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**ABSTRACT**

of the dissertation for the degree of Doctor of Philosophy

**PREPARATION AND RESEARCH OF COMPOSITE  
MATERIALS BASED ON BUTADIENE-NITRILE RUBBER  
WITH THE PARTICIPATION OF CHLORINE AND EPOXY  
ORGANIC COMPOUNDS**

Speciality: 2318.01 – Chemistry and technology of composite  
materials

Field of science: Technical sciences

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## GENERAL CHARACTERISTICS OF THE WORK

### **Relevance and degree of development of the topic.**

Crosslinking is considered the most important process in the technology of processing elastomers. It is sufficient to say that all synthetic rubbers produced, with some exceptions, are crosslinked by vulcanization.

The physicochemical and technical properties of the vulcanizate depend on all parameters of the structure of this material, including the intermolecular bonds formed as a result of the addition of active organic crosslinking agents (OCA) to macromolecules. However, as it is shown in this study, chemical series bonds - their structure, density and nature of distribution - have a positive effect on the physicochemical, mechanical and operational properties of the vulcanizate.<sup>1</sup>

In the modern era, in order to meet the demand for the most important composite materials made from elastomers in industrial enterprises, the continuous improvement of their quality and service life is of particular importance.

At present, the resources for expanding the range of rubbers through new monomers are practically limited. Therefore, the production trend of elastomer materials is not directed towards the synthesis of new ones but rather towards searching for rational ways of using traditional rubbers.

This search is achieved by modifying various elastomers through the application of chemically active high and low molecular weight compounds.

A sharp shortage of vulcanizing agents is observed in the elastomer industry, and in this regard, the work carried out in the direction of expanding the range is highly relevant.

It is clear that the most important technological problem of obtaining an elastomer with the required technical properties can be rationally solved only when a relationship is determined and formed

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<sup>1</sup>Dogadkin, B.A. Chemistry of elastomers / B.A. Dogadkin, V.A. Shershnev. – M.: – Chemistry, – 1981. – p. 373. [in Russian]

between the nature of the vulcanizate structure and its effect on the physicochemical and operational properties of elastomer materials<sup>2</sup>. This issue constitutes the main content of our research.

To solve this problem, it was necessary to develop new crosslinking systems and methods for studying vulcanization structures that would provide their quantitative assessment. Only the presence of such an assessment would allow to determine a relationship between the types of vulcanization structures and their influence on the most important technical properties of the vulcanizate, such as dynamic endurance, fracture toughness, resistance to heat and aggressive environments.

To better understand the changes that occur during crosslinking, it is necessary to dwell on the methods of its implementation. For this purpose, it is appropriate to generalize the materials for the crosslinking of elastomers. In the elastomer industry, various crosslinking methods have been used for a long time. In this case, there is no clear distinction between the method of carrying out the crosslinking process and its effect on the change in the chemical and molecular structure of the elastomer. In a generalized form, the most clearly distinguished is the thermochemical method of vulcanization of elastomers.

In the dissertation, the thermochemical crosslinking process of butadiene-nitrile rubber (BNR) has been developed, taking into account its compatibility with chlorine-containing aromatic compounds (CCAC), epoxy resin (ER), and dithiobisphenylmaleimide (DTBPM).

**Object and subject of the research.** The object of the conducted research is composites based on butadiene-nitrile rubber resistant to aggressive environments. The object of the research is the thermochemical vulcanization of butadiene-nitrile rubber, which is resistant to aggressive environments, oil and gasoline, and thermally stable vulcanizates with the participation of chlorine-containing

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<sup>2</sup> Bahrololoumi, A. A failure model for damage accumulation of cross-linked polymers during parallel exposure to thermal aging & fatigue / A. Bahrololoumi, M. Shaafaey, G. Ayoub, R. Dargazany // International Journal of Non-Linear Mechanics. – 2022. Vol. 146, issue 12, – e. 104142.

aromatic compounds as a crosslinking agent, modifier epoxy resin, and stabilizer dithiobisphenylmaleimide.

**The goals and objectives of the research.** Formation of the chemical structure in the macromolecule of butadiene-nitrile rubber, selection of new organic chlorine-containing vulcanizing agents (CCVA), modifier (ER) and stabilizer (DTBPM) for thermochemical construction of butadiene-nitrile rubber, creation of composite materials resistant to heat and aggressive environments.

To achieve this goal, the following issues need to be addressed:

- Development of a new method for the preparation of compounds based on BNR;
- Study of the effect of the structure of chlorine-containing aromatic compounds on their crosslinking activity as a result of thermochemical effects;
- Determining the role of oxides as activators of BNR crosslinking reactions using CCAC and epoxy compounds;
- Evaluation of the ratio of chemical bonds and physical intermolecular interactions in the structure of vulcanizates;
- Discovery of the stabilizing effect of maleimides in thermochemical processes of macromolecule crosslinking;
- Determination of the basic regularities of the crosslinking reactions of elastomer mixtures;
- Clarification of ways to increase the efficiency of vulcanization processes, based on the developed concept of the activation mechanism of chemical reactions of elastomer crosslinking;
- Approval of the recommended vulcanization method for obtaining composite materials resistant to aggressive environments and high temperatures under repeated deformation conditions.

### **Research methods.**

The composition mixture was prepared in a roller (Walsen d=300x300). During the study, the spatial structure parameters of the elastomer mixture were determined by the sol-gel analysis method. Based on the viscosity according to Mooney (Montsando rheometer ISOOS). The kinetic parameters of the vulcanization process are characterized according to the Flory - Reiner theory and characteristic viscosity to the Mark - Havnik formula, (Ubellode VPJ – 2)

molecular weight, linear relationships, degree of construction, chemical yield and other rheological, plasto-elastic properties were analyzed. Changes occurring as a result of the effect of temperature on the composite material, crosslinking mechanism, spectral analysis of the vulcanizate (Fourier – Varion 640 FTIR  $\nu=4000 - 400 \text{ cm}^{-1}$ ) and EPR (BRUKER), Emx “Plus” X-band) were studied. In accordance with the technical conditions (TY 38005204-71), resistance to fuel and aggressive environments was determined.

The strength and durability of rubber were determined in a tensile machine (MRS-2) at a constant maximum deformation time.

The study of stress relaxation of elastomers was carried out under axial compression at a temperature of  $100^{\circ}\text{C}$  in accordance with GOCT 9982-62.

The physical and mechanical properties of vulcanizates were determined by physical and mechanical tests in accordance with GOCT 269–78, GOCT 270–76, GOCT 261–67, GOCT 241–59, GOCT 271–67, GOCT 265–66, GOCT 263-75.

The thermal (DTA, TGA) properties of the composite obtained with the use of CCAC were comparatively investigated.

#### **The main provisions put forward for defense:**

- the possibility of using chlorine-containing, epoxy, and maleimide compounds as a crosslinking agent for thermochemical crosslinking of butadiene-nitrile rubber (SKN-40M);
- Results of the study of the role of metal oxides in the thermochemical crosslinking of BNR;
- low molecular weight crosslinking agent (LMWCA) and epoxy resin (ER) on the molecular structures of butadiene-nitrile rubber and the efficiency of crosslinking;
- results of the study of chemical transformations of butadiene-nitrile rubber (BNR) under the influence of temperature;
- explanation of the interaction mechanism of the studied chlorine-containing compounds with SKN-40M;
- possible ways to significantly improve the properties of elastomers using the proposed BNR crosslinking method;
- Results of the study of the characteristics of the composition creation of the regularities of the process of crosslinking of

elastomer mixtures based on BNR;

- Clarifying of influence of efficiency of the spatial chain structure ( $-C-C-$ ) on the physical and mechanical properties of the elastomer;
- According to the method proposed by the author, it is possible to obtain rubber technical products (RTP) for the oil industry by crosslinking that are resistant to aggressive environments and have a service life significantly longer than that of known products.

#### **Scientific novelty of the study:**

- The binary and quasi-binary systems were prepared to investigate the effect of the components included in the composition on the overall formulation. The amounts of sol-gel fractions of these systems were determined.
- Based on the investigation of the physicochemical properties of the obtained heterogeneous systems, it was determined that in the range of 1–3 phr of CCAC concentrations, the composition possesses a macrostructure.
- It was determined that in the joint presence of CCAC and ZnO, an intermolecular reaction occurs in the elastomer with the formation of  $-C-C-$  bonds, and the resulting  $ZnCl_2$  reacts with the nitrile groups of the elastomer, forming a complex and participating in the cross-linking process.
- The structural parameters of the vulcanization network, such as the concentration of active chains and the number of cross-linked molecules, were determined based on the equilibrium swelling degree. It was established that in the presence of CCAC, the network density and the degree of cross-linking of the vulcanizates are higher.
- For the first time, a sulfur-free thermochemical vulcanization process has been developed. Using this method, a rubber compound resistant to high temperatures and aggressive environments, suitable for use in the oil and mechanical engineering industries, has been obtained.

