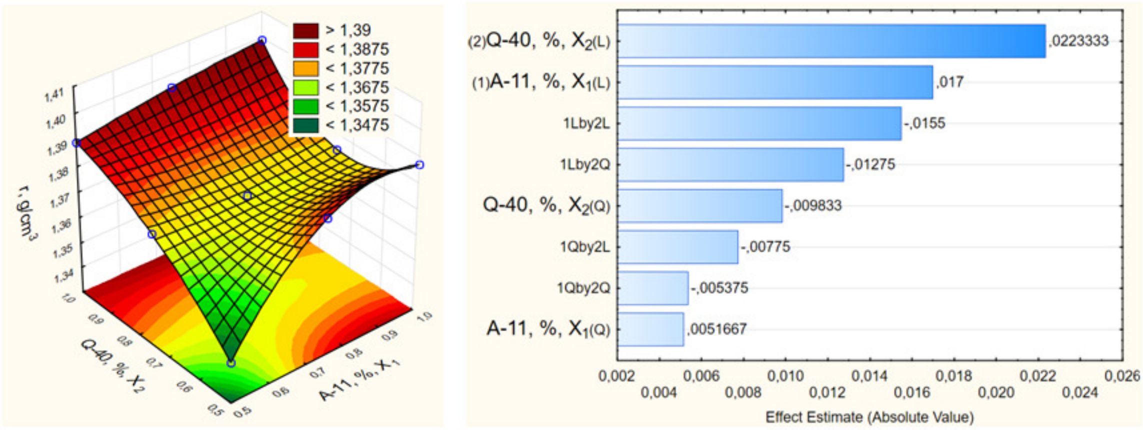
$$s = 0.905 - 0.009x_1 + 0.013x_2 - 0.019x_{11} - 0.031x_{22} + 0.026x_1x_2 \quad (7)$$

Coefficients of spreading, f, mN/m (the equation is adequate, $F_{calculated}$=8.48 < $F_{tabular}$=19.3 by Fisher's criterion):

$$f = -13.767 - 0.092x_1 + 1.222x_2 - 4.245x_{11} - 6.435x_{22} + 4.835x_1x_2 \quad (8)$$

Analysis of mathematical models (1-8) allows us to note the following that the change in the density of fire-retardant aluminosilicate paints is most fully influenced by the factors x1, x2 and x22; the change in the technological viscosity is most fully influenced by the factors x1, x22 and the multiplier product of the factors x1x2; the change in the indicators of surface tension, the work of the forces of adhesion and cohesion is most fully influenced by the factors x2, x11 and x22; the change in the indicators of the work of the wetting forces, the wetting and spreading coefficients is most fully influenced by the x2 multipliers and the multiplier product of the x1x2. The article does not provide data on the approximation error (the absolute error of the regression equations. This will be taken into account in subsequent works in this direction.

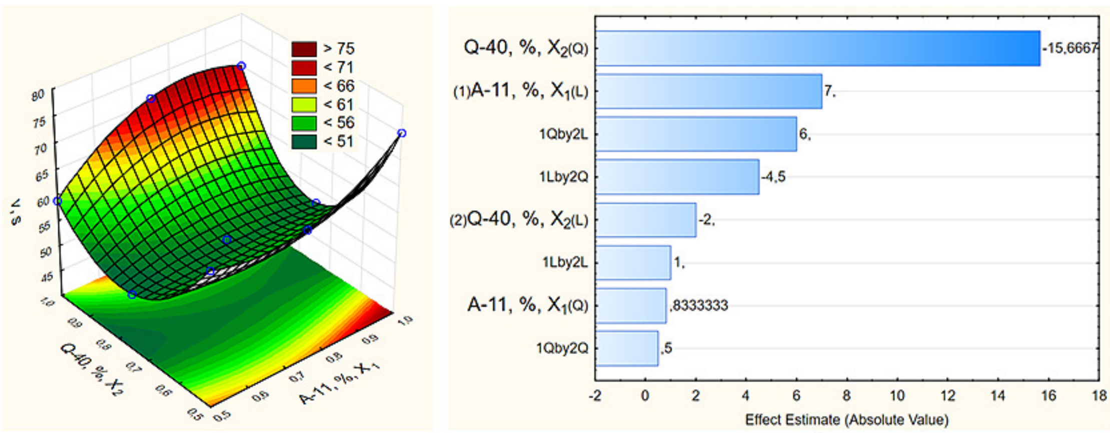
On the response surface (Fig. 1, a), the area of minimum density values is clearly visible, which is limited by the concentration values of Betolin® A-11 (factor x1) from 0.5 to 0.6% and Betolin® Q 40 (factor x2) from 0 , 5 to 0.66% and has a density value lower than that of the control composition. All other areas of the response surface meet the regulatory level requirement. The absolute value of the effect estimates (0.022) corresponds to the factor x2 (Fig. 1, b). Betolin additions increase the density value by 1.02 times in comparison with the control one.



