PREPARATION AND RESEARCH OF NICKEL PHTHALOCYANINE PIGMENT BASED ON MAGNESIUM-BORON CATALYST

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Abstract: *This study investigated the synthesis of nickel phthalocyanine pigment and the physicochemical properties of the obtained pigments using a boron-containing catalyst. As part of the research, the technology for securing nickel phthalocyanine pigment was developed and its molecular structure, thermal stability, SEM analysis, spectral properties, and other physicochemical parameters were analyzed. The obtained results demonstrated the efficiency of the boron-containing catalyst in the synthesis of nickel phthalocyanine. This research provided a scientific basis for the application of these pigments in various fields and will help expand future production and application possibilities of nickel phthalocyanine pigments.*

Keywords: *nickel phthalocyanine, photophysical chemistry, electrocatalysts, photocatalysts, and solar cells.*
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Introduction

Phthalocyanines (Pcs) are durable and bright blue pigments, important for their high chemical, thermal and light stability, and true photophysical properties. The use of electrocatalysts and photocatalysts based on the electrochemistry and photophysical chemistry of phthalocyanines is noteworthy. In photocatalysis, photodynamic antimicrobial chemotherapy, in electrocatalysis, phthalocyanines are used to detect pollutants and molecules of environmental importance [1]. In particular, due to the dye-sensitizing property of phthalocyanine molecules, solar cell (DSSC) polyethylene products occupy a very important place in the development of products with photodynamic properties, since they are of practical importance as photosensitizers to be added to these devices [2]. To improve the application of phthalocyanine molecules, large-scale structural modification methods are used. Identification of various optically active porphine and phthalocyanine molecules as bioactive substrates is carried out with possible future research directions [3]. After introducing various derivatives into the molecules of phthalocyanines and porphyrins, and all aspects of structural variability are of practical importance. Determination of the variability of various phthalocyanines using synthetic methods is considered by converting them to expected symmetrically or asymmetrically substituted derivatives using special methods [4]. The chemical "inertness" of metal phthalocyanines (MePs) is one of their key characteristics, making them stable and long-lasting industrial dyes. The redox properties of metal phthalocyanines have also been studied in recent years, and some detailed information is available to carry out research with redox catalysts in chemical processes. Here, the catalytic activity of metal phthalocyanines and their dioxide as oxidants is studied with particular emphasis on the last decade [5]. The solubility properties of a series of substituted metal phthalocyanines with different metal atoms such as Co, Cu, Fe, -, Mn, Ni, Sn, and Zn were quantitatively investigated using three different solvents, i.e., common solvents, ionic liquids, and acids. Liquids include

20 typical representatives from acetone to toluene [6-10]. Because phthalocyanines (Pc) have high photophysical properties, their useful properties as photosensitizers for photodynamic therapy of cancer are of practical importance. To this end, the optimized photoproperties of phthalocyanines with secondary therapeutic actions have been used in various strategies [11, 12]. The same photocatalysis is of practical importance in reactions that produce chemical compounds with high selectivity for energy production. Some photocatalysts are used in synthetic materials in traditional ways [12, 13].

The aim of this research is to synthesize nickel-containing phthalocyanine (Ni-Pc) pigment based on substances such as Phthalanhydride, Urea, Magnesium Acetate, Nickel Chloride and Orthoboric Acid, study its composition and physicochemical properties, as well as its application.

Experimental part

Materials. Phthalanhydride, Urea, Magnesium Acetate, Nickel Chloride and Orthoboric Acid were used for synthesis of nickel-containing phthalocyanine (Ni-Pc) pigment. All substances were used in chemical purity suppliers of materials: Varnish: OJSC "Krata" sh. Tambov, RF; Titanium Dioxide: Du Pont USA; Merit Chemicals. Nephras and microcalcite are local raw materials.

Methods. *IR analysis* of pigment was performed using SHIMADZU IR-Fury spectrophotometer (Japan) at 400 and 4500 cm^{-1}. *SEM-EDX- analysis***.** The images of the surface of the pigment obtained in different sizes were taken on a JSM-IT200 device with elemental dispersion analysis (SEM - EDX) belonging to the Japanese company JEOL. *TGA and DTA analysis*. Thermogravimetric studies of changes in the physicochemical properties of the obtained pigment under the influence of temperature were studied on the DTG-60 device, SHIMADZU (Japan). Analytical conditions: in an argon atmosphere (80 mi/min), the rate of heating was 10 C/min.

Pigment synthesis (Fig. 1.). The catalyst is of particular importance in the synthesis of nickel-containing phthalocyanine (Ni--Pc) pigment: Phthalanhydride - 18 g, Urea - 72 g, Magnesium acetate — 1.7 g, Nickel chloride - 6 g, Orthoboric acid - 0.3 g.

Determining the role of the catalyst. Bor (B) stimulates reaction kinetics due to its structural properties, which increases the efficiency of the synthesis process and reduces the formation of by-products. Magnesium, in turn, provides an alkaline environment during complex formation and reinforces the role of the nickel ion as the central metal. In the process of synthesis, all substances are measured in specified quantities, mixed thoroughly and placed in a heat-resistant glass. Then this glass is placed in a special oven at a temperature of 187°C, and the reaction is continued for 2.2 hours. When the substance in the beaker is weighed after the reaction is complete, it is found that 42.6 g of the substance remains. The remaining substance is crushed and 43 ml of sulfuric acid (H_2SO_4) is added to it. This mixture is dissolved in acid medium for a day. After the reaction, the substance formed is placed in a 1-liter container, washed in clean water, and a 3% alkali solution is added for neutralization.