**Theoretical and practical significance of the research.** Under the influence of temperature, the prepared composite system, like most other elastomers, undergoes active crosslinking. The ability of

thermochemical crosslinking of elastomers is of primary practical interest, since it is a necessary condition for the formation of a spatial chain network in the volume of materials (vulcanization), the creation of a vulcanization structure with different energies.

Thermochemical vulcanization provides the production of rubber products using more modern technology, and also allows for the production of products with new, improved properties compared to known sulfur vulcanization methods.

Thermochemical vulcanization is based on the ability of BNR to form a spatial chain network under the influence of high temperature.

Based on the obtained results, a rubber composite resistant to a temperature of 386°C was developed, and the composite was tested in seawater, oil solutions, clay-containing waters, and aggressive environments (in a gasoline-benzene mixture). The developed rubber composite can be used as sealing gaskets in the oil and mechanical engineering industries. These gaskets were tested in electric submersible pumps at the “Experimental Production Enterprise for the Repair and Rental of Submersible Equipment” of the “AzNeft” Production Union. Based on the test results, an industrial application certificate was obtained. The innovation and technical solution are protected by Patent No. İ 2024 0046 issued by the Intellectual Property Agency of the Republic of Azerbaijan.

Additionally, with the support of SOCAR and the Partner Support Fund for the Development of Science, a grant project titled “Development and application of highly durable sealing gaskets to prevent leaks during the transportation of oil products” was developed (No. AİB 25-23 LR, May 11, 2023).

#### **Author's personal contribution.**

The author played a leading role in conducting the experimental research, analyzing and discussing the obtained results, developing and implementing the strategy of the dissertation work, writing the dissertation, publishing articles, and participating in the discussion of reports and thesis materials at international conferences.

**Approval and application.** A total of 21 scientific works related to the topic of the dissertation have been published (including 7 articles, 13 conference materials and 1 patent of the Republic of

Azerbaijan).

I International Scientific Conference of Students and Young Researchers dedicated to the 97th anniversary of the birth of the national leader Heydar Aliyev. Baku Higher Oil School, (Baku 2020), The VIII International Scientific and Practical Conference "Science, trends and development methods", (Tokyo, 2022); Innovative Materials and Technologies: Proceedings of the International Scientific and Technical Conference of Young Scientists, (Minsk 2022); The IX International Scientific and Practical Conference "Promising ways of solving scientific problems", (Brussels, 2023); The I International Scientific and Practical Conference "Modern methods for the development of science", (Haifa, 2023); The II International Scientific and Practical Conference "Discussions for the improvement of science", (Berlin, 2023); The VII International Scientific Conference "Science, trends and modern methods of solving problems", (Lisbon, 2023); "IV International Scientific Conference of Students and young Researchers" Sustainable Chemistry and Chemical Engineering, "Innovations for building better world "dedicated to 100th anniversary of national leader Heydar Aliyev, BHOS, (Baku, 2023); Scientific and technical conference on "Radiation technologies and their application" dedicated to the 100th anniversary of the national leader H.Aliyev, Institute of Radiation Problems, (Baku, 2023); International Science Group, International Scientific and practical conference «World educational trends: lifelong learning in the information society» Proceedings of the VII International Scientific and Practical Conference, (Athens 2024), "Modern Problems of Macromolecular Compounds Technology", dedicated to the 60th anniversary of the establishment of the Department of "Technology of Organic Substances and High Molecular Compounds", (Baku 2024), XII All-Russian conference with international participation "Rubber and rubber-2025: traditions and innovations", (Moscow 2025), International Scientific and Practical Seminar Dedicated to the 100th Anniversary of the Birth of Y.I. Dytnerksy "PACT 2025", (Moscow 2025).

**Name of the organization where the dissertation work was performed.** Azerbaijan State Oil and Industry University, Department

of “Technology of Organic substances and High molecular compounds.

**The total volume of the dissertation, indicated with the signs of its structural sections separately.** The dissertation consists of an introduction, 5 chapters, a conclusion, a list of references, and an appendix. The total length of the dissertation is 169 pages. It includes 18 figures, 40 graphs, 1 scheme, and 33 tables. The list of references contains 201 sources. At the end of each section, the results of the research are presented. Excluding figures, graphs, the scheme, tables, and the list of references, the dissertation contains a total of 193,110 characters (introduction – 15,560 characters, Chapter I – 45,845 characters, Chapter II – 17,160 characters, Chapter III – 46,945 characters, Chapter IV – 34,640 characters, Chapter V – 30,580 characters, conclusion – 2,380 characters).

**The introduction** provides the relevance of the topic, the purpose of the work, the issues that need to be resolved to achieve the set goal, the objects of research, scientific innovation, and the main scientific propositions submitted for defense. The practical and scientific significance of the implementation, approval, and publication of the dissertation work is also substantiated.

**The first chapter** is devoted to the consideration of the problem of crosslinking elastomers and the formation of chemical bonds with elastomer molecules, based on the analysis of scientific, technical and patent literature. The main scientific considerations are made in the formation of the spatial chain structure of elastomers, which determines the physical-chemical, chemical and operational properties of organic crosslinking agents, elastomer materials.

**The second chapter** describes the methods of studying elastomer mixtures and vulcanizates. The object of research is butadiene nitrile elastomer, which is a product of the copolymerization of butadiene and acrylonitrile. Rubber macromolecules consist of statically distributed butadiene and acrylonitrile chains, with a predominance of cis-trans chains of butadiene, and are recommended as the main raw materials.

**The third chapter** discusses the results of the study of rheological and structural parameters in binary systems with the

participation of CCAC, the study of the effect of CCAC, ER and DTBPMI on the plastoelastic properties of elastomer mixtures based on SKN-40M, the nature of the resulting linear bonds and the properties of the mixtures, the structure of the crosslinking agents used, vulcanization conditions, equilibrium swelling data, as well as the values of the structural parameters of the macrogels of BNR crosslinked with CCAC obtained by calculation using the equations of sol-gel analyses.

**In the fourth chapter**, the effect of the structure and composition of the elastomer on the chemical transformation of BNR was studied. The crosslinking effect of CCAC with rubber was studied, the molecular structure of BNR during its interaction after heating was studied and determined. For the SKN-40M+ACDX systems, a decrease in the optical density of the absorption band at 967 cm was observed, which was determined to be characteristic of double bonds in the  $-\text{CH}=\text{C}-$  groups. It was shown that when SKN-40M+CCAC was heated, the chemical interaction of the vulcanizing agent with the double bonds of rubber occurred due to the release of chlorine.

**In the fifth chapter**, the properties of elastomers depending on their composition and vulcanization structures were studied. It was found that the introduction of the organic crosslinking CCAC into the SKN-40M system allows obtaining vulcanizates that are superior to sulfur and peroxide vulcanizates in terms of elasticity, heat resistance, fatigue resistance and accumulation of residual deformation during compression. A thermochemical vulcanization process consisting of the proposed vulcanizing agents was developed. The advantage of the properties of the resulting vulcanizate C-C series bonds was determined.

At the end of the dissertation, the scientific results obtained from the research work carried out, a list of cited literature, and a list of abbreviated terms are provided.

## MAIN CONTENT OF THE WORK

### **The current state of research in the field of obtaining composite materials based on unsaturated elastomers.**

The main scientific discussions have been conducted on the formation of spatial chain structure through the influence of organic crosslinking agents on the physicochemical and performance properties of elastomeric materials.

In this section, the problems of BNR and its crosslinking with various organic crosslinking agents have been reviewed in depth and critically.

The analysis presented in this chapter shows that currently, with the application of thermochemical technology, the use of organic crosslinking agents has great prospects. The literature, shows that there is no clear difference in the choice of crosslinking agents for BNR depending on the technology and field of application.

### **Research areas and methods.**

Hexachloroparaxylylene (HCPX), -octachloro-4,4-dimethyl-diphenylmethane (OCDMDPMM) and 6-decachloro-4,4-dimethyl-1,4-dibenzylbenzene (DCDMBB) were used for the vulcanization of BNR. Chlorine-containing aromatic compounds (CCAC) are obtained by chlorination of a mixture of chloromethylene and xylene isomers of aromatic products.

ED-20 epoxy resin was used as a modifier in the vulcanization process. Chemical modification of BNR was carried out on a rolling mill.

4,4-dithiobis-N-phenylmaleimid (DTBPMI) was used to stabilize thermochemical processes, especially vulcanization.

Metal oxides were used to accelerate the role of BNR in chemical processes of crosslinking activation. P324 filler (technical carbon) was used to modify the thermal properties of elastomer mixtures and materials, as well as to strengthen elastomer mixtures.

The elastomer mixtures were prepared on a rolling mill. The crosslinking of the elastomer mixtures was carried out in an electric press at 150 °C.