a b

Figure 1: Response surfaces from the influence of variable factors on changes in density (a) and Pareto effects (b)

In fig. 2, a, two areas of the factor space are marked, which satisfy the normative level of technological viscosity. The first area is limited by the concentration of Betolin® A-11 (factor x1) from 0.5 to 0.58%, Betolin® Q 40 (factor x2) from 0.71 to 0.88%; second area, the concentration of Betolin® A-11 (factor x1) additives from 0.84 to 1.0%, Betolin® Q 40 (factor x2) from 0.72 to 0.86%. Betolin additives contribute to the thickening of paints by 1, 31 times in comparison with the additive-free composition. Slight thickening does not interfere with the application of fire-retardant paint to wood substrates. The absolute values of the effect assessment (0.83-1 and 6-7) correspond to the factor x1 (Fig. 2, b).

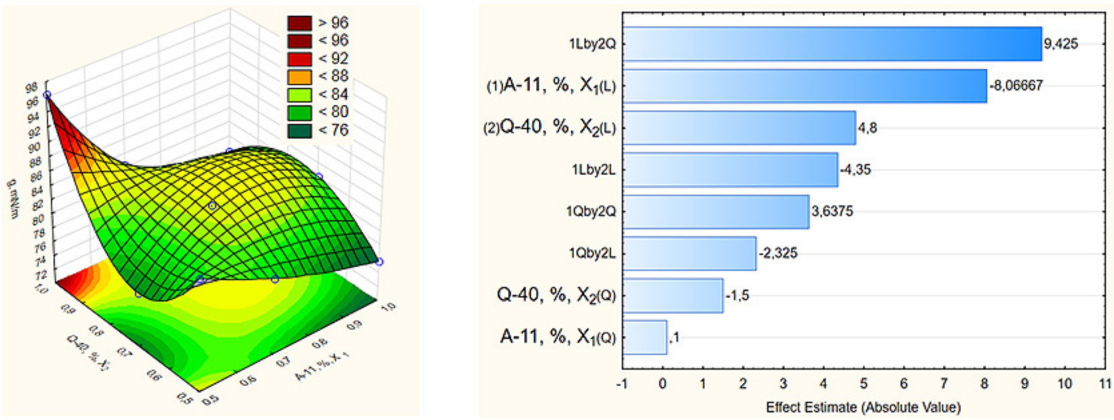


a b

Figure 2: Response surfaces from the influence of variable factors on changes in process viscosity (a) and Pareto effects (b)