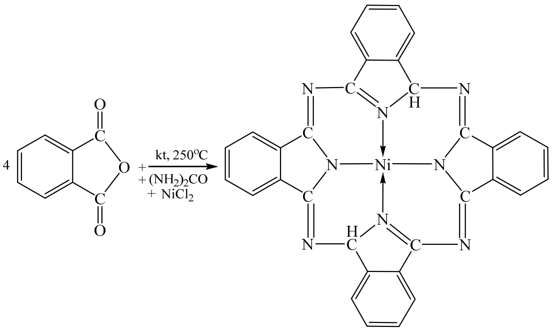

Fig. 1. Reaction of nickel-preserving phthalocyanine pigment.

We studied the IR (infrared) spectroscopy analysis of the resulting nickel phthalocyanine (NiPc) pigment.

IR spectrum analysis. Chemical bonds and functional groups in the structure of nickel phthalocyanine (NiPc) are determined using IR spectroscopy. Below is an explanation of the wavenumbers of the main bands in the loaded spectrum and their relationship to molecular vibrations.

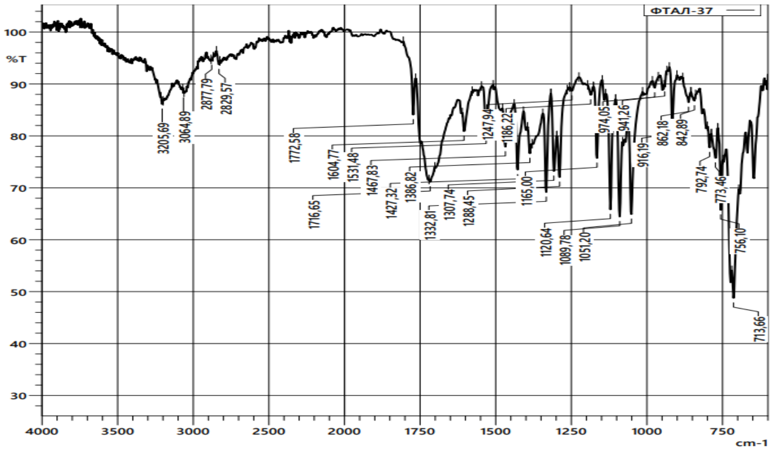

Fig. 2. IR spectrum of a nickel-containing phthalocyanine pigment.

This phthalocyanine is useful in various paints, electronic sensors, and solar batteries. Information in the IR spectrum confirms the complex structure of the substance and its chemical inertness and stability (Fig. 2.):

1. 3205 cm⁻¹ – 3400 cm⁻¹: valence vibrations of O–H or N–H bonds are observed in this range. This may indicate the presence of companion hydroxyl or amine groups in the phthalocyanine molecule.
2. 2925 cm⁻¹ – 2850 cm⁻¹: C–H valence vibrations indicate the presence of paraffinic or aliphatic chains, which may indicate organic linkages or new alkyl additions.
3. 1720 cm⁻¹ – 1700 cm⁻¹: in the case of C=O (carbonyl groups), additional organic functional groups are likely present.
4. 1600 cm⁻¹ – 1500 cm⁻¹: bands in this range are characteristic of C=C vibrations of aromatic rings. This reflects the aromatic bonds and porphyrin-like structures in the phthalocyanine molecule.
5. 1280 cm⁻¹ – 1100 cm⁻¹: corresponds to C–N or C–O–C vibrations. This range confirms the presence of nitrogen bonds or ether groups in the metal-complex.
6. 1100 cm⁻¹ – 900 cm⁻¹: the bands here refer to vibrations of the bond between the central nickel and nitrogen atoms.
7. 750 cm⁻¹ – 700 cm⁻¹: these are thermal vibrations of the aromatic rings, indicating the presence of a multi-ring system in the phthalocyanine structure.

This IR spectrum analysis clearly shows the presence of aromatic rings, nitrogen and metal bonds in the nickel phthalocyanine (NiPc) molecule. As can be seen from the spectrum, the material has a highly stable and metal-bonded organic structure. Nickel and carbon atoms form a central structure bonded to nitrogen, which provides electrical conductivity and optical properties to the pigment.

TGA and DTA analysis (Fig. 3.). The variation of pigment yield concerning temperature was studied during synthesizing of nickel-containing phthalocyanine (NiPc) pigment. The best temperature for synthesizing nickel-retaining phthalocyanine (NiPc) pigment was found to be 200 °C. Based on the experiments, the nickel-preserving phthalocyanine pigment gives the highest result at 200 °C. It can be seen that the significance of the intensity of pigment synthesis is characteristic of pigments obtained at low temperatures [14, 15].

The first stage: 27.30°C — 252.36 °C, mass loss was 45.316% (-2.046 mg). DTA analysis: this stage is an endothermic process with a temperature range of 192.90 °C (onset)–230.03 °C (endset); peak point was 218.23 °C; heat amount was (-1.53) J. The mass loss is mainly due to the separation of adsorbed water and volatile molecules. This is due to the first thermal transformation of the nickel phthalocyanine pigment.