At the end of the chapter, information on methods for studying composites structure their physical and mechanical properties is provided.

**Investigation of the vulcanization and technological properties of elastomers in the presence of chlorine-containing organic compounds.**

The crosslinking of a BNR with CCAC, as a rule, occurs with components of different structures. In principle, any technological property of BNR is based on the relative amount of the structural features of each component.

The initial values of the Mooney viscosity of elastomers, the amount and density of the gel in their composition, and the change in these indicators were determined depending on the processing conditions in the rolling mill, and the effect of these factors, the interaction and nature of the elastomer mixtures and the filler on the properties of the elastomer mixtures was studied during vulcanization. Binary and quasi-binary mixtures were prepared in a rolling mill at 25-30°C for 13-17 minutes.

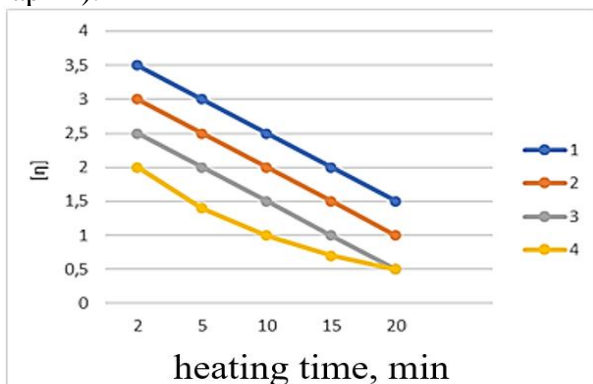
From the data in Table 1, it can be seen that all mixtures containing CCAC have a large amount of dense gel in SKN-40M, but in the absence of organic crosslinking agents, in the quasi-binary system, which has a higher viscosity than binary mixtures there is no gel.

**Table 1.**

**Changes in gel content and Mooney viscosity of mixtures after plasticization**

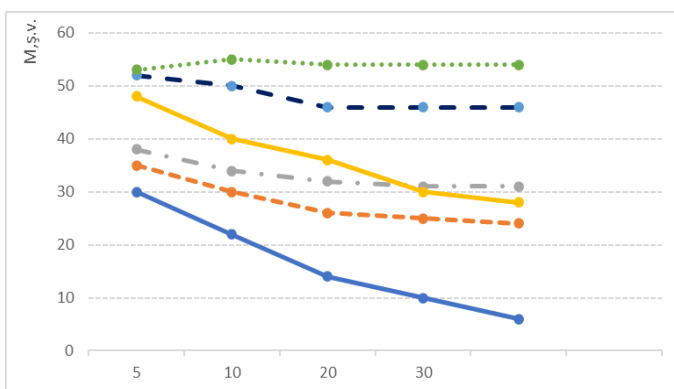
Mixed	Gel content, %	Density of the gel, g/cm <sup>3</sup>	Muni viscosity, etc.
SKN -40M+ P -324	0	-	25
SKN -40M+ HCPX	78	3.8	43
SKN -40 M+ OCDMDPM	84	4.4	45
SKN -40 M+ DCDMDBB	90	4.5	49
SKN -40 M + HCPX + P -324	85	4.1	50
SKN -40 M+ OCDMDPM + P -324	91	4.7	55
SKN -40M + DCDMDBB + P -324	93	4.8	58

During mechanical plasticization of uncrossed-linked BNR, the polymer backbone chains are clearly broken down, it is evidenced by the decrease in the intrinsic viscosity of the polymer in toluene solution (Graph 1).



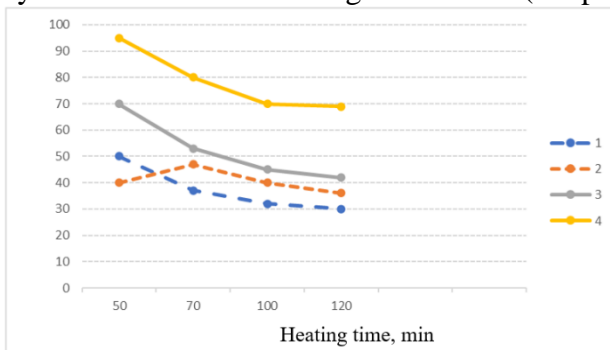
**Graph 1. The effect of mechanical plasticization time on the intrinsic viscosity ( $\eta$ ) of the sol fraction of the mixtures: 1-SKN-40M+ DCDMDBB; 2-SKN-40M+ ODMDPM +P324; 3-SKN-40M+HCPX+P324; 4-SKN-40M+P324.**

During plasticization, the Mooney viscosity of both the crosslinked and uncrosslinked elastomers at 25°C (Graph 2) and the gel content in the crosslinked elastomers change slightly.



**Graph 2. Effect of plasticization time at 25°C on the Mooney viscosity of mixtures: : 1-SKN-40M+ DCDMDBB; 2-SKN-40M+ OODMDPM; 3-SKN-40M+ HCPX.**

Indeed, by incorporating technical carbon (P324) into the crosslinked elastomers (BNR), the Mooney viscosity of the mixture increases dramatically and a carbon elastomer gel is formed (Graph 3).



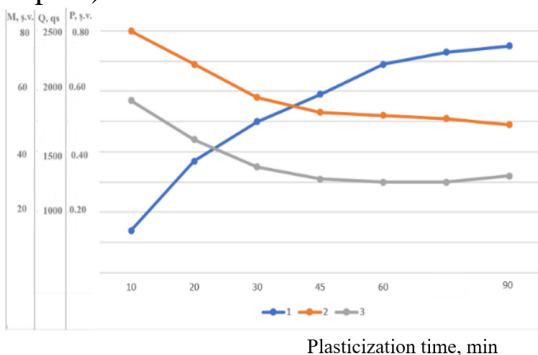
**Graph 3. Change in Mooney viscosity of mixtures depending on heating time: 1-SKN-40M+ OCDMDPM ; 2-SKN -40M + DCDMDBB ; 3-SKN-40M+ OCDMDPM +P324; 4-SKN-40M+ DCDMDBB +P324.**

Carbon black is added to crosslinked elastomers, it appears that only a weak physical interaction of the elastomer with carbon black occurs. Most likely, the radicals formed during the breakdown of the main polymer chains are unable to react with carbon black, since, despite the breakdown of the molecular chains, SKN-40M + P324 does not form a carbon-elastomer gel (Table 2).

**Table 2. Effect of technical carbon P324 on the Mooney viscosity of BNR and the formation of carbon-elastomer gel in them**

Indicators	SKN -40 M + P 324	SKN -40 M + HCPX + P 324	SKN -40 + OCDMDPM + P 324	SKN -40M + DCDMDBB + P 324
The color of the mixture	dark	dark	dark	dark
Elastomer gel amount, %:				
At 25 °C	32	75	90	86
At 70 °C	22	53	69	72
Mooney viscosity change	12	28	35	31

Mechanical plasticization of binary mixtures, (SKN-40M + HXPX) with increasing plasticization time, plasticity, hardness and Mooney is characterized by a change in viscosity. Thus, when chlorine-containing aromatic compounds are used as organic crosslinking agents for crosslinking BNR, binary and quasi-binary vulcanized samples are characterized by significantly better technological properties compared to mixtures based on uncrosslinked elastomers (Graph 4).



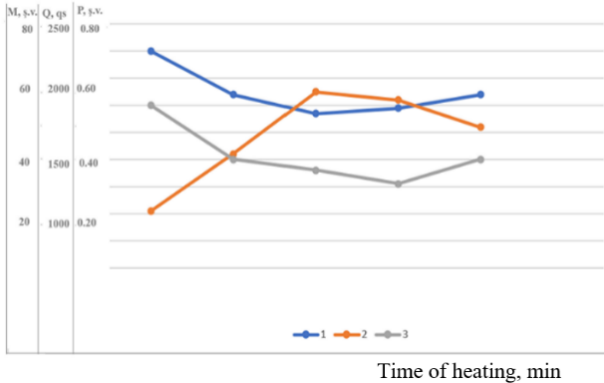
**Graph 4. Dependence of SKN 40M + HCPX binary mixtures on plasticity (1), hardness (2) and Mooney viscosity (3)**

It can be seen from Graph 4 that slight changes in plasticity are observed during mechanical plasticization of binary mixtures for 20 minutes. Increasing the plasticization time to 30 minutes leads to slight changes in plasticity parameters and increasing the plasticization time to 30 minutes leads to a sharp decrease.

The kinetics of changes in the intrinsic viscosity of the elastomer mixture are described by monotonically decreasing curves (Graph 5).