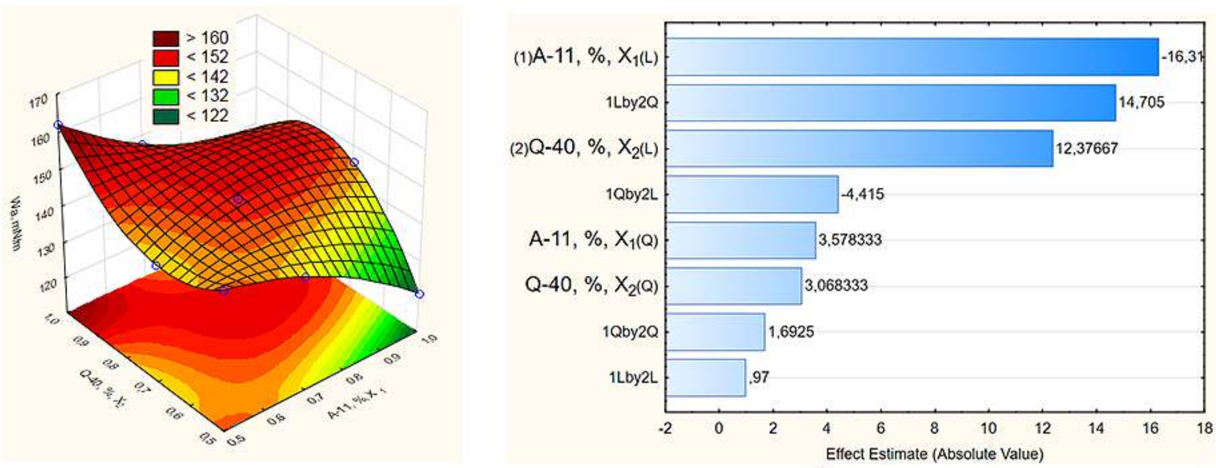
In fig. 3, a, three areas of the factor space are identified that satisfy the normative level of surface tension. The first area is limited by the concentration of Betolin® A-11 (factor x1) from 0.5 to 0.58%, Betolin® Q 40 (factor x2) from 0.58 to 0.82%; second area, the concentration of Betolin® A-11 additives (factor x1) from 0.76 to 1.0%, Betolin® Q 40 (factor x2) from 0.5 to 0.65%; the third area with concentrations of additives Betolin® A-11 (factor x1) from 0.76 to 1.0%, Betolin® Q 40 (factor x2) from 0.94 to 1.0%. Betolin additives increase the surface tension of the paint by a factor of 1.31 in the thickening of paints compared to the control composition, which is not a detrimental moment when the paint is applied to the substrate. The absolute values of the effect assessment (4,8) correspond to the factor x2 (Fig. 3, b).

In fig. 4, a the area of the factor space is marked, limited by the concentrations of Betolin® A-11 (factor x1) from 0.82 to 1.0% and Betolin® Q 40 (factor x2) from 0.5 to 0.6% in which the values the indicator of the work of the forces of adhesion to the substrate does not correspond to the normative levels. All other areas of factor space located on the response surface satisfy the requirements. Betolin additives increase the values of the work of adhesion forces by 1.2 times in comparison with the control composition. The absolute values of the effect assessment (1.69-3.58 and 12.38-14.71) correspond to the factor x2 (Fig. 2, b). (Fig. 4, b).



a b

Figure 3: Response surfaces from the influence of variable factors on changes in surface tension (a) and Pareto effects (b)



a b

Figure 4: Response surfaces from the influence of variable factors on the work of cohesion forces (a) and Pareto effects (b)

In fig. 5, a, two areas of the factor space are highlighted that satisfy the normative level of the work of the forces of cohesion. The first area is limited by the concentration of Betolin® A-11 (factor x1) from 0.5 to 0.52%, Betolin® Q 40 (factor x2) from 0.62 to 0.78%; the second area, with the concentration of the additives Betolin® A-11 (factor x1) from 0.88 to 1.0%, Betolin® Q 40 (factor x2) from 0.5 to 0.56%. Betolin additions increase the values of the work of cohesion forces by 1.3 times in comparison with the control composition. The absolute values of the estimate of the effect (9.6) correspond to the factor x2 (Fig. 5, b).