The second stage covers the temperature range of 252.36 °C to 484.03 °C with a mass loss of 12.647% (-0.571 mg). DTA analysis: peak represents the exothermic reaction, with 293.96 °C (onset) and 327.06 °C (endset) temperatures, peak point at 318.34 °C, and thermal energy of (-459.98) J. In this stage, organic components burn and produce gas. Decomposition of organic compounds in the structure of nickel phthalocyanine occurs. The release of molecules resistant to high temperatures is also observed.

The third stage occupies temperature range from 484.03 °C to 801.63 °C, mass loss was 40.952% (-1.849 mg). DTA analysis: at this stage, endothermic or exothermic reactions occur, resulting in a temperature range from 503.61 °C (onset) to 608.46 °C (endset), a peak point of 530.04 °C, and thermal energy of (+5.23) J. Intensive decomposition and carbonation processes occur. Complete combustion of large volumes of organic matter and the release of final mineral oxides are observed [16, 17].

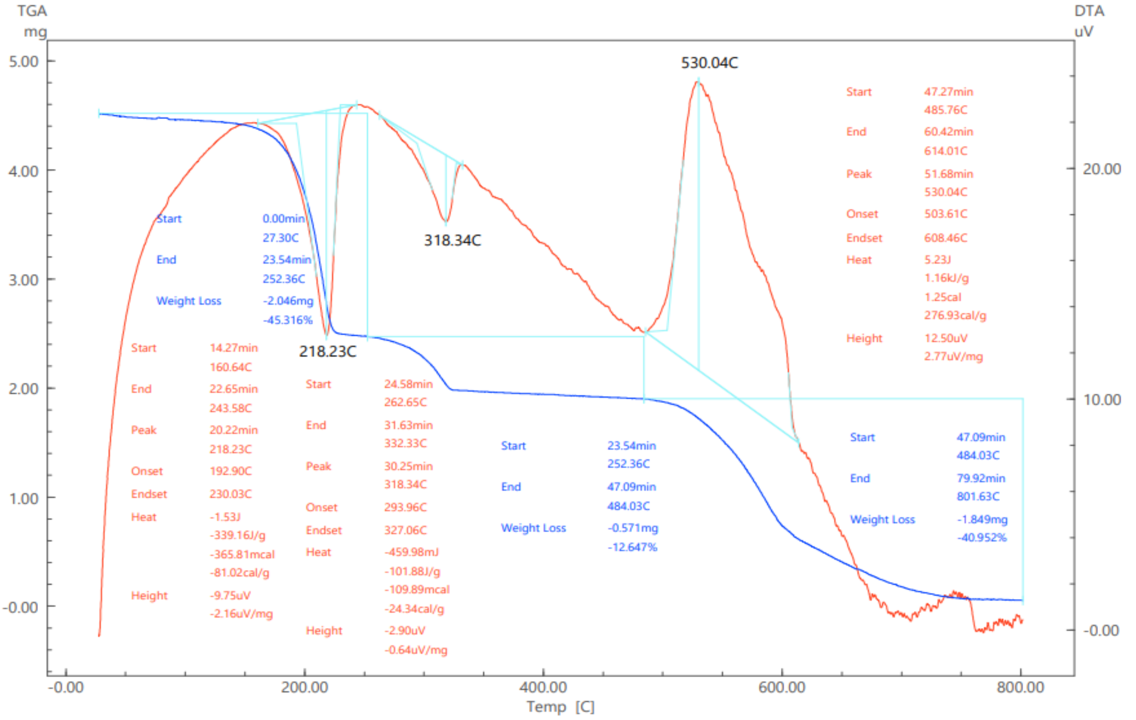

Fig. 3. TGA and DTA curves for Nickel-retaining phthalocyanine pigment (Ni--Pc)

The results of the TGA is presented in Table 1. The highest mass loss occurs in the 1st stage (45.316%). A detailed analysis of the TGA and DTA data is given in Table 1 below.

Table 1. Thermal-oxidative degradation of nickel-containing phthalocyanine pigment

№	dw 4,51	1/T	dw/dt	Mass (mg)	Minutes	T^0+K
1	4,45	0.0026	0,007	0,06	8,06	373
2	3,77	0.0021	0,040	0,74	18,31	473
3	2,26	0.0017	0,079	2,25	28,4	573
4	1,94	0.0014	0,066	2,57	38,53	673
5	1,87	0.0012	0,054	2,64	48,73	773
6	0,73	0.0011	0,064	3,78	58,93	873
7	0,17	0,0010	0,063	4,34	69,33	973
8	0,04	0,0009	0,056	4,47	79,75	1074

Thus, based on the experimental data obtained on the kinetics of processes in the temperature range from 27.30 to 801.63 °C, the characteristics of the thermal-oxidative degradation of the nickel-preserving phthalocyanine pigment (NiPc) sample were studied (Table 2).