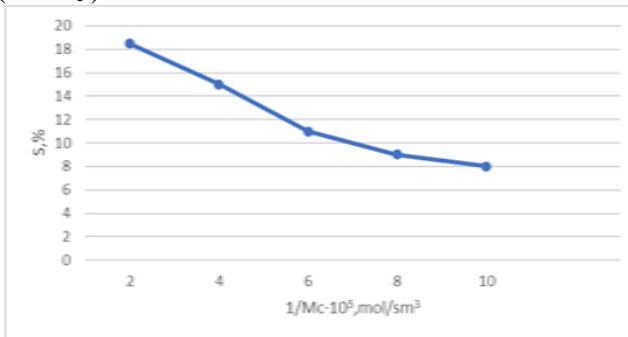
The obtained data (Graph 5) show that the plasticity of thermovulcanizates occurs 40 minutes after the start of the reaction. Destructive changes in thermovulcanizates are completed, and then after 60 minutes, plasticity increases monotonically until it reaches a constant value. On the contrary, a change in the hardness of thermovulcanizates is observed, that is, if during the first 10 minutes the hardness is 1100 gs, then in the next 30 minutes it increases sharply

and becomes equal to 1750 gs, and after 60 minutes it decreases sharply.



**Graph 5. Dependence of vulcanizate (SKN 40M + HCPX + P-324) plasticity (1), hardness (2), Mooney viscosity (3) on the heating time (153°C x 90')**

The most sensitive parameter of the network structure is the composition and amount of the sol fraction. The results of the sol-gel analysis of the studied vulcanizates are shown in Graph 6, where it is seen that the amount of the sol fraction depends on the network structure ( $1/M_c$ ).



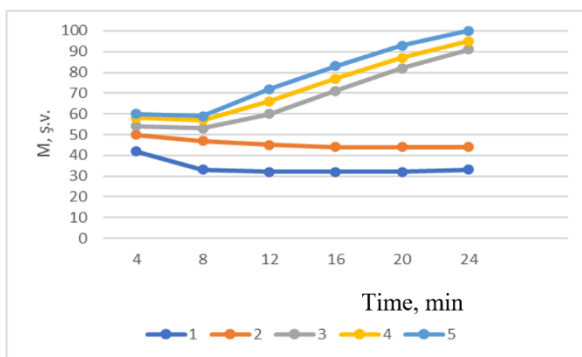
**Graph 6. Dependence of the amount of sol fraction on the concentration of active chains of the vulcanizate network (SKN-40M+HCPX+P-324)**

To study the effect of metal oxide on the vulcanization rate and properties of mixtures based on BNR, mixtures containing 100 wt.h.

SKN-40M elastomer, 5.0 wt.h. CCAC + 5.0 wt.h metal oxides were prepared.

For the study, the selection of oxides is carried out depending on the value of the electronegativity difference, which determines the polarizability of the oxide, as well as its chemical activity during interaction with HCl. The adsorption capacity of oxides, which is related to the value of the specific surface area, was also taken into account. The effect of metal oxides on the rate of the crosslinking process was evaluated by changing the viscosity of the mixture in VR-2, the degree of crosslinking was determined from the equilibrium swelling in m-xylene using the Flori-Renar equation. Crosslinking changes occurring with the CN group of the elastomer during vulcanization were determined from the spectra obtained in IQS-22.

The results of the study showed that in the absence of oxides, the process of crosslinking BNR with CCAC is slow and the degree of crosslinking is low (Graph 7).



**Graph 7. Metal oxides on the change in Mooney viscosity of model mixtures based on SKN-40M containing HCPX during heating at 150°C: 1- no oxide; 2- aluminum oxide; 3 – cadmium oxide; 4 – magnesium oxide; 5 – zinc oxide**

In Table 3, the effect of metal oxides on the rate of cross-linking is evaluated based on the change in viscosity measured using the VR-2 device. The degree of cross-linking is determined using the Flory–Rehner equation based on the equilibrium swelling degree in m-xylene. As seen from Table 3, vulcanizates containing ZnO exhibit better properties compared to known sulfur vulcanizates and those prepared with other oxides.

**Table 3.**

**The effect of various oxides on the formation of cross-links  
(Nc·10<sup>9</sup>, bonds/cm<sup>3</sup>) during the vulcanization process**

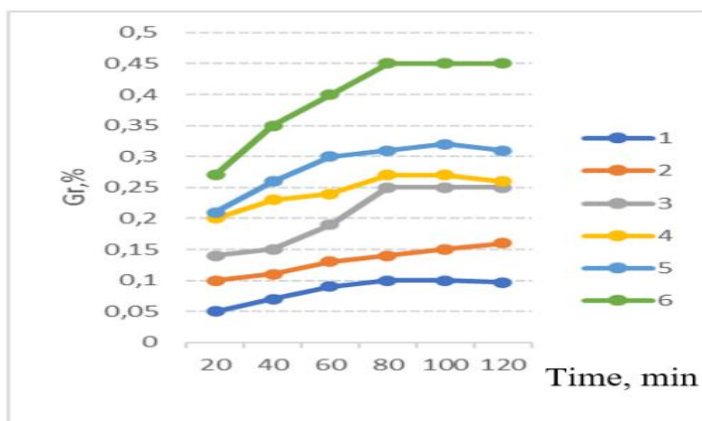
Components, per 100 parts by weight of rubber (phr)	m-xylene	chloroform
Oxide-free	8,0	6,7
SKN-40M + HCPX + ZnO	16,4	15,0
SKN-40M + HCPX + MgO	9,3	8,9
SKN-40M + OCDMDFM + ZnO	14,3	12,2
SKN-40 M+ OCDMDFM + MgO	10,7	8,1
SKN-40M + DCDMDBB + ZnO	12,3	10,3
SKN-40 M+ DCDMDBB + MgO	9,1	7,2

As it is known, the use of epoxy compounds as modifying agents improves the technological properties of BNR. It has been previously shown, epoxy Diamine compounds (ED-20, ED- 40) are effective modifying agents for the vulcanization of BNR. The rubber mixtures studied are listed in Table 4.

**Table 4**

**Elastomeric mixtures with the presence of CCAC and epoxy resin**

Components, The kh per 100 kh of rubber.	Number of mixtures								
	1	2	3	4	5	6	7	8	9
SKN -40M	100	100	100	100	100	100	100	100	100
Sulfur	2.0	-	-	-	-	-	-	-	2.0
DCP (dicumyl peroxide)	-	-	-	-	-	-	-	2.5	-
ZnO	5.0	-	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Stearic acid	-	-	-	-	-	-	5.0	-	3.0
HCPX	-	-	-	3.0	-	-	5.0	-	3.0
OCDMDPM	-	-	-	-	2.5	-	-	-	-
DCDMDBB	-	-	-	-	-	2.5	-	-	-
Captax	2.0	-	-	-	-	-	-	-	-
ED-20	-	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0



**Graph 8. Kinetics of gel formation in the system:**  
**1-SKN-40M+ED-20; 2- SKN -40 M +ZnO+ED-20;**  
**3-SKN-40M+HCPX+ED-20;**  
**4-SKN-40M+ZnO+OCDMDPM+ ED-20;**  
**5- SKN -40 M + ZnO + DCDMDBB +ED- 20;**  
**6 – Peroxide vulcanizate (known)**

Graph 8 shows, the studied crosslinking for SKN-40 Examples 4, 5, 6 of the systems are the most active in terms of crosslinking speed. With the addition of epoxy resin, the density of the spatial chain network of thermochemical vulcanizates increases by 3-4 times compared to thermovulcanizates.

Table 5 below provides information on the composition of rubber compounds with different amounts of technical carbon added.

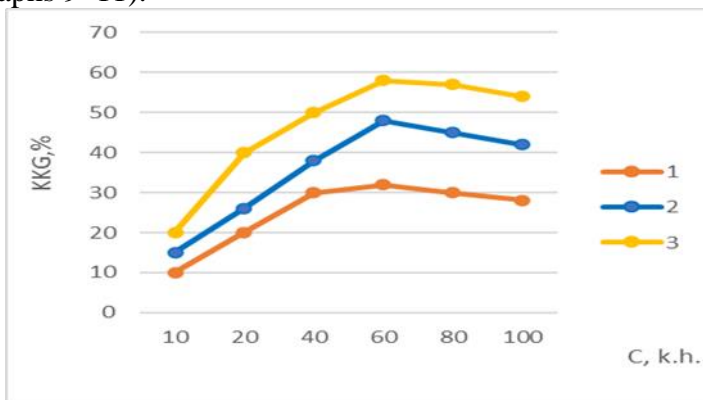
**Table 5**

**Composition of the investigated rubber compounds**

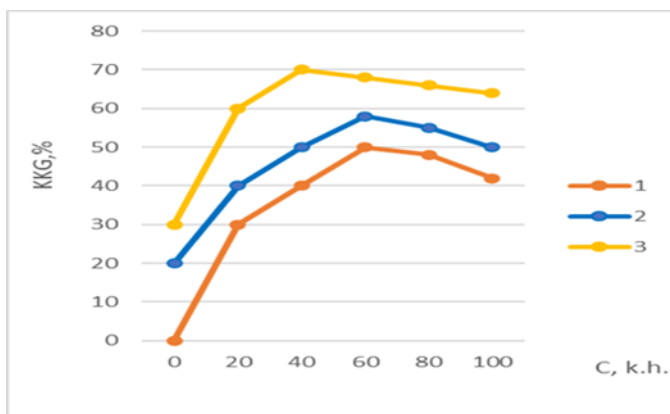
Components	Mixture numbers								
	1	2	3	4	5	6	7	8	9
SKN-40M	100	100	100	100	100	100	100	100	100
ZnO	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0
HCPX	1,0	-	-	2,0	-	-	3,0	-	-
OCDMDFM	-	1,0	-	-	2,0	-	-	3,0	-
DCDMDBB	-	-	1,0	-	-	2,0	-	-	3,0
Stearin	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
ED-20	2,0	2,0	2,0	4,0	4,0	4,0	6,0	6,0	6,0
P 324	20	20	20	40	40	40	60	60	60

Technical carbon was introduced into the elastomer composition in the mixer at 70°C; samples were taken every 2 minutes after the mixing with technical carbon began.

