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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

SYNTHESIS AND STUDY OF ADDITIVES TO BITUMEN BASED ON SYNTHETIC PETROLEUM ACIDS

Specialty: 3321.01 – Petroleum- Gas- Coal
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GENERAL CHARACTERISTICS OF THE WORK

Relevance and Degree of Elaboration of the Topic. It's well established that the current level of development in road transportation is directly dependent on the steadily increasing share of freight transport and the dynamic movement intensity of cargo vehicles. This results in greater dynamic loading on road pavements. Road construction is an integral part of a country's economic development, and the improvement of highway quality is one of the most pressing issues not only globally but also for our country. These objective factors necessitate the development of asphalt-concrete pavements with high physical and mechanical properties and, accordingly, require the improvement of road bitumen performance properties through innovative technical and technological processes in order to ensure the durability of road structures.

Bitumen, obtained from petroleum refining processes, is a widely used binding component in road construction and in the construction industry in general¹. Currently, bitumen is used as a binding, anti-corrosion, and waterproofing material in industry, civil and military construction, as well as in various other technological fields, including for protection against radioactive radiation. The main areas of bitumen application are the construction and repair of roads and airfields, and the construction of civil and industrial buildings and structures.

The quality of bitumen must meet the requirements of national standards and be continuously improved. The variation in quality requirements is dependent on differences in the technology used for asphalt concrete production, as well as on the specific performance expectations for bitumen. Low-quality bitumen significantly reduces the service life of road pavements. In order for bitumen to function effectively as a binding material, it must exhibit strong adhesion characteristics and a high resistance to the formation of plastic deformations. Moreover, it should have a wide plasticity interval to

¹ Porto, M. The Structure of bitumen: conceptual models and experimental evidences / Michele Proto, Ruggero Angelico, Paolino Caputo [et all] // *Materials*, - 2022.V.15, Is.3. -p. 905

ensure stability against cracking at low temperatures, while also maintaining stable performance at elevated temperatures.

In recent years, there has been an increasing global demand in road construction for polymer-modified or polymer-bitumen binders (PBBs)². The use of such binders enhances the water resistance coefficient of asphalt concrete and reduces water absorption, which is a critical factor in prolonging the service life of road pavements. The primary function of bitumen is to bind the particles of mineral materials and maintain a long-term structural framework. It is known that various additives are used to improve the adhesion of bitumen to aggregate, i.e., its adhesion performance. For this purpose, cationic surfactants such as amidoamines, imidazolines, amine compounds, and their salts are most commonly employed³. Although numerous studies have been conducted on the addition of such additives to improve the performance properties of road bitumen, the development of new, high-quality surface-active substances (SASs) remains a relevant and ongoing challenge.

Extensive research is also being conducted by researchers in our Republic to obtain high-quality road bitumen. In Azerbaijan, road bitumen is mainly produced by oxidizing the residues (vacuum bottoms) of low-paraffin marine crude oils. Although the road bitumen produced at the Heydar Aliyev Baku Oil Refinery meets the required quality standards, some performance properties still fall short of current demands. For instance, under cold conditions, the bitumen becomes brittle, and due to the formation of ice with a larger volume as a result of water freezing, the degradation of asphalt concrete pavements becomes a more serious issue. Considering these factors, it can be concluded that the development of modifiers and additives aimed at improving the quality of road bitumen remains a current and important scientific problem.

Object and Subject of the Research. The object of the research

² Gaikanova, R.N. Modern Concepts of Bituminous Products // R.N. Gaikanova, V.A. Budnik, R.N. Muratshin // Oil Refining and Petrochemistry, 2011, No. 10, pp. 8-13

³ Okhotnikova, E.S. Influence of Olefin Polymer Properties on the Quality of Modified Bitumen / E.S. Okhotnikova, T.N. Yusupova, Yu.M. Ganeeva [et al.] // Oil Refining and Petrochemistry, 2010, No. 11, pp. 35-39

is the synthesis of synthetic organic acids through the catalytic oxidation in the liquid phase of naphthenic-paraffinic hydrocarbons separated from the diesel distillate fraction of Azerbaijani crude oil mixtures, as well as the preparation of nitrogen-containing derivatives and metal salts of these acids. The subject of the research is the development of highly effective adhesion additives for road bitumen based on the synthesized compounds.

Aims and Objectives of the Research. The primary aim of the dissertation is improving the quality of road bitumen by synthesizing synthetic petroleum acids from raw materials abundantly available in our country, followed by the derivation of their nitrogen-containing compounds and metal salts, and using them as adhesion additives in road bitumen. Another key aim is to determine their optimal compositions. For the purpose of achieving these goals, the following objectives were pursued:

- synthesis of synthetic petroleum acids (SPA) and synthetic oxy acids (SOA) via the catalytic oxidation of aromatics-free diesel fractions with atmospheric oxygen in the liquid phase in the presence of variable-valence metal salts (Mn, Cr, Co);
- synthesis of amidoamines in various molar ratios (1:1-6:1) and imidazolines (1:1-2:1) based on SPA and polyethylene polyamine (PEPA), and their testing as adhesion additives for road bitumen;
- synthesis of metal salts (Ca, Al, Mn, Ba) of SPA and investigation of their effects on the quality parameters of road bitumen upon addition;
- synthesis of amino esters by reacting SPA with ethanolamines (mono-, di-, triethanolamines – MEA, DEA, TEA) in 1:1 molar ratio, and evaluation of their effects on the operational properties of bitumen;
- preparation of compositions based on SPA–PEPA-derived amidoamines and various lubricating oil distillates (AK-15, Aftol, and T-30 oil), and assessment of their impact on bitumen performance properties when used as additives;
- preparation and testing of compositions based on SPA metal salts (Ca, Al, Mn, Ba) and lubricating oil distillates (AK-15,

- Aftol, and T-30 oil) as adhesion additives for road bitumen, and evaluation of their impact on bitumen performance properties;
- preparation of compositions based on SPA-derived amino esters (synthesized with ethanolamines in 1:1 molar ratio) and various lubricating oil distillates, and investigation of their effect on the operational properties of bitumen;
 - development of multicomponent systems comprising SPA-PEPA-derived amidoamines (imidazolines), metal salts (in a 1:1 mass ratio), and AK-15 oil distillate, followed by evaluation of their performance as adhesion additives in road bitumen;
 - creation of three-component systems based on SPA-PEPA-derived amidoamines, SPA-derived amino esters synthesized with triethanolamine, and AK-15 oil distillate, and investigation of their effect on the quality parameters of road bitumen as adhesion additives.

Research Methods. The studies was carried out in accordance with modern methodologies and standards. The synthesis of synthetic petroleum acids (SPA) and synthetic oxy acids (SOA) was performed using a bubbling apparatus. The acid number was determined in accordance with GOST 5985-79. The structure and composition of the synthesized compounds were confirmed using modern spectroscopic methods, including IR spectroscopy and ^1H NMR spectroscopy.

The testing of performance properties following the addition of adhesion additives to road bitumen involved the following analyses:

- determination of brittleness temperature using the BPA 5 apparatus by Anton Paar;
- tensile testing using the DDA3 ductilometer;
- measurement of penetration depth using the PNR 12 penetrometer;
- determination of softening point using the Ring-and-Ball (R&B) apparatus.

Main Provisions Submitted for Defense. Synthetic organic acids were synthesized via aerobic oxidation in the liquid phase of naphthenic-paraffinic hydrocarbons in the presence of catalytic amounts of variable-valence metal salts. Amidoamines and imidazolines were synthesized from SPA and polyethylene polyamine

(PEPA), and their application as adhesion additives in road bitumen demonstrated high effectiveness. Amino esters based on SPA and monoethanolamine (MEA), diethanolamine (DEA), and triethanolamine (TEA), as well as metal salts of SPA, were synthesized, and their effects on the performance properties of road bitumen were studied. Compositions were formulated by combining SPA-derived amidoamines, imidazolines, metal salts, and amino esters with various grades of lubricating oil distillates, and their influence on bitumen performance properties was evaluated. Multicomponent systems consisting of SPA-derived amidoamines, metal salts, and AK-15 oil distillate, as well as systems consisting of SPA-derived amidoamines, amino esters, and AK-15 oil distillate, were developed, and their effects on the quality parameters of road bitumen were studied following incorporation.

Scientific Novelty of the Research.

- ✓ For the first time, amidoamines and imidazolines were synthesized from synthetic petroleum acids (SPA) and polyethylene polyamine (PEPA) in various molar ratios, and their properties as adhesion additives for road bitumen were studied for the first time.
- ✓ Metal salts of SPA with calcium (Ca), manganese (Mn), barium (Ba), and aluminum (Al) were synthesized, and their effect on bitumen adhesion was studied through their incorporation into road bitumen.
- ✓ Amino esters of SPA with monoethanolamine (MEA), diethanolamine (DEA), and triethanolamine (TEA) were synthesized in a 1:1 molar ratio for the first time, and their positive impact on the performance properties of road bitumen was identified. It was demonstrated that these synthesized amino esters improve the performance characteristics and adhesion properties of bitumen (achieving a rating of 1 point on the adhesion scale). It was determined that when 0,4% of the amino ester synthesized from SPA and TEA was added to the bitumen, the softening point reached 48,5°C, the penetration depth at 25°C was 50·0,1 mm, ductility at 25°C exceeded 100 cm, and the brittleness temperature was -24°C.

- ✓ It was established that compositions of SPA–PEPA-derived amidoamines and SPA metal salts with various lubricating oil distillates exhibit high adhesion performance when used as additives in road bitumen.
- ✓ It was proven that various concentrations of compositions based on amino esters synthesized from SPA and ethanolamines with different oil distillates, when added to road bitumen, increased adhesion to a maximum rating of 1 point, while also improving other performance properties of the bitumen.
- ✓ It was determined that compositions made from amidoamines synthesized from SPA and PEPA in molar ratios of 1:1 to 6:1, combined with SPA metal salts in a 1:1 weight ratio (85–95%) and AK-15 mineral oil distillate (5–15%), as well as multicomponent systems consisting of amidoamines (SPA:PEPA = 1:1–6:1 mol), amino esters (SPA:TEA = 1:1 mol), and AK-15 oil distillate, possess a synergistic effect as adhesion additives. These systems resulted in improved performance indicators: softening point of 52°C, penetration depth of 55·0,1 mm, ductility >100 cm, and brittleness temperature of –28°C. Adhesion was rated at the maximum score of 1 point.

Theoretical and Practical Significance of the Research. The significant improvement in the performance properties of road bitumen upon the incorporation of compounds synthesized from nitrogen-containing derivatives and metal salts of synthetic petroleum acids (SPA), obtained from abundantly available raw materials, confirms their potential applicability as adhesion additives in road bitumen. Specifically, the addition of very small amounts of imidazolines synthesized from SPA and polyethylene polyamine (PEPA), as well as amino esters synthesized from SPA and ethanolamines, leads to a noticeable enhancement in the performance characteristics of bitumen, with adhesion ratings improving from 3 to 1 point.

The use of multicomponent systems based on SPA nitrogen-containing derivatives, amino esters, and mineral oil distillates also

appears highly promising. These systems are economically advantageous and contribute to a reduction in production costs. Furthermore, their use significantly improves operational properties: ductility increases from 75 cm to over 100 cm, while brittleness temperature improves from -18°C to -28°C . Other parameters also show substantial improvements.

Author's Personal Contribution. The author personally carried out all aspects of the dissertation work, including the collection of literature materials, execution of the experimental research, generalization of experimental results, and the writing and formatting of scientific articles, theses, and the dissertation.

Approval and Implementation. 17 scientific works have been published based on this dissertation, including 7 articles, 1 patent, 9 conference papers and theses.

The main findings of the dissertation have been presented and discussed at the following scientific conferences: 3rd International Turkic World Conference on Chemical Sciences and Technologies (Baku, 2017); 1st National Student Scientific Conference dedicated to the 96th anniversary of National Leader Heydar Aliyev (Baku Higher Oil School, 2019); International Scientific Conference on "Current Issues of Modern Natural and Economic Sciences" dedicated to the 96th anniversary of National Leader Heydar Aliyev (Ganja, 2019); International Scientific Conference on "Topical Issues of Modern Chemistry" (Baku, 2019); International Conference on "Technical Thermodynamics: Thermophysical Properties and Energy Systems" (Rostock, Germany, 2020); National Scientific Conference on "Modern Problems of Chemistry" (Sumgayit, 2021); International Scientific Conference on "Current Issues of Modern Natural and Economic Sciences" (Ganja, 2021); International Conference on "Technical Thermodynamics: Thermophysical Properties and Energy Systems" (Rostock, Germany, 2021); Proceedings of Higher Technical Schools of Azerbaijan; 2nd International Conference of Azerbaijan State Oil and Industry University (Baku, 2022); International Scientific Conference on "Modern Problems of Petroleum Chemistry and Lubricant Technologies" dedicated to the 100th anniversary of Academician M.A. Mammadyarov (Baku, 2024).

The dissertation research was carried out at academician Y.H. Mammadaliyev Institute of Petrochemical Processes of the Ministry of Science and Education of the Republic of Azerbaijan, specifically in the laboratories of Study of Petroleum and Technology for Oil Production “Study of Petrochemicals and Oil Production Technology” and “Liquid Phase Oxidation.”

Structure and Volume of the Dissertation. The dissertation comprises 177 pages and includes the introduction (14692 characters), 4 chapters (Chapter I – 74543 characters; Chapter II – 15385 characters; Chapter III – 51572 characters; Chapter IV – 38150 characters), the conclusion (4233 characters), a list of 165 references, and a list of abbreviations. The total character count (excluding figures, tables, graphs, appendices, and bibliography) is 198575 characters. The dissertation includes 48 tables, 52 figures and 1 schematic diagram.

The Introduction presents the relevance of the topic, the object and subject of the research, its scientific novelty, aims and objectives, practical significance, approbation of the work, research methods and information about the structure and volume of the dissertation.

Chapter I provides a literature review on road bitumen production technologies and quality requirements, its composition, structure, properties, modification methods, types of additives used to improve the performance characteristics of road bitumen, their synthesis methods, as well as production methods and application areas of synthetic petroleum acids used as raw materials for additive synthesis.

Chapter II describes the experimental methodology: determination of structural-group composition and physicochemical parameters of raw materials and synthesized compounds, synthesis of catalysts used in oxidation processes, their characterization using modern spectroscopic instruments, analytical methods employed to assess the performance properties of bitumen, instruments used for these analyses, study of physicochemical properties of the compounds synthesized as additives for bitumen, structural-group confirmation using various spectral analysis techniques, and information on the

synthesis and physical methods used to study synthetic petroleum acids (SPA).

Chapter III is dedicated to the synthesis of amidoamines (at 1:1-6:1 molar ratios) and imidazolines (at 1:1-2:1 ratios) from SPA and PEPA, the synthesis of SPA-based metal salts, the preparation of amino esters from SPA and ethanolamines, and the evaluation of their properties. This chapter also explores the effect of these synthesized compounds at various concentrations on the quality parameters of road bitumen when used as adhesion additives. Additionally, the synthesis of amidoamines and imidazolines from mixtures of SPA and oxidized petroleum acids (OPA) with PEPA and their influence on bitumen properties is analyzed.

Chapter IV presents and analyzes the results of research on the use of SPA-PEPA-derived amidoamines and imidazolines, SPA metal salts, and amino esters in combination with mineral oil distillates in the preparation of additive compositions for road bitumen. This chapter also discusses the synthesis of multicomponent systems consisting of amidoamines, metal salts, and mineral oil distillates, as well as amidoamines, amino esters, and mineral oil distillates, and evaluates their performance as additives to road bitumen.

At the end of the dissertation, the main conclusions of the conducted research are provided, followed by a list of references and abbreviations.

MAIN CONTENT OF THE DISSERTATION

Synthetic petroleum acids (SPA) were selected as the raw material for the development of additives to be used in road bitumen. The SPAs were obtained by aerobic oxidation in the liquid phase of the aromatic-free diesel fraction derived from a blend of Azerbaijani crude oils, in the presence of variable-valency metal salts as catalysts. Metal salts and nitrogen-containing derivatives of SPA were synthesized, and these compounds - as well as their compositions with mineral oils - were tested as adhesion additives for road bitumen.

The IR spectra of SPA and its derivatives were recorded using an ALPHA FT-IR spectrometer (manufactured by BRUKER,

Germany) in the wavenumber range of 600-4000 cm^{-1} . The NMR spectra were recorded at room temperature using a 300 MHz NMR spectrometer (BRUKER AFR), with deuterated chloroform and acetone as solvents.

Thermal analyses of the obtained additives were performed using the STA-449 “Jupiter F3” synchronous thermal analyzer (NETZSCH, Germany).

The base road bitumen used as a raw material was PRB 50/70 grade bitumen, produced at the Heydar Aliyev Baku Oil Refinery. The performance properties of the bitumen were determined by standard methods, including penetration (needle penetration depth), softening point, brittleness temperature, ductility, and adhesion.

The quality parameters of the bitumen and the standards applied in Azerbaijan for road bitumen are presented in Tab. 1.

Table 1. Performance properties of road bitumen produced at the Baku Oil Refinery

Properties	Road bitumen	Requirements for PRB 50/70 grade viscous petroleum road bitumen according to TC AZ 3536601.242-2015
Needle penetration depth, 0,1 mm at 25°C	48	51-70
Softening point (Ring-and-Ball method), °C	48	46-54
Ductility, cm at 25°C	75	50
Brittleness temperature, 0°C	-18	-15
Adhesion to crushed stone, points	3	1, 2, 3 points

The thermogravimetric analysis of the bitumen is presented in Fig. 1. Based on the figure, it can be stated that the thermal stability of the road bitumen extends up to 289.9°C. According to the thermal analysis, the bitumen undergoes decomposition in the temperature ranges of 289.9-419.6°C and 419.6-485.1°C. The analysis also

The ^1H NMR spectrum of the amidoamine synthesized from synthetic petroleum acids (SPA) and polyethylenepolyamine (PEPA) at a 3:1 molar ratio was recorded (Fig. 2). Based on Fig. 2, the following data were obtained: ^1H NMR (BRUKER-Fourier 300 MHz, CDCl_3 , δ , ppm): 0,60-1,00 (CH_3), 1,00-1,49 (CH_2), 1,49-2,09 (CH , CH_2 , cyclic), 2,09-3,10 (Ar-CH , Ar-CH_2 , $\text{CH}_2\text{-CO}$), 3,10-3,80 ($\text{CH}_2\text{-NH}_2$), 4,05 (NH_2), 6,05-8,40 (Ar).

For the purpose of improving the performance properties of road bitumen, the synthesized amidoamines based on SPA and PEPA were added to bitumen in concentrations of 0,4% and 0,6%. The results of these modifications are presented in Tab. 2 and 3.

As is evident from Tab. 2, the best additive effect was observed in Sample 4. When this additive was introduced to the bitumen at 0,4%, the penetration depth at 25°C reached $51 \times 0,1$ mm, the ductility was 70 cm, and the brittleness temperature decreased to -22°C .

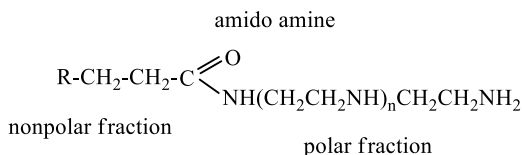
In comparison, the penetration depth and brittleness temperature of the unmodified bitumen were 48 mm and -18°C , respectively, indicating inferior performance. However, the softening point and ductility values of the bitumen with additive were slightly lower than those of the base bitumen.

Table 2. Performance properties of road bitumen modified with 0,4% synthesized amidoamines

No.	Addition of synthesized amidoamines to road bitumen	Softening point, $^\circ\text{C}$	Penetration depth, $\cdot 0,1\text{mm}$ 25°C	Ductility, cm	Brittleness temp., $^\circ\text{C}$	Adhesion points
				25°C		
1	Road bitumen	48	48	75	-18	3
2	SPA:PEPA at 1:1 molar ratio	50,2	44	50,6	-19	1
3	SPA:PEPA at 2:1 molar ratio	50,6	40	38,18	-26	1
4	SPA:PEPA at 3:1 molar ratio	46,3	51	70	-22	1
5	SPA:PEPA at 4:1 molar ratio	46,3	50	55,25	-19	1
6	SPA:PEPA at 5:1 molar ratio	46,6	50	62,9	-23	1
7	SPA:PEPA at 6:1 molar ratio	46	52	35,5	-18	1

Table 3. Performance properties of road bitumen modified with 0,6% synthesized amidoamines

No.	Addition of synthesized amidoamines to road bitumen	Softening point, °C	Penetration depth, 0.1mm 25°C	Ductility, cm	Brittleness temp., °C	Adhesion
				25°C		points
1	Road bitumen	48	48	75	-18	3
2	SPA:PEPA at 1:1 molar ratio	47,5	49	33	-23	1
3	SPA:PEPA at 2:1 molar ratio	46,5	50	61,65	-23	1
4	SPA:PEPA at 3:1 molar ratio	47,5	50	>100	-26	1
5	SPA:PEPA at 4:1 molar ratio	48,8	46	43	-30	1
6	SPA:PEPA at 5:1 molar ratio	47,6	48	73	-29	1
7	SPA:PEPA at 6:1 molar ratio	46,3	51	40	-20	1



Based on Tab.3, the addition of 0.6% of the amidoamine synthesized at a SPA:PEPA molar ratio of 3:1 significantly improves the performance characteristics of the bitumen: the softening point reaches 47,5°C, the penetration depth at 25°C is 50×0,1 mm, ductility exceeds 100 cm, and the brittleness temperature drops to -26°C. Among these, only the softening point remains nearly identical to that of the unmodified bitumen. In both concentrations (0,4% and 0,6%), the adhesion of the bitumen improves, with the adhesion rating decreasing from 3 points to 1 point.

Thus, based on the results obtained, it can be concluded that the amidoamine synthesized at a SPA:PEPA molar ratio of 3:1 is the most favorable for use as an adhesion additive in road bitumen.

For the purpose of improving the adhesive properties of bitumen for road pavements, it's advisable to increase the number of polar components in nitrogen-containing compounds. In this context, the

use of PEPA in the synthesis of amidoamines is considered appropriate. Furthermore, the presence of a long-chain hydrocarbon radical ensures better incorporation and compatibility within the bitumen matrix.

As a result, the synthesized compound acts as a molecular bridge between the polar mineral surface and the hydrophobic bitumen, with the amidoamine molecule facilitating the adhesion of bitumen to the mineral component of the pavement. The role of the synthesized amidoamines as high-performance adhesion additives can be attributed to the presence of oxygen and nitrogen heteroatoms in the system (which enhance chemisorption - due to the presence of lone-pair electron groups that intensify adsorption), the increased number of active centers, molecular size, and electron density. Additionally, a key advantage of the synthesized amidoamine lies in the large alkyl radical of the SPA used in its preparation.

Moreover, in an effort to further improve the quality parameters of road bitumen, imidazolines were synthesized using the known methodology by combining SPA and PEPA at molar ratios of 1:1 and 2:1. quality

The results obtained from the addition of 0.4% and 0.6% of the synthesized imidazolines to road bitumen are presented in Tab. 4 and 5.

Table 4. Performance properties of road bitumen modified with 0,4% synthesized amidoamines

№	Addition of synthesized amidoamines to road bitumen	Softening point, °C	Penetration depth, ·0,1mm 25°C	Ductility, cm	Brittlene ss temp., °C	Adhesion points
				25°C		
1	Road bitumen	48	48	75	-18	3
2	SPA:PEPA (1:1)	47	49	27	-22	2
3	SPA:PEPA (2:1)	47,8	48	42,87	-25	1

As seen from Tab. 4, the imidazoline obtained by SPA and PEPA in a 2:1 molar ratio (Sample 3) yields better results when added

to road bitumen at 0,4% concentration: the softening point reaches 47.8°C, the penetration depth at 25°C is 48×0,1 mm, ductility at 25°C is 42,87 cm, and the brittleness temperature is -25°C. However, similar to Sample 2, the ductility is lower in comparison to the unmodified bitumen.

Table 5. Performance properties of road bitumen modified with 0.6% imidazoline

No.	Addition of synthesized amidoamines to road bitumen	Softening point, °C	Penetration depth, ·0.1mm 25°C	Ductility, cm	Brittleness temp., °C	Adhesion
				25°C		points
1	Road bitumen	48	48	75	-18	3
2	SPA:PEPA (1:1)	46,6	50	30,4	-18	1
3	SPA:PEPA (2:1)	48,2	46	75	-23	1

As is evident from Tab. 5, when the SPA:PEPA molar ratio is 2:1, the performance properties of the bitumen improve, with a softening point of 48.2°C, penetration depth at 25°C of 46·0,1 mm, ductility of 75 cm, and brittleness temperature of -23°C. Therefore, based on the tables, it can be concluded that using 0,6% of the imidazoline synthesized at SPA:PEPA = 2:1 molar ratio as an adhesion additive in road bitumen is considered more favorable.

Synthesis of Ba, Al, Ca, and Mn Salts of SPA and Study as Additives in Road Bitumen at Various Concentrations

Based on a known methodology, salts of calcium (Ca), manganese (Mn), barium (Ba), and aluminum (Al) were synthesized from synthetic petroleum acids (SPA) obtained through liquid-phase aerobic oxidation of a naphthenic-paraffinic hydrocarbon mixture. These metal salts were added to road bitumen at concentrations of 0,4% and 0,6%, and the performance properties of the resulting bitumen were evaluated. The results are presented in Tab. 6.

As seen, an increase in concentration leads to a significant improvement in the performance properties of the bitumen. The conducted studies show that the effectiveness of nitrogen-containing

derivatives of SPA as adhesion additives is higher compared to their metal salts. This can be explained by the greater number of amide groups in the polyamide molecule capable of forming hydrogen bonds.

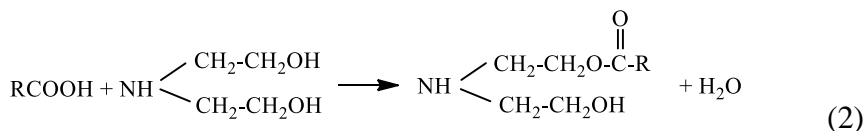
Table 6. Performance properties of road bitumen modified with 0,4% and 0,6% of SPA metal salts

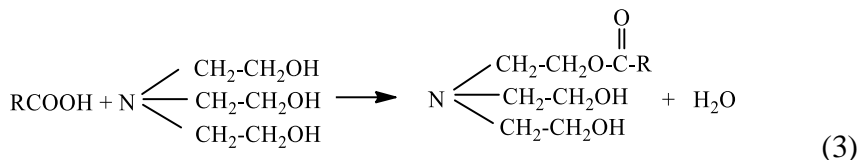
No.	Addition of SPA salts to road bitumen	Concentration, %	Softening point, °C	Penetration depth, at 25°C	Ductility, cm	Brittleness point, °C	Adhesion
					25°C		Points
1	Road bitumen		48	48	75	-18	3
2	Ba salt of SPA	0,4	46,8	51	32,4	-14	2
		0,6	46,7	51	34,4	-16	2
3	Al salt of SPA	0,4	46,2	51	40,4	-24	2
		0,6	46,4	52	38	-22	2
4	Ca salt of SPA	0,4	46,7	51	68	-16	2
		0,6	46,5	51	68	-17	2
5	Mn salt of SPA	0,4	46,3	51	57	-23	2
		0,6	46,2	51	62	-24	2

Synthesis of Amino Esters of SPA with Ethanolamines and Study as Bitumen Additives at Various Concentrations

Amino esters were synthesized based on SPA and mono-, di-, and triethanolamines (MEA, DEA, and TEA) in a 1:1 molar ratio. The reaction was carried out for 7-8 hours at 80-85°C in the presence of NaOH as a catalyst and benzene as the solvent. The amount of catalyst used was approximately 2-3 wt.% relative to the raw materials. The yields of each of the obtained amino esters were 98-99%.

The interaction reaction between SPA and MEA, DEA, or TEA can be illustrated as follows:





The IR spectrum of the amino ester synthesized from SPA and DEA is presented in Fig. 3 and the corresponding ^1H NMR spectrum is shown in Fig. 4.

The following absorption bands were observed based on the IR spectrum: deformation (724, 1376, 1454 cm^{-1}) and valence (2853, 2921 cm^{-1}) vibrations of C-H bonds in CH_3 and CH_2 groups; Deformation vibrations (1619 cm^{-1}) of the N-H bond; valence vibrations (1209 cm^{-1}) of the C-N bond; valence vibrations of the C-O and C=O bonds (1161 and 1736 cm^{-1} , respectively) belonging to the ester group; valence vibrations (1052 cm^{-1}) of the C-O bond in the alcohol group; valence vibrations (3324 cm^{-1}) of the O-H bond associated with the hydroxyl group in the alcohol.

According to Fig. 4, the ^1H NMR spectrum (BRUKER-Fourier 300 MHz, CDCl_3 , δ , ppm) shows the following chemical shifts: 0,62-1,00 ppm (CH_3), 1,00-1,48 ppm (CH_2), 1,48-2,10 ppm (CH , CH_2 , cyclic), 2,10-3,10 ppm (Ar-CH, Ar- CH_2 , $\text{CH}_2\text{-CO}$), 3,41-3,62 ppm ($\text{CH}_2\text{-NH}_2$), 3,62-3,74 ppm ($\text{CH}_2\text{-OH}$), 4,18 ppm (OH), 4,88 ppm (NH_2), 6,60-7,80 ppm (Ar).

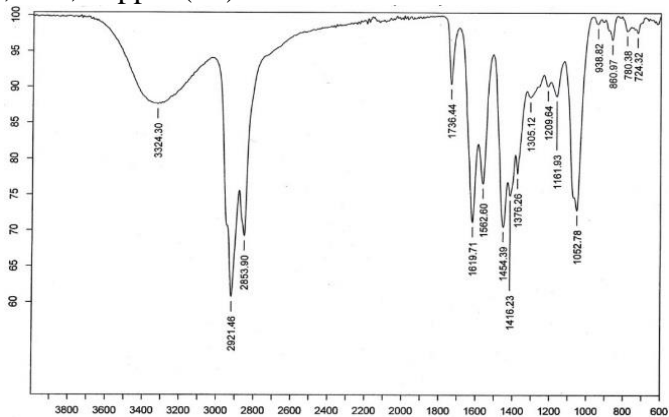


Fig. 3. IR spectrum of the amino ester obtained by SPA:DEA in 1:1 molar ratio

process that starts at 225.4°C is completed, the second process begins at 343.4°C and reaches its maximum at 377.6°C. The corresponding mass losses for these processes are 22,75% and 44,02%, respectively. In the final decomposition process, which peaks at 474.6°C, a mass loss of 15,70% is recorded with precision.

Amino esters were added to road bitumen in concentrations of 0,4% and 0,6%, and the quality indicators of the resulting samples are presented in Tab. 7. As is evident from Tab. 7, among the synthesized compounds, the best results in bitumen modification were obtained with the 2nd and 3rd samples. Specifically, when the 2nd sample was added to bitumen at 0,6% concentration, the softening point of the bitumen increased from 48°C to 48,3°C; the penetration depth at 25°C was 48·0,1 mm; ductility at 25°C increased from 71 cm to 92 cm; and the brittleness temperature decreased from -18°C to -25°C. Even higher performance was achieved with the 3rd sample. When used at a concentration of 0,4%, the softening point was 48,5°C, penetration depth at 25°C was 50·0,1 mm, ductility at 25°C exceeded 100 cm, and the brittleness temperature reached -26°C. When the 3rd sample was added at 0,6%, the results were as follows: softening point 48,2°C, penetration depth at 25°C 51·0,1 mm, ductility at 25°C was 96,8 cm, and brittleness temperature was -25°C. In all samples, the adhesion score was 1 point.

Table 7. Performance properties of bitumen after the addition of 0,4% and 0,6% of synthesized amino esters

Sample	Additive amount, %	Softening temperature, °C	Penetration depth, 0,1 mm at 25°C	Ductility, 25°C, cm	Brittl. temp., °C	Adhesion, points
PRB 50/70	-	48	48	75	-18	3
PRB 50/70+ Sample-1	0,4	47,5	49	87	-25	1(2)
	0,6	47,2	50	90	-24	1(2)
PRB 50/70+ Sample-2	0,4	47,2	50	96,8	-24	1(2)
	0,6	48,3	48	92	-25	1
PRB 50/70+ Sample-3	0,4	48,5	50	>100	-26	1
	0,6	48,2	51	96,8	-25	1

Note: Sample 1 – amino ester synthesized at a 1:1 molar ratio of SPA:MEA; Sample 2 – amino ester synthesized at a 1:1 molar ratio of SPA:DEA; Sample 3 – amino ester synthesized at a 1:1 molar ratio of SPA:TEA; PRB – petroleum road bitumen.

The thermal properties of the mixture obtained by adding 0,6% of the amino ester synthesized from SPA and DEA to bitumen were studied (Fig. 6). According to Fig. 6, the thermogravimetric analysis of the sample containing 0,6% amino ester differs significantly from the thermogram of the pure amino ester. Notably, unlike the amino ester, which begins to decompose at 225,4°C, the modified bitumen sample exhibits thermal stability up to 371,7°C and undergoes a single-stage decomposition process.

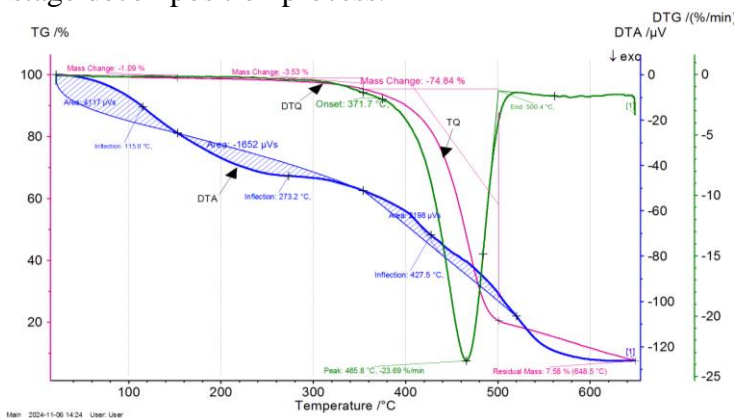


Fig. 6. TG/DTA thermogram of the mixture obtained by adding 0,6% of the SPA-DEA amino ester as an additive to bitumen

Fig. 7 presents the dependence of the bitumen brittleness temperature on its softening point after the addition of 0,4% of amino esters as additives. Fig. 8 shows the dependence of the penetration depth on the brittleness temperature under the same conditions.

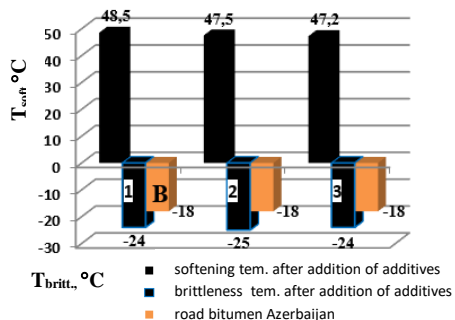


Fig. 7. Dependence of softening point on brittleness temperature after the addition of 0.4% of amino esters synthesized from SPA and MEA, DEA, TEA to road bitumen

Here: B – brittleness temperature of road bitumen, 1 – amino ester synthesized at a 1:1 molar ratio of SPA:TEA, 2 – amino ester synthesized at a 1:1 molar ratio of SPA:MEA, 3 – amino ester synthesized at a 1:1 molar ratio of SPA:DEA