Table 2. Activation energy values of nickel-retaining phthalocyanine pigment (Ni--Pc)

№	dw	Ln(W_1/W_2)	1/T *10^{-3}
1	4,45	0,0134	2,6
2	3,77	0,1792	2,1
3	2,26	0,6909	1,7
4	1,94	0.8437	1,4
5	1,87	0,8804	1,2
6	0,73	1,8213	1,1
7	0,17	3,2807	1
8	0,04	4,7330	0,9

SEM and EDX analyses of the nickel-containing phthalocyanine pigment showed the presence and spatial distribution of key elements such as carbon (C), oxygen (O), sulfur (S), and nickel (Ni) in the pigment structure. SEM of nickel-retaining phthalocyanine pigment was performed under a high vacuum. Microanalysis of chemical elements of pigments was carried out in the same device, studied in fields with an accelerating voltage of 20 keV and a current of 1 nA. A scanning electron microscope view of the resulting nickel-containing phthalocyanine (NiPc) pigment is given. Figure 4 shows that the initial substances are completely dispersed [18, 19].

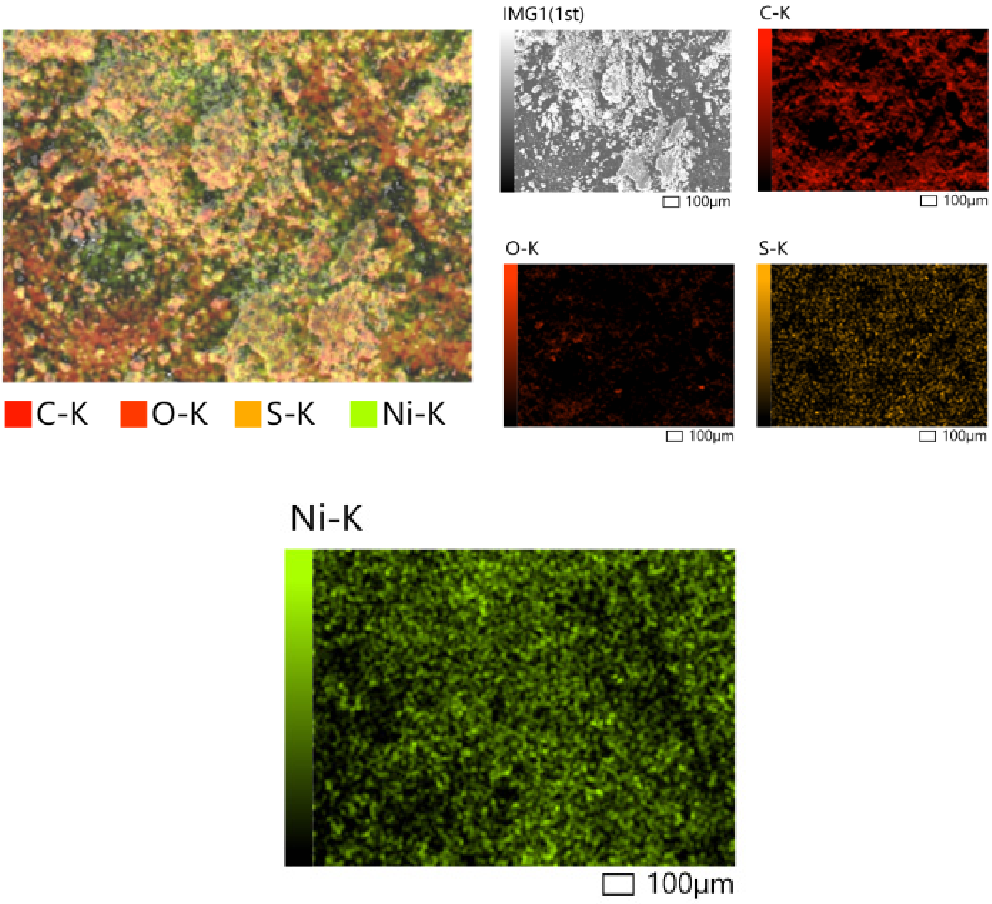

Fig. 4. SEM analysis of nickel-containing phthalocyanine pigment

C-K (Carbon): marked in red and indicates the main organic structure in the pigment. Carbon atoms form the backbone of the phthalocyanine molecule, highlighting its aromatic ring structure. O-K (oxygen): given in orange and confirms the presence of oxygen.

This element can interact with metal ions to form oxides or hydroxyl groups. The presence of oxygen is important in catalytic processes. S-K (sulfur): given a yellow color and indicates the presence of thiophene or sulfide groups in the pigment. This substance can affect the optical and electrical properties of the pigment. Ni-K (Nickel)—shown in green and shows the distribution of nickel as the central metal complex of the pigment. The nickel ion is the central atom and acts as a catalyst or conductive component in the phthalocyanine structure. The uniform distribution of nickel indicates that it provides a homogeneous metal-complex structure. These SEM and EDS analyses confirm the presence of elements important for the electrical and catalytic activity of the nickel and magnesium-containing phthalocyanine pigment. In this pigment, metal ions bound to the carbon structure and organic substances interact, opening the way for its application in various fields. The presence of nickel makes it an especially effective catalyst for oxidation reactions and electrochemical sensors [20, 21].