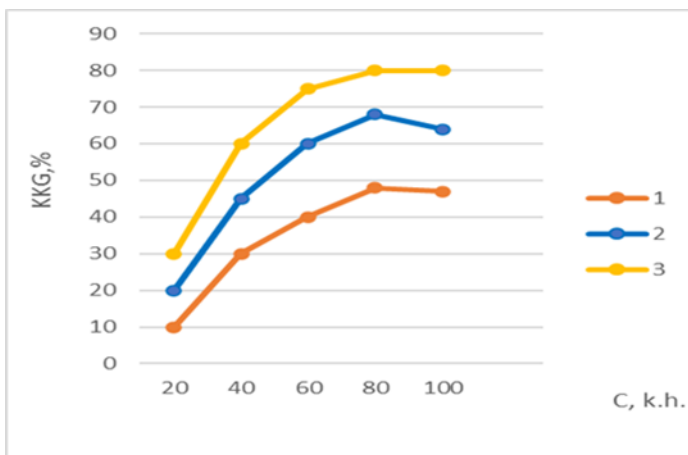
The degree of interaction between the elastomer and the filler was evaluated based on the amount of carbon–rubber gel (CRG) determined after extracting the samples with toluene at 80°C for 24 hours (Graphs 9–11).



**Graph 9. Dependence of the amount of carbon–rubber gel on the dosage of technical carbon in elastomers with different molecular structures (P324): 1 – mixture 1; 2 – mixture 4; 3 – mixture 7.**



**Graph 10. Dependence of the amount of carbon–rubber gel on the dosage of technical carbon in rubbers with different molecular structures (P324): 1 – mixture 2; 2 – mixture 5; 3 – mixture 8.**



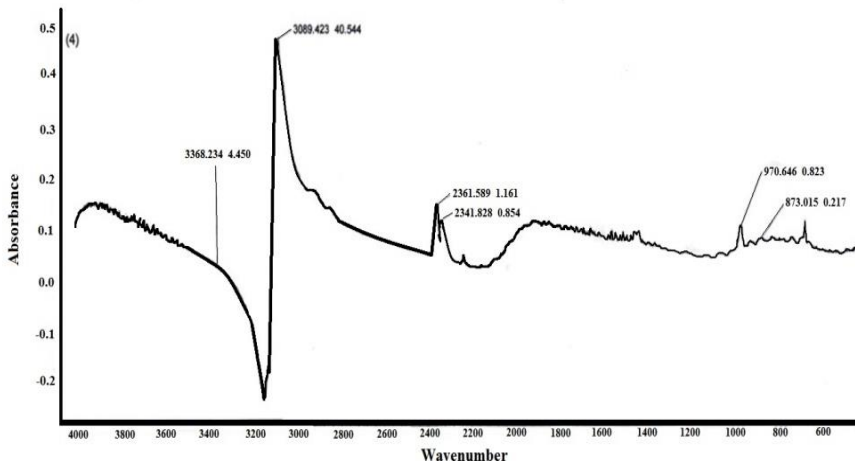
**Graph 11. Dependence of the amount of carbon–rubber gel on the dosage of technical carbon in elastomers with different molecular structures (P324): 1 – mixture 3; 2 – mixture 6; 3 – mixture 9.**

The maximum amount of carbon–rubber gel is formed in elastomers filled with 40–60 phr of technical carbon (grade P324). At higher filler loadings, the CRG content remains nearly constant.

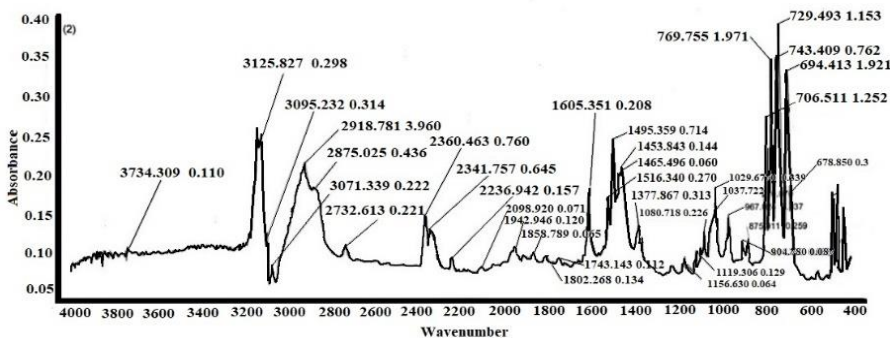
### **The influence of the structure and composition of BNR on chemical transformations.**

The SKN-40M + CCAC system is characterized by the polarity of both components, therefore, the process of crosslinking SKN-40M and HCPX is mainly determined by the polar groups  $-C\equiv N-$  and  $C-Cl$  and their active reactivity during mechanical-thermal interactions. From here, it can be said that the main attention is paid to the study of the intensity of the stretching vibration band of the nitrile group located at  $2235\text{cm}^{-1}$ , which is characterized by exceptional stability both in frequency and shape. Based on the IR spectra presented in Figures 1 and 2, it can be concluded that when the SKN-40M + HCPK elastomer system is heated, the crosslinking agent chemically interacts with the double bonds of the polymer due to the release of active chlorine. The resulting biradicals dissociate hydrogen from the elastomer molecules, forming macroradicals that can be crosslinked. Chain breakage can occur mainly as a result of the

recombination of chlorine radicals with the elastomer macroradical.



**Figure 1. IR spectrum of SKN-40M rubber without the presence of CCAC**

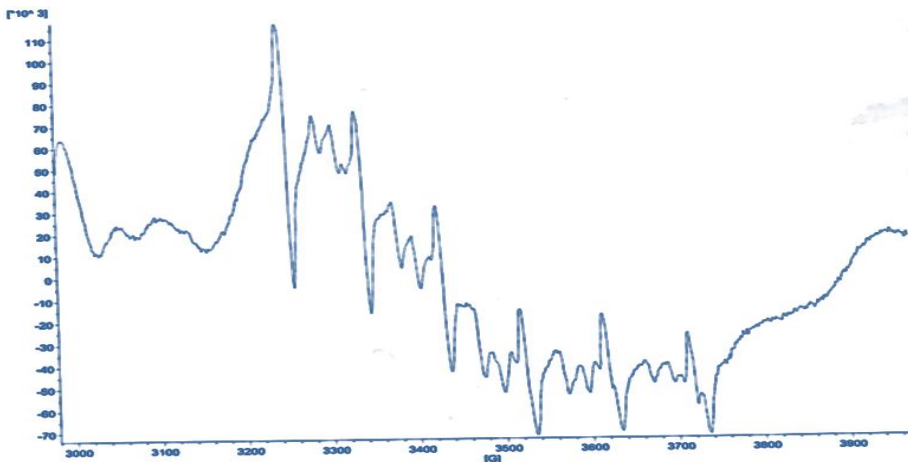


**Figure 2. IR spectrum of SKN-40M+CCAC+ZnO model vulcanizate**

Using the obtained data, we can say that the peaks at 484-555  $\text{cm}^{-1}$  corresponding to the Zn-N bond and the peaks at 729-789  $\text{cm}^{-1}$  corresponding to the ZnCl resonance indicate that ZnCl participates in the crosslinking by forming a complex. It can be summarized as the interaction of chlorine atoms of HCPX with the nitrile groups of the elastomer, resulting in the formation of branched structures with high molecular weight substituted nitrile salts.