In fig. 6, a show the area of the factor space, limited by the concentrations of Betolin® A-11 (factor x1) from 0.56 to 1.0% and Betolin® Q 40 (factor x2) from 0.5 to 1.0%, in which the values the work of the forces of wetting paints with the base corresponds to the normative levels. Betolin additives increase the values of the work of adhesion forces by 1.09 times compared to the control composition. The absolute values of the estimate of the effect (**??**) correspond to the factor x2 (Fig. 2, b). (Fig. 6, b).

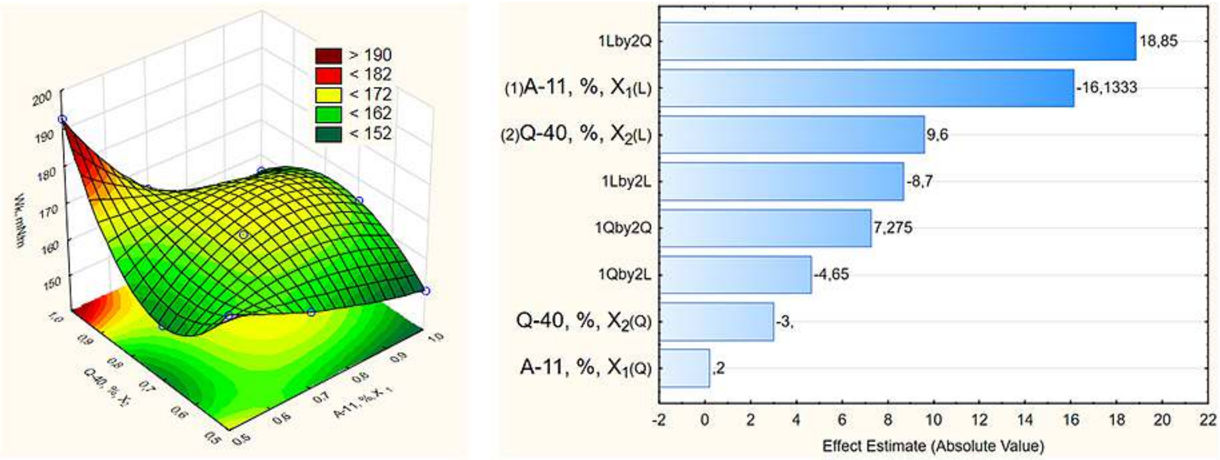


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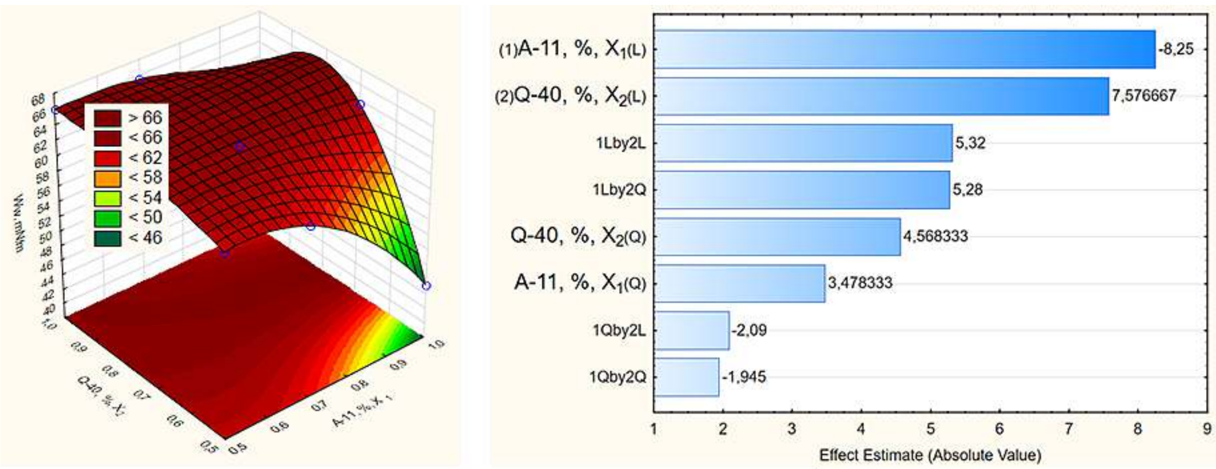
Figure 5: Response surfaces from the influence of variable factors on the work of cohesion forces (a) and Pareto effects (b)



a b

Figure 6: Response surfaces from the influence of variable factors on changes in the work of wetting forces (a) and Pareto effects (b)