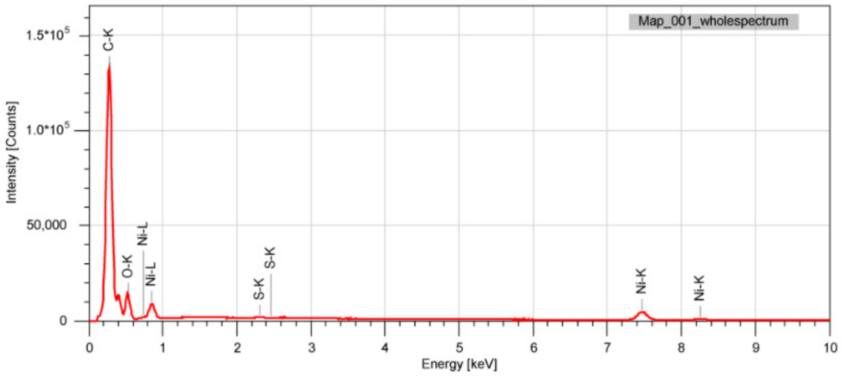

Fig. 5. Elemental analysis of nickel-containing phthalocyanine (NiPc) pigment.

Table 3. Elemental analysis of nickel-containing phthalocyanine (NiPc) pigment

Element	C	O	S	Ni
Mass%	78,44	15,56	0,11	5,89
Atom %	85,85	12,78	9,72	1,32

According to the SEM elemental analysis of the nickel-containing phthalocyanine (NiPc) pigment we synthesized, it was found that the nickel-containing phthalocyanine (NiPc) pigment contains all the elements in the complex compound. This means that the nickel-containing phthalocyanine (NiPc) pigment is actually complexed [22].

Preparation of the paint: a laboratory pearl mill was used to make paint from the synthesized (NiPc) pigment. The requirement for paint products is to mix the coloring pigment well and bring it into a homogeneous system. As a result of this, dispersing, i.e., sharply crushing the pigment particles, spreading agglomerates, or obtaining a fine suspension, is ensured. In the production of paint, pigment and paint raw materials are mixed at high speed in a special iron container with the help of a dispersing knife, and the solids are transferred to the same suspension medium [23]. When making paints by adding alkyd enamels (NiPc) pigment, a pigment paste is obtained according to the recipe. It is prepared according to the content given in Table 4.

Table 4. PF-115 blue alkyd enamel composition

№	**Components name**	**Content mass. %**
1	Varnish PF-060 (52%)	69,8
2	Titanium dioxide R-706	0,5
3	Copper-calcium phthalocyanine	4,5
4	Microcalcite	20,04
5	Bentogel BG-4	0,4

6	Dry MIX	0,2
7	Methylethylketoxime	0,3
8	Nefras C-4 135/220	4,26

After adding varnish, titanium dioxide, copper-calcium phthalocyanine, microcalcite, and bentogel, it is dispersed in a bead mill at room temperature for 2 hours (dsh = 3-3.5 mm, 1500-2000 min^{-1}) until it reaches a homogeneous state and a pigment paste is prepared, then enamel is formed by adding siccative, methylethylketoxime, and nephros.

Table 5. Comparison of PF-115 enamels with synthetic nickel-preserving phthalocyanine (NiPc) pigment on standard demand

№	**Name of pointers**		**Indicator standard**	**Su-CaPc Result**
1		The color of the enamel coating	"Kortotek" number	Suit
	a)	The blue	423, 424	
	b)	Blue	427, 428	
2		Appearance of the coating	After drying, the enamel forms a smooth, homogeneous coating without foreign particles	Suit
	a)	The blue 423		
	b)	Blue		
3		The glossiness of the coating according to the photoelectric blescomer device, %, is not low	Standard according to GOST 896-69	
	a)	The blue 423	50	52
	b)	Blue	50	50
4		Viscometer VZ-246 (nozzle diameter 4mm) conditional viscosity at a temperature of 20±0.5 °C	Standard according to GOST 8420-74	
	a)	The blue 423	80-120	108
	b)	Blue	80-120	103
5		Mass fraction of non-volatile substances, %	Standard according to GOST 17537-72	
	a)	The blue 423	60-66	63
	b)	Blue	60-66	62
6		28-30 s dilution rate viscometer VZ-246 (nozzle diameter 4mm) at a temperature of 20±0.5 °C, %, not much	Standard according to GOST 17537-72	
	a)	The blue 423	20	20
	b)	Blue	20	20
7		Grinding degree, µm, not much	Standard according to GOST 6589-74	
	a)	The blue 423	25	25
	b)	Blue	25	25
8		Density of dried coating, g/m2, not much	Standard according to GOST 8784-75	
	a)	The blue 423	60	60
	b)	Blue	40	40
9		20±2 °C ҳароратда қуриш вақти даражаси, соат, кўп эмас	Standard according to GOST 19007-73	
	a)	The blue 423	24	24
	b)	Blue	24	24