The given EPR spectrograms show that the effect of HCPX,

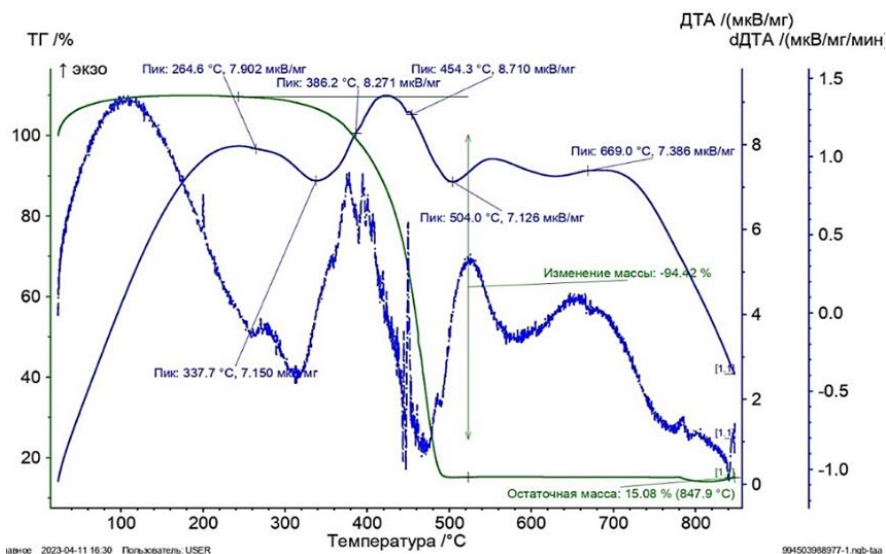
OCDMDPM and DCDMDBB is based on their homologous decomposition. This fact gives reason to assume that in the initial period of low-speed vulcanization in the presence of CCAC (long duration of the induction period) the homologous decomposition of chlorine-containing compounds into C-Cl-bonds is associated with a low rate (Figure 3).



**Figure 3. EPR spectra after heating in the SKN-40M + HCPX + ZnO system in the (155°Cx30') mode**

Thus, the crosslinking of BNR with CCAC in the presence of metal oxides is associated with their ability to bind chlorine in ionic or radical form, as well as the effect of metal chlorides formed as a result of the reaction on the crosslinking process.

The following effects were observed in the DTA curve (Figure 4). At a temperature of 120°C, there is a slightly diffuse endoeffect associated with the glass transition of the elastomer. The next process that occurs during heating is thermal oxidation, which begins at a temperature of 290°C (the beginning of the exo-effect). At a temperature of 386.2°C, the first mass loss occurs in the sample.



**Figure 4. DTA and ER curves for SKN-40M based samples containing CCAC**

There is some mass loss in the TQ curve (thermogravimetry). The rate of the thermal oxidation process was 0.1 mg/min. The 2nd mass loss starts at 454.3°C. The mass loss stops at 504°C. In this temperature range, 94.42% of the mass is decomposed, leaving 15% residual mass.

Studies have shown that the crosslinking of BNR with CCAC and ER causes changes in thermal resistance and activation energy due to differences in the structures with C-C bonds, since the structure of BNR with a chlorine-containing group, nitrile and epoxy groups in the mixtures are involved.

### **Investigation of the properties of the elastomer compound depending on its composition and vulcanization structure.**

The properties of the obtained vulcanizates have been investigated depending on their composition and vulcanization structures. Table 6 presents the results of comparative testing of

various vulcanizates prepared with CCAC with sulfur and peroxide vulcanizates. Table 6 shows, CCAC vulcanizates have, on average, similar strength values, resistance to repeated tensile deformations, and are superior to known sulfur and peroxide vulcanizates in terms of resistance to thermal aging.

**Table 6.**

**Physical and mechanical properties of vulcanizates obtained by the thermochemical method in the presence of CCAC and ER. (150°C×40 min)**

Indicators	Vulcanization type				
	Sulfurous	Peroxide	CCAC		
			1	2	3
Stress at 300% elongation, MPa	10	8	8	10	11
Fracture strength, (f <sub>p</sub> ), MPa	19	21	23	24	25
Relative elongation (ε <sub>p</sub> ), %	500	520	480	470	470
Elasticity, %	25	32	30	28	28
Hardness according to TM-2, sh.v	76	65	57	60	63
Residual deformation during compression (20%, 159.72 s.)	70	60	62	60	57
Dynamic endurance during repeated elongation (N) (150%, 500 cycles/min), thousand cycles	16	18	20	22	22
Thermal degradation coefficient (150°C, 150 hours)					
strength f <sub>p</sub>	0.51	0.65	0.70	0.82	0.85
relative elongation ε <sub>p</sub>	0.32	0.40	0.52	0.58	0.61
dynamic endurance N	0.51	0.63	0.75	0.77	0.80
gasoline + benzene (3:1), 80°C, 24 hours, % (mass)	45	40	38	35	30

From the data given in Table 6, it can be seen that vulcanizates containing HCPX + ER, compared to conventional vulcanizates containing 2.5 wt.% sulfur, show significantly higher resistance to thermal aging, better elasticity and resistance to aggressive environments.

**Table 7.****Comparative properties of vulcanizates obtained with the participation of CCAC**

Indicators	Crosslinking		
	Sulfurous	Peroxide	Thermo-chemical
300% elongation during stress, MPa	10	8	13
In the breakup strength limit ( $f_p$ ), MPa	26	24	28
Relative elongation ( $\varepsilon_p$ ), M Pa	500	520	460
Rebound elasticity, %	25	32	30
Hardness according to TM - 2, s.v.	76	65	65-67
Compression residue at deformation (20%, 150°C, 72 s)	70	60	52
Repeated elongation during dynamic endurance (N) (150%, 500 cycles / min), thousand cycles	16	18	25
Thermal degradation coefficient (150°C, (150°C 150 hours)			
strength $f_p$	0.51	0.65	0.87
relative elongation $\varepsilon_p$	0.32	0.40	0.70
dynamic tolerance N	0.51	0.63	0.82
Mass change in a mixture of gasoline + benzene (3:1) during swelling, 150°C, 24 hours, % (mass)	45	40	26

Thus, after three days of aging at 150°C, vulcanizates with HCPX+ER retain 80% of the initial residual deformation, while for sulfur and peroxide rubbers this figure does not exceed 60%. The results of determining some structural parameters of the vulcanization networks formed under the influence of HCPX + ER by the sol-gel analysis method allow to more fully characterize the properties of vulcanizates obtained with the use of this crosslinking agent. (Table 7)

To study the effect of temperature and operating conditions on the performance of RTMs, comparative tests of rubbers based on SKN-40M at 150°C in aggressive environments where pump

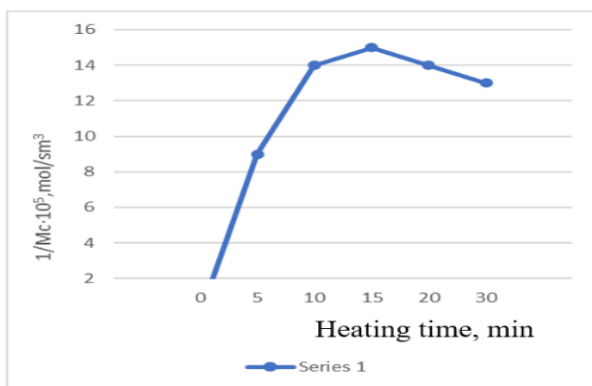
fasteners, rotors and other devices of drilling rigs operate in the oil industry were conducted (Table 8). The data obtained show that in test samples containing HCPX and ER-20, the degree of swelling and accumulation of residual compression deformation is low, and the coefficient of thermal wear in seawater and oil-containing solutions is high compared to sulfur and peroxide vulcanized rubbers.

**Table 8.**

**Comparative performance of SKN-40M-based filled rubbers obtained with the participation of HCPX and epoxy resin after operation in seawater (I), oil (II) and clay solutions (III)**

Indicators	Vulcanization type		
	Sulfurous -C-S <sub>x</sub> -C- known [20]	Peroxide -S-S- known [24]	Thermochemica l C -C- proposed
Conditional elongation strength ( $f_p$ ), MPa			
I	9	8	11
II	11	9	13
III	13	11	17
Thermal wear coefficient (I/II)			
$\varepsilon_p$	0.45/0.60	0.40/0.57	0.70/0.77
$f_p$	0.57/0.72	0.63/0.81	0.72/0.87
Residue deformation accumulation during compression			
I	70	62	55
II	55	50	45
III	60	52	49
Mass change during swelling % (mass)			
I	135	110	103
II	86	72	65
III	63	54	50

It should be noted that the number of active chains in SKN-40M with added stabilizer is 2-3 times higher than in known sulfur vulcanizates (Graph 12).