In fig. 7, a, three areas of the factor space are identified that satisfy the standard level of the wetting coefficient. The first area is limited by the concentration of Betolin® A-11 (factor x1) from 0.5 to 0.53%, Betolin® Q 40 (factor x2) from 0.65 to 0.82%; the second area, the concentrations of the additives Betolin® A-11 (factor x1) from 0.72 to 0.92%, Betolin® Q 40 (factor x2) from 0.92 to 1.0; the third area, the concentrations of the additives Betolin® A-11 (factor x1) from 0.95 to 1.0%, Betolin® Q 40 (factor x2) from 0.78 to 0.92%. The addition of betolin promotes a 1.01-fold increase in the wetting of fire-retardant paints over the surface of the substrate in comparison with the control composition. The absolute values of the estimate of the effect (0.04) correspond to the factor x2 (Fig. 7, b).

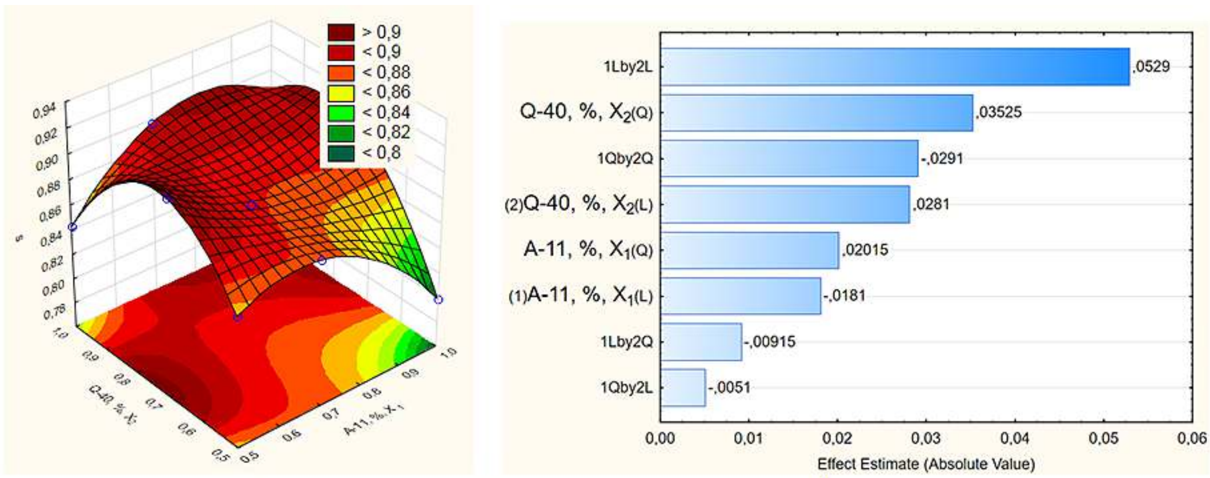


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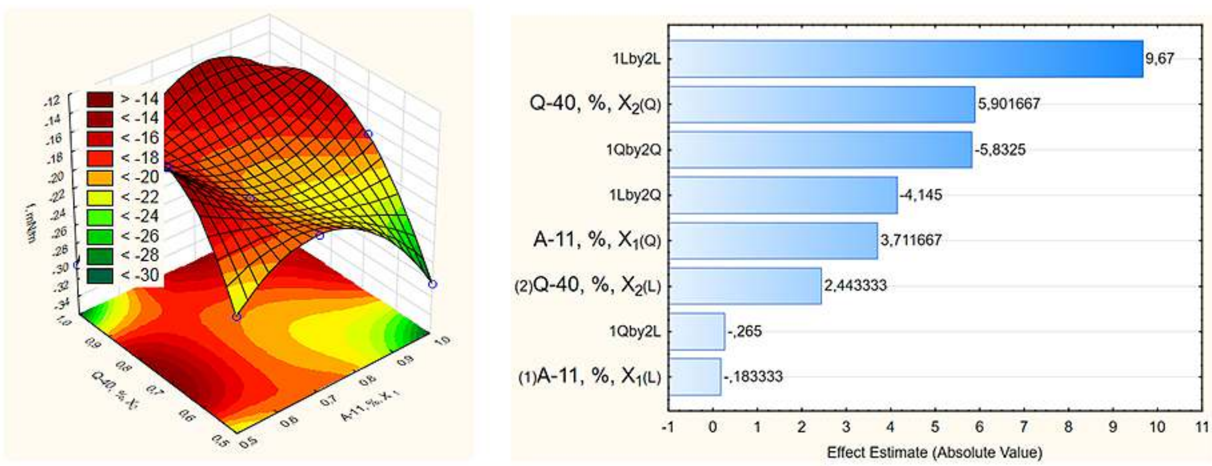
Figure 7: Response surfaces from the influence of variable factors on changes in the wetting coefficient (a) and Pareto effects (b)

In fig. 8, a, three areas of the factor space are identified that satisfy the standard level of the spreading coefficient. The first area is limited by the concentration of Betolin® A-11 (factor x1) from 0.5 to 0.63%, Betolin® Q 40 (factor x2) from 0.6 to 0.86%; the second area, the concentrations of the additives Betolin® A-11 (factor x1) from 0.72 to 0.92%, Betolin® Q 40 (factor x2) from 0.92 to 1.0; the third area, the concentrations of the additives Betolin® A-11 (factor x1) from 0.99 to 1.0%, Betolin® Q 40 (factor x2) from 0.84 to 0.9%. The addition of betolin, in the marked areas of the response surface factor space, promotes a 1.05-fold increase in the spreadability of fire-retardant paints over the substrate surface as compared to the control composition. The absolute values of the estimate of the effect (9.67) correspond to the factor x2 (Fig. 8, b).