10	The elasticity of the coating in bending, mm, is not much		Standard according to GOST 6806-73	
	a)	The blue 423	1	1
	b)	Blue	1	1
11	The impact resistance of the coating according to the U-1 tool, cm, is not less		Standard according to GOST 4765-73	
	a)	The blue 423	40	40
	b)	Blue	40	40
12	The hardness of the coating on the pendulum tool M-3, ShB (conditional symbol), is not less		Standard according to GOST 5233-89	
	a)	The blue 423	0,25	0,25
	b)	Blue	0,25	0,25
13	Coating adhesion (score), not much		Standard according to GOST 51140-98	
	a)	The blue 423	1	1
	b)	Blue	1	1
14	At a temperature of 20±2 °C, the resistance of the coating to the static effect of water, hours, is not less		Standard according to GOST 9,403-80	
	a)	The blue 423	2	2
	b)	Blue	2	2
15	Resistance to the static effect of a 0.5% solution of coating detergents, min, is not less		Standard according to GOST 9,403-80	
	a)	The blue 423	15	15
	b)	Blue	15	15
16	The resistance of the coating to the static effect of transformer oil at a temperature of 20±2 °C, hours, is not less		Standard according to GOST 9,403-80	
	a)	The blue 423	24	24
	b)	Blue	24	24

From the Table 5 above, it is clear that these blue phthalocyanine enamel coatings comply with "Kortotek" standards, have a smooth and uniform structure, gloss at the required level, viscosity and dry coating density within the specified range, meet GOST standards for flexibility, impact resistance, hardness and adhesion, and demonstrate high resistance to water and washing solutions, which confirms their high quality.

Derivatogram of alkyd enamel PF-115.

The derivatogram of an alkyd enamel PF-115 sample containing nickel-phthalocyanine (NiPc) pigment is presented, comprising two curves (Fig. 7). No endothermic or exothermic effects were detected on the differential thermal analysis (DTA) curve.

The first stage (24.49°C–266.42°C) is an endothermic process with an 8.19% mass loss (-0.167 mg), where volatile molecules like water are released due to heat absorption. This continuous process depends on the desorption energy of molecules.

The second stage (266.42°C–541.52°C) is exothermic, with a 31.09% mass loss (-0.634 mg) and energy release due to the decomposition and combustion of organic substances, particularly the thermal breakdown of nickel phthalocyanine's aromatic rings. This stage involves gas evolution, radical reactions, and intense energy release, as indicated by DTA data.

The third stage (541.52°C–801.61°C) is also exothermic, with a 26.39% mass loss (-0.538 mg), involving the combustion of residual organic matter and its conversion into carbonates or oxides. Nickel phthalocyanine components show high thermal stability, and the total energy release of 5.23 J confirms the complete degradation process.

The first stage covers the temperature range from 24.49°C to 266.42°C, the mass loss is 8.190% (-0.167 mg), peak temperature is 25.41 min, reaching a downward point. (Endothermic) process in which adsorbed volatile molecules (e.g. water) are released under the influence of heat. Energy is required to separate the volatile molecules from the substance. It is a continuous endothermic process, the energy consumption of which depends on the desorption energy of the molecules.

The second stage covers the temperature range from 266.42°C to 541.52°C, mass loss was 31.094% (-0.634 mg), and the peak temperature at 52.33 minutes. Energy release is observed. (Exothermic) process, in which decomposition and combustion of organic substances occur. The aromatic rings of nickel phthalocyanine undergo thermal decomposition. The exothermic character is accompanied by energy release since the combustion process of organic substances occurs. The reaction at this stage involves the decomposition of organic rings, the evolution of gases, and the release of energy. The amount of energy in these processes is extremely high since the combustion of nickel phthalocyanine accelerates the energy release;

The third stage is from 541.52°C to 801.61°C; mass loss was 26.385% (-0.538 mg) and peaks at temperature 80.23 minutes. Energy release is observed. This stage is characterized by the combustion of organic matter remaining at high temperatures and the carbonation or mineralization of residual matter. This process is exothermic, and the release of the resulting gases is accompanied by energy release. A large amount of organic and structural matter is converted to carbonates or oxides. Nickel phthalocyanine components are resistant to high temperatures, and their conversion to mineral residues is observed. An energy release of 5.23 J or more is recorded. This confirms the complete degradation process at low temperatures.

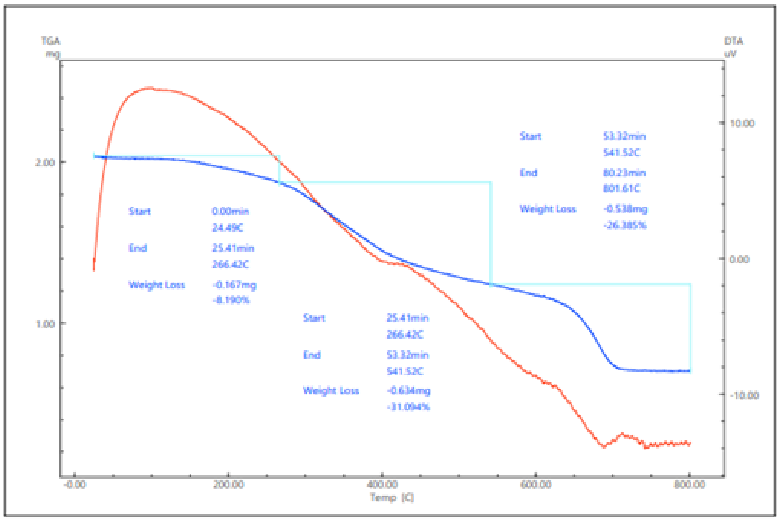

Fig.7. TGA and DTA curves for alkyd enamel PF-115 sample with addition of nickel-preserving phthalocyanine (NiPc) pigment

A detailed analysis of the TGA and DTA curves is given in Table 6 below.