**Graph 12. Effective range of mixtures based on SKN-40M  
Dependence of the number of connections on the heating time**

**Table 9.  
Comparative performance of vulcanizates including stabilizer**

Indicators	Known	Thermo-chemical
300% elongation during stress, MPa	10	12
In the breakup strength limit ( $f_p$ ), MPa	24	28
Relative elongation, % ( $\epsilon_p$ )	500	450
Rebound elasticity, %	25	32
Hardness according to TM - 2, s.v.	70	67
Residue deformation during compression (20%, 150°C, 72 s)	70	55
Repeated elongation during dynamic endurance (N) (150°C, 500 cycles / min), thousand cycles	16	24
Thermal degradation coefficient (150°C, 150 hours)		
strength $f_p$	0.51	0.90
relative elongation $\epsilon_p$	0.32	0.68
dynamic endurance N	0.51	0.83
Mass change in a mixture of gasoline + benzene (3:1) during swelling, 80°C, 24 hours, % (mass)	45	26

As it can be seen from the data presented in Table 9, the thermochemical vulcanizate outperforms the known sulfur rubbers in terms of strength indicators. Studies have shown that the higher the vulcanization time, the more pronounced its activation ability to affect the physical and mechanical properties of the proposed construction systems.

Based on the experimental data, a regression mathematical model of the process was developed and constructed. The physical and mechanical properties of the thermochemically vulcanized compounds ( $150^{\circ}\text{C} \times 40$  minutes) are presented in Table 10.

**Table 10.**

**Results obtained based on experimental data**

Indicators	Vulcanizates		
	CCAC		
	1	2	3
300% elongation during stress, MPa	8	10	11
In the breakup strength limit ( $f_p$ ), MPa	23	24	25
Elongation, % ( $\epsilon_p$ )	480	470	470
Rebound elasticity, %	30	28	28
Hardness according to TM - 2, s.v.	57	60	63
Residue deformation during compression (20%, $150^{\circ}\text{C}$ , 72 s)	62	60	57
Repeated elongation during dynamic endurance (N) ( $150^{\circ}\text{C}$ , 500 cycles/min), thousand cycles	20	22	22
Thermal degradation coefficient ( $150^{\circ}\text{C}$ , 150 hours)	0,70	0,82	0,85
strength $f_p$	0,52	0,58	0,61
relative elongation $\epsilon_p$	0,75	0,77	0,80
dynamic endurance N			
Mass change in a mixture of gasoline + benzene (3:1) during swelling, $80^{\circ}\text{C}$ , 24 hours, % (mass)	38	35	30

Statistical analysis of the obtained model was carried out, and its consistency with the experimental data was confirmed (Table 11). Optimal values among the mixtures were identified, and it was proven that the primary, i.e., mixture I, is the most optimal variant. For

determining the optimal results, the base mixture (I) was taken as: 100 parts by weight of rubber and 3 parts by weight of CCAC (chlorine-containing organic compounds).

**Table 11.**

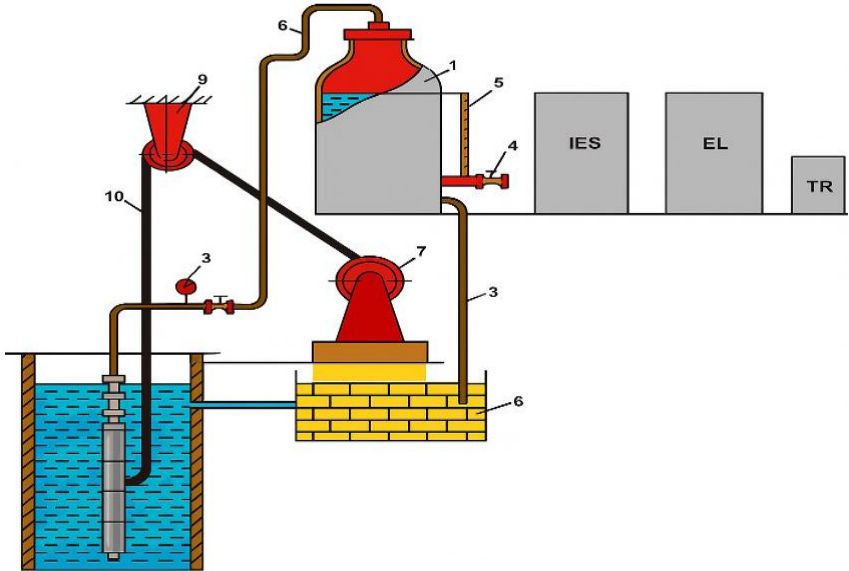
**Results obtained by calculation**

Indicators	Vulcanizates		
	CCAC		
	1	2	3
300% elongation during stress, MPa	8,4	10	11
In the breakup strength limit ( $f_p$ ), MPa	22,7	23,6	25,2
Elongation, % ( $\epsilon_p$ )	477,5	470	470,3
Rebound elasticity, %	29,7	28,1	27,7
Hardness according to TM - 2, s.v.	56,6	60,4	63
Residue deformation during compression (20%, 150°C, 72 s)	61,7	60,4	57,1
Repeated elongation during dynamic endurance (N) (150°C, 500 cycles/min), thousand cycles	19,5	21,9	22,2
Thermal degradation coefficient (150°C, 150 hours)			
strength $f_p$	0,70	0,80	0,85
relative elongation $\epsilon_p$	0,54	0,58	0,61
dynamic endurance N	0,74	0,77	0,80
Mass change in a mixture of gasoline + benzene (3:1) during swelling, 80°C, 24 hours, % (mass)	38	35,2	30

The use of new active ingredients, CCAC, epoxy resin, dithiobisphenylmaleimide, allows obtaining vulcanizates with high resistance to thermal aging in aggressive environments. Rubber technical products (RTP) obtained by the proposed technology can be successfully used as sealing elements of machines and aggregates operating at high temperatures under complex dynamic loading conditions, in clay and oil-containing solutions and in seawater. The direction of my research work was adopted as the field of application of the new composite material - oilfield equipment - centrifugal

electric submersible pumping units (CESPU), which is one of the mechanized methods used in oil production.

The test work was carried out on a stand in a special test well at the “Experimental Production Enterprise for Repair and Rental of Submersible Devices” of the “Azneft” Production Union. The scheme and working principle of the test stand are as follows.



**Scheme 1. Schematic diagram of the ESP test stand:**

- 1-Measuring container; 2-Discharge container; 3-Discharge pipe;**
- 4-Valve; 5- Measuring scale; 6-Pipe; 7-Drum; 8-Monometer;**
- 9-Hanging roller; 10-Cable.**

From these composites, sealing rings of size 080-086-36 (78.5x3.6) for submersible electric motors; 105-110-25 (103x2.5) for diaphragm submersible electric pumps; 075-081-36 (73.5x3.6) for hydroprotection, prepared according to ГOCT TY38.1051082-86, were tested. The results of the tests showed that the service life of the experimental sealing rings increased by 25-28% compared to the seals used in industry.

## CONCLUSIONS

1. A new sulfur-free vulcanization process has been developed for obtaining composite materials based on BNK using chlorinated aromatic compounds (CCAC) as vulcanizing agents in systems created with epoxy resin as a modifier, dithiobisphenylmaleimide (DTBFMI) as a stabilizer, and metal oxides as activators [2, 18].
2. The effect of temperature on the structural parameters of BNK containing CCAC was investigated. The resulting rubber compound is resistant to temperatures up to 386.2°C. Based on sol-gel analysis data, the rate of reactions between BNK and the investigated CCACs was used to determine the output of the chain network in the macromolecule: the gel fraction content depends on the type of CCAC and ranges from 85% to 93% [9, 14].
3. The effect of metal oxides (ZnO, MgO, Al<sub>2</sub>O<sub>3</sub>, CdO) as activators on the cross-linking process of BNK in the presence of CCAC, EB, and DTBFMI was studied. In this case, the amount of effective cross-links (per 100 g of compound) reaches  $16.4 \times 10^{19}$ . An increase is observed in the number of cross-linked molecules ( $1/M_{nr}$ ) and in the yield of cross-links ( $1/M_s$ ). The activity of the oxides in these processes was determined as follows: ZnO > MgO ≥ CdO > Al<sub>2</sub>O<sub>3</sub> [10, 12].
4. The effect of technical carbon on the rheological properties of elastomers was studied, and it was found that the gel fraction content in mixtures containing technical carbon reached 90%. Furthermore, the Mooney viscosity of these mixtures was 74 MU. The amount of carbon-rubber gel was found to be maximal in elastomers filled with 40–60 phr of technical carbon [8].
5. The SKN-40M + CCAC + ZnO cross-linked system confirmed that the resulting metal chlorides form complexes with the  $-C\equiv N$  groups of the elastomer, participating in the cross-linking process. A reaction scheme was also developed [10, 11, 20].
6. Results of EPR studies show that radicals formed during vulcanization increase the cross-linking rate of BNK and the total number of cross-links between molecular chains of the elastomer. As a result, the vulcanization time is reduced to 18 minutes [12,

13, 21].