a b

Figure 8: Response surfaces from the influence of variable factors on changes in the spreading coefficient (a) and Pareto effects (b)

Using the method of superposition of response surfaces, the optimal ranges of concentrations of Betolin additives are determined, which satisfy the regulatory levels of fire retardant paints, namely: the first area limited by the concentrations of Betolin® A-11 (factor x1) from 0.5 to 0.54%, Betolin® Q 40 (factor x2) from 0.62 to 0.68%; the second area, the concentrations of the additives Betolin® A-11 (factor x1) from 0.72 to 0.88%, Betolin® Q 40 (factor x2) from 0.9 to 1.0%.

The optimization results were implemented in the production of fire-retardant paints for products and structures of their wood in the conditions of Geofip LLC (Kropyvnytskyi, Ukraine) under the FD5 trademark.

4 Conclusion

The paper presents the results of studies on the effect of viscosity stabilizers on the rheological properties of fire-retardant paints for products and structures of their wood. Optimization of viscosity stabilizers was carried out using a two-factor three-level design of the Box-Benkin experiment. Using the method of superposition of the response surfaces of the output parameters, the optimal ranges of the concentrations of Betolin additives were determined, which satisfy the regulatory levels for fire retardant paints, namely: the first area limited by the concentrations of Betolin® A-11 (factor x1) from 0.5 to 0.54%, Betolin® Q 40 (factor x2) 0.62 to 0.68%; in the second area - the concentration of additives Betolin® A-11 (factor x1) from 0.72 to 0.88%, Betolin® Q 40 (factor x2) from 0.9 to 1.0%.

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References

Barrer, R. (1982). *Hydrothermal chemistry of zeolites.* London Academic Press.