Table 6. Effect of temperature on weight loss of alkyd enamel PF-115 sample with nickel-preserving phthalocyanine (NiPc) pigment

№	dw 2.03	1/T	dw/dt	M.g	Min	T^0+K
1	2.01	0.0026	0.002	0.02	7.68	373
2	1.96	0.0021	0.003	0.07	17.68	473

3	1.82	0.0017	0.007	0.21	27.68	573
4	1.48	0.0014	0.014	0.55	37.68	673
5	1.29	0.0012	0.016	0.74	44.35	773
6	1.19	0.0011	0.014	0.84	57.65	873
7	0.87	0.0010	0.017	1.16	67.63	973
8	0.70	0.0009	0.016	1.33	80.23	1099

The activation energy values of this process are shown for a sample of alkyd enamel PF-115 with addition of nickel-retaining phthalocyanine (NiPc) pigment (Table 7).

Table 7. Results of thermal-oxidation analysis of alkyd enamel PF-115 sample with addition of nickel-preserving phthalocyanine (NiPc) pigment

№	dw 2.03	Ln(W_1/W_2)	1/T $*10^{-3}$
1	2.01	0.0099	2.6
2	1.96	0.0351	2.1
3	1.82	0.1092	1.7
4	1.48	0.3160	1.4
5	1.29	0.4535	1.2
6	1.19	0.5340	1.1
7	0.87	0.8474	1.0
8	0.70	1.0647	0.9

Thus, on the basis of the experimental data obtained on the kinetics of processes in the temperature range from 297.49 to 1074.61 K, the characteristics of the thermal-oxidative degradation of the alkyd enamel PF-115 sample with the addition of nickel-preserving phthalocyanine (NiPc) pigment were studied.

Conclusion

According to the results of the research, the molecular structure of the nickel-containing phthalocyanine (NiPc) pigment was determined using IR-spectroscopy and the bonds between metal-complex ions and nitrogen atoms were confirmed. According to TGA analysis, 65.669% of the total mass was thermally decomposed up to a temperature of 801.61 °C. Alkyd enamel PF-115 sample with added nickel phthalocyanine (NiPc) pigment is resistant to this temperature and proved to be thermally stable. Through SEM and EDS analysis of the pigments, the regional distribution of elements such as carbon, nickel, oxygen, and sulfur was studied, and their importance for electrical conductivity and catalytic activity was shown. The stable structure and susceptibility of this compound to additives increase its potential for use in various fields, including photocatalysis, electrochemistry, and solar cell production. At the same time, pigments of this type play a key role for important innovative applications in industry and have great potential for applications in new areas such as photodynamic therapy and electronic sensors.

References

1. Nyokong T. A career in photophysicochemical and electrochemical properties of phthalocyanine - a Linstead Career Award paper. *Journal of Porphyrins and Phthalocyanines*. 2020, **Vol. 24(12)**, p. 1300-1319
2. Urbani M., Ragoussi M.-E., Nazeeruddin M.K., Torres T. Phthalocyanines for dye-sensitized solar cells. *Coordination Chemistry Reviews*. 2019, **Vol. (381)**, p. 1-6.
3. Lu H., Kobayashi N. Optically active porphyrin and phthalocyanine systems. *Chemical reviews*. 2016, Vol. 116(10), p. 6184-6261.