7. The formation of C–C and C–S<sub>x</sub>–C type chemical bonds in the BNK molecule, and the addition of CCAC to the SKN-40M + DTBFMI system, resulted in significantly improved resistance in aggressive media compared to sulfur and peroxide vulcanized rubbers: swelling degree in a benzene–benzol mixture was 26%, thermal aging coefficient was 0.87, residual deformation under compression was 52%, and dynamic fatigue resistance during repeated elongation was 25 cycles/min. Additionally, tests in seawater, clay-containing, and oil-containing waters also showed high performance, with thermal aging coefficients  $\epsilon_p$  and  $f_p$  being 0.72 and 0.82, respectively [1, 12].
8. Depending on their composition, the physicochemical and operational properties of elastomers were investigated. It was determined that the most intensive cross-linking occurs at a temperature range of 150–155°C [12].

#### **List of published scientific works on the topic of the dissertation:**

1. Abdullayeva, İ.Q., Əzizova, G.H. Doldurucuların epoksid qətranların xassələrinə təsiri // Ümummilli lider Heydər Əliyevin anadan olmasının 97-ci ildönümünə həsr olunmuş Tələbə və Gənc tədqiqatçıların I Beynəlxalq Elmi Konfransları. Bakı Ali Neft Məktəbi, Bakı: – 8-11 iyun, – 2020, – s. 166.
2. Азизова, Г.Г. Свойства вулканизатов на основе бутадиен-нитрильного каучука в присутствии галогенметил содержащих соединений / Г.Г. Азизова, С.С. Машаева, Ф.А. Амиров, И.Г. Мовлаев, Г.А. Мамедова, Д.Ш. Мамедов, С.А. Валиева, Ш.М. Мамедов // Journal of Baku Engineering University Mechanical and Industrial Engineering, – 2022. № 2, – с. 95-102.
3. Azizova, G., Ismayilova, P., Amirov, F. Structuring of nitrile butadiene rubbers in the presence of chlorine containing chlorine and epoxy compounds // The VIII International Scientific and Practical Conference «Science, trends and development methods». Tokyo, Japan: – 19-21 december, – 2022, – p. 40-41.
4. Azizova, G., Ismayilova, P., Amirov, F. Structure and properties

- of butadienenitrile rubber vulcanizates with chlorinecontaining compounds // Promising ways of solving scientific problems Abstracts of IX International Scientific and Practical Conference. Belgium, Brussels: – 26-28 december, – 2022, – p. 27-28.
5. Азизова, Г.Х., Машаева, С.С., Амиров, Ф.А., Мамедов, Б.А. Анилин формальдегидные смолы // Инновационные материалы и технологии: материалы Междунар. науч.-техн. конф. молодых ученых, г. Минск, – 23-24 марта, – 2022, – с.539.
  6. Azizova, G., Amirov, F., Ismayilova, P. Structuring of butadienenitrile rubber with the participation of organochlorine compounds // I international Science Conference «Modern methods for the development of science». Haifa, Israel: – 09-11 january, – 2023, – p. 51-52.
  7. Azizova, G., Amirov, F., Ismayilova, P. Technological aspects of nitrile butadiene rubber vulcanization in the presence of chlorine containing maleimide compounds // II International Science Conference «Discussions for the improvement of science». Berlin, Germany: – 16-18 january, – 2023, – p. 54.
  8. Azizova, G., Ismayilova, P., Mammadov, S. Obtaining heat and aggressive resistant elastomer materials based on nitrile butadiene rubber // The VII International Scientific and Practical Conference «Science, trends and modern methods of solving problems». Lisbon, Portugal: – 20-22 february, – 2023, – p. 32-33.
  9. Mammadov, Sh.M. Investigation of the theological structural parameters of a network of NBR-based vulcanizates with the participation of chlorine-containing / Sh.M. Mammadov, G.G. Azizova, R.F. Khankishiyev, F.A. Amirov, G.A. Mammadova, I.G. Movlayev, J.S. Mammadova // Journal of new Technology and Materials, – 2023. No.1, – p. 70-74.
  10. Mammadov, Sh. The effect of composition and structure of nbr-based elastomer blends in the vulcanization process and study of their aging by exposure to heat and radiation / Sh. Mammadov, G. Azizova, G. Mammadova, R. Khankishiyeva, I. Movlayev, J. Mammadov // Chemistry & Chemical Technology, – 2023. No.4, – p. 829-835.

11. Mammadov, Sh.M. Properties of vulcanizates based on nitrile butadiene rubber in the occurrence of halomethyl-containing compounds / Sh.M. Mammadov, G.G. Azizova, G.A. Mammadova, R.F. Khankishieva, F.A. Amirov, I.G. Movlaev, J.Sh. Mammadov // *Functional Materials*, – 2023. No.3, – p. 393-397.
12. Azizova, G.G. Effect of heating on structural parameters of nitrile butadiene rubber in the presence of chlorine-containing compounds / G.G. Azizova, F.A. Amirov, I.G. Movlayev, G.A. Mammadova, R.F. Khankishiyeva, Sh.M. Mammadov // *Azerbaijan Chemical Journal*, – 2023. No 4, – p. 91-97.
13. Məmmədov, Ş.M. Polihalogenmetil tərkibi olan birləşmələrin iştirakı ilə butadien-nitril kauçuklarının kükürdsüz vulkanlaşması / Ş.M. Məmmədov, G.H.Əzizova, F.A.Əmirov, İ.Q.Mövlayev, G.A.Məmmədova, P.İ.İsmayılova, R.F.Xankişiyeva // *Pedaqoji Universitetin xəbərləri*, – 2023. Cild 71, №3, – s.75.
14. Азизова, Г.Г. Исследование особенности вулканизации и характера вулканизационных структур бутадиен-нитрильного каучука / Г.Г. Азизова, Ф.А. Амиров, И.Г. Мовлаев, Р.Ф. Ханкишиева, Г.А. Мамедова, Ш.М. Мамедов // *Sumqayıt Dövlət Universiteti Elmi Xəbərlər. Təbiət və Texniki Elmlər Bölməsi*, – 2023. № 3, – s. 19-24.
15. Азизова, Г., Мовлаев, И., Мамедова, Г., Мамедов, Д., Мамедов, Ш. Влияние молекулярного строения ускорителей и эпоксидных смол на технологически и механические свойства эластомерных смесей и вулканизаторов // *Ümummilli lider Heydər Əliyevin 100 illik yubileyinə həsr olunmuş tələbə və gənc tədqiqatçıların IV beynəlxalq elmi konfransları "Dayanıqlı Kimya və Kimya mühəndisliyinə doğru: Daha yaxşı bir dünya qurmaq üçün yeniliklər"*, Bakı Ali Neft Məktəbi, Bakı: – 12aprel-5 may, – 2023, – c. 510-511.
16. Мамедов, Ш.М., Азизова, Г.Г., Ханкишиева, Р.Ф., Салехов, А.Х., Мамедов, Д.Ш., Мамедова, Г.А. Влияние состав эластомерных смесей на старение воздействием тепла и радиации // *Ulu öndər H.Əliyevin anadan olmasının 100 illiyinə həsr olunmuş "Radiasiya texnologiyaları və onun tətbiqi"*

- mövzusunda Elmi-texniki konfrans, Radiasiya Problemləri İnstitutu, Bakı: – 5 may, – 2023, – с. 136-137.
17. Butadien-nitril kauçuku əsasında elastomer qarışığı. İxtira 2024 0046, Azərbaycan Respublikası / Əzizova G.H., Mustafayev İ.İ., Mehdiyeva R., N. Əsgərov O.V., Mövlayev İ.H., Məmmədova G.A. Xankişiyeva R.F., Məmmədov C.Ş., Əzizova A.S. – 2023.
  18. Amirov, F.A. Thermochemical structuring of nitrile butadiene rubber with the participation of chlorine-containing compounds / F.A. Amirov, G.G. Azizova, I.G. Movlayev // Processes of Petrochemistry and Oil Refining, – 2024. No. 1, – p. 175-181.
  19. Azizova, G., Amirov, F. Effect of different ingredients of elastomer mixtures on vulcanization with chlorinated aromatic compounds // International Science Group International Scientific and practical conference «World educational trends: lifelong learning in the information society» Proceedings of the VII International Scientific and Practical Conference, Athens, Greece: – 15-18 october, – 2024, – p. 44-45.
  20. Азизова, Г. Структурирование бутадиен-нитрильных каучуков в присутствии хлорсодержащих и эпоксидных соединений // XII Всероссийская конференция с международным участием «Каучук и резина-2025: традиции и новации», Москва, – 15-16 апреля, – 2025, – с.79.
  21. Азизова, Г., Амиров, Ф. Свойства вулканизатов на основе бутадиен-нитрильного каучука в присутствии галлогенметил содержащих соединений // Международный научно-практический семинар, посвященный 100-летию со дня рождения Ю.И. Дытнеского, Москва, – 10-11 апреля, – 2025, – с. 458.





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