Berzins, A., Morozovs, A., Gross, U., Iejavs, J. (2017). Mechanical properties of wood–geopolymer composite. *Eng Rural Dev*, 16, 1167–1173.

Ershov, Yu.A. (2013). Colloidal chemistry. Physical chemistry of dispersed systems. *GEOTAR-Media*, Moscow, 352.

Guzii, S.G., Krivenko, P.V. (2011). Wood protection from burning using the geopolymer compositions. Building materials, products and sanitary engineering, *J. Collection of scientific publications,* 41, 56-64 (in Russian).

Guzii, S., Krivenko, P., Bondarenko, O., Kopylova, T. (2019). Study on physico-mechanical properties of the modified alkaline aluminosilicate adhesive-bonded timber elements. *Solid State Phenomena,* 296, 112-117.

Guzii, S., Bazhelka, I., Svitlychna, N. Lashchivskiy, V. (2020). Protection of Wood from Burning with Paints on Alkaline Aluminosilicates-Based. *Materials Science Forum*, 1006, 19-24.

Guzii, S.G., Kopylova, T.I., Bazhelka, I.K. (2020). Assessment of fire-retardant properties of mineral paints for wood. Problems of Emergency Situations: Proc. *Inter. Scien. & Pract. Conf.*, Kharkiv, National University of Civil Protection of Ukraine, 45-47.

Guzii, S.G. (2017). Investigation of the influence of organomineral additives on the colloid-chemical properties of geocement dispersion. *J. Technology audit and production reserves*, *1*(35), 38-43.

Guzii, S., Kryvenko, P., Guzii, O., Yushkevych, S. (2019). Determining the effect of the composition of an aluminosilicate binder on the rheotechnological properties of adhesives for wood. *Eastern-European Journal of Enterprise Technologies*, *6*(6).

Glazacheva, E.N., Uspenskaya, M.V. (2015). Colloidal chemistry. Methodical instructions for laboratory work. St. Petersburg: *ITMO University*, 62.

Kravchenko A., Guzii, S. (2015). Determining the fire resistance properties of timber, protected by geocement-based coatings. *Eastern-European Journal of Enterprise Technologies*, *1*(5), 38-41.

Krivenko, P.V., Tsapko, Yu.V., Guzii, S.G. (2018). Fire protection of timber building structures. Theory and Practice: Monograph. Kharkiv, *Publishing house and printing house LLC Technological center*, 348.

Krivenko, P.V., Pushkareva, K.K., Sukhanevich, M.V., Guzii, S.G. (2009). Fireproof coatings on the basis of alkaline aluminum silicate systems. In: Proc. Developments in Strategic Materials: *Ceramic Engineering and Science Proceedings*, WILEY, 29(10), 129-142.

Krivenko, P.V., Guzii, S.G., Bondarenko, O.P. (2019). Alkaline Aluminosilicate Binder-Based Adhesives with Increased Fire Resistance for Structural Timber Elements. *Key Engineering Material,* 808, 172-176.

Kryvenko, P., Kyrychok, V., Guzii, S. (2016). Influence of the ratio of oxides and temperature on the structure formation of alkaline hydro-aluminosilicates. *Eastern-European Journal of Enterprise Technologies*, *5*(5-83), 40-48.

Otrosh, Yu.A., Morozova, D.N. (2019). Determination of the technical condition of buildings to ensure technogenic safety. Materials of the Third Scientific and Practical Conference *Construction Law: Problems of Theory and Practice*, Kyiv, 163-165.

Otrosh, Yu.A. (2018). Development of an approach to determining the technical state of building structures under the action of force and high-temperature influences. *Bulletin of the Odessa State Academy of Civil Engineering and Architecture*, 71, 54-60.

Rasev, A.I., Kosarin, A.A., Krasukhina, L.P. (2010). Technology and equipment for protective wood processing. *MGUL*, Moscow, 171.

Voznesensky V.A., Lyashenko T.V., Ogarkov B.L. (1989). *Numerical methods for solving construction and technological problems on a computer*. Kyiv, High School, 328.