4. Malyasova A.S., Kostrova E.A., Abramov I.G., Maizlish V.E., Koifman O.I. Synthesis, acid-base interactions, and photostability of copper(II) tetrakis(3,5-di-tert-butylbenzoyloxy)phthalocyanine. *Russ. Chem. Bull.* 2022, **Vol. 70(12)**, p. 2405–2415. https://doi.org/10.1007/s11172-021-3360-7.
5. Botnar A.A., Domareva N.P., Erzunov D.A., Futerman N.A., Tikhomirova T.V., Maizlish V.E., Vashurin A.S. Metal complexes of tetrakis(2-carboxyphenylsulfanyl)phthalocyanine. Synthesis, spectral and catalytic properties. *Russ. Chem. Bull.* 2021, **Vol. 70(7)**, p. 1297–1303. https://doi.org/10.1007/s11172-021-3214-3.
6. El-Refaey A., Shaban Sh.Y., El-Kemary M., El-Khouly M.E. A light harvesting perylene derivative–zinc phthalocyanine complex in water: spectroscopic and thermodynamic studies. *Photochem. Photobiol. Sci.* 2020, **Vol. 16(6)**, p. 861–869. https://doi.org/10.1039/C7PP00055C.
7. Andreev V.N., Ovsyannikova E.V., Alpatova N.M. Immobilization of phthalocyanines in conducting polymers. Polyaniline-copper tetrasulfophthalocyanine. *Russ. J. Electrochem.* 2010, **Vol. 46(9)**, p. 1056–1062. https://doi.org/10.1134/S1023193510090120.
8. Germinario G., Van Der Werf I.D., Sabbatini L. Pyrolysis gas chromatography mass spectrometry of two green phthalocyanine pigments and their identification in paint systems. *J. Anal. Appl. Pyrolysis*. 2015, **Vol. 115**, p. 175–183. https://doi.org/10.1016/j.jaap.2015.07.016.
9. Mikheev Y.A., Guseva L.N., Ershov Y.A. The nature of chromaticity of triphenylmethane, xanthene, phthalocyanine, and thiazine dyes. *Russ. J. Phys. Chem. A*, 2010, **Vol. 84(10)**, p. 1778–1791. https://doi.org/10.1134/S003602440809032X.
10. Wang M., Ishii K. Photochemical properties of phthalocyanines with transition metal ions. *Coordination Chemistry Reviews*. 2022, **Vol. (468),** 214626. https://doi.org/10.1016/j.ccr.2022.214626
11. Lo P.C., Rodríguez-Morgade M.S., Pandey R.K., Ng D.K.P., Torres T., Dumoulin F. The unique features and promises of phthalocyanines as advanced photosensitisers for photodynamic therapy of cancer. *Chemical Society Reviews*. 2020, **Vol. 49(4)**, p. 1041-1056.
12. Mak C.H., Han X., Du M., Kai J.-J., Tsang K.F., Jia G., Cheng K.-Ch., Shen H.-H., Hsu H.-Y. Heterogenization of homogeneous photocatalysts utilizing synthetic and natural support materials. *Journal of Materials Chemistry A*. 2021, **Vol. 9(8)**, p. 4454-4504. https://doi.org/10.1039/D0TA08334H
13. Lourenço L.M.O., Neves M.G.P.M.S., Cavaleiro J.A.S., Tomé J.P.C. Synthetic approaches to glycophthalocyanines. *Tetrahedron*, 2014, **Vol. 70(17)**, p. 2681-2698. https://doi.org/10.1016/j.tet.2014.01.058
14. Li W., Guo X., Geng P., Du M., Jing Q., Chen X., Zhang G., Li H., Xu Q., Braunstein P., Pang H. Rational design and general synthesis of multimetallic metal–organic framework nano-octahedra for enhanced Li–S battery. *Advanced Materials*. 2021, **Vol. 33(45)**, 2105163. https://doi.org/10.1002/adma.202105163
15. Nomozov A.K., Beknazarov Kh., Khodjamkulov S., Misirov Z., Yuldashova S. Synthesis of Corrosion Inhibitors Based on (Thio)Urea, Orthophosphoric Acid and Formaldehyde and Their Inhibition Efficiency. *Baghdad Sci. J.* 2024, **Vol. 22(4)**, https://doi.org/10.21123/bsj.2024.10590**.**
16. Nomozov A.K., Eshkaraev S.Ch., Jumaeva Z.E., Todjiev J.N, Eshkoraev S.S., Umirqulova F.A. Experimental and Theoretical Studies of *Salsola oppositifolia* Extract as a Novel Eco-Friendly Corrosion Inhibitor for Carbon Steel in 3% NaCl. International Journal of Engineering Trends and Technology, 2024, **Vol. 72(9)**, p. 312-320. https://doi.org/10.14445/22315381/IJETT-V72I9P126.
18. Turaev Kh.Kh., Eshankulov Kh.N., Umbarov I.A., Kasimov Sh.A., Nomozov A.K., Nabiev D.A. Studying of Properties of Bitumen Modified based on Secondary Polymer Wastes Containing Zinc. *International Journal of Engineering Trends and Technology*, 2023, **Vol. 71(9)**, p. 248-255.

https://doi.org/10.14445/22315381/IJETT-V71I9P222.

19. Sadygova A.I. Synthesis of 1-(p-vinylphenyl)-2-diethylaminomethylcyclopropane and its radical copolymerization with methyl methacrylate. *Chemical Problems.* 2021, **Vol. 19(3)**, p. 173-178. https://doi.org/10.32737/2221-8688-2021-3-173-178.
20. Nomozov A.K. Study of processe of obtaining monopotassium phosphate based on monosodium phosphate and potassium chloride. *Chemical Problems*. 2023, **Vol. 21(3)**, p. 279-293. https://doi.org/10.32737/2221-8688-2023-3-279-293.
21. Durdibaeva R., Beknazarov K., Nomozov A., Demir M., Berdimurodov E. Exploring protective mechanisms with triazine ring andhydroxyethyl groups: experimental and theoretical insights. *Kuwait Journal of Science*. 2024, **Vol. 52**. 100341. https://doi.org/10.1016/j.kjs.2024.100341.
22. Nabiev D.A., Turaev Kh.Kh. Study of Synthesis and Pigment Characteristics of the Composition of Copper Phthalocyanine with Terephthalic Acid. *International Journal of Engineering Trends and Technology*. 2022, **Vol. 70(8)**, p. 1-9. https://doi.org/10.14445/22315381/IJETT-V70I8P201.
23. Shaymardanova M., Mirzakulov Kh., Melikulova G., Khodjamkulov S., Nomozov A.K., Toshmamatov O. Studying of The Process of Obtaining Monocalcium Phosphate based on Extraction Phosphoric Acid from Phosphorites of Central Kyzylkum. *Baghdad Sci. J.* 2024, **Vol. 22(1)**, p. 3996-4014. https://doi.org/10.21123/bsj.2024.9836**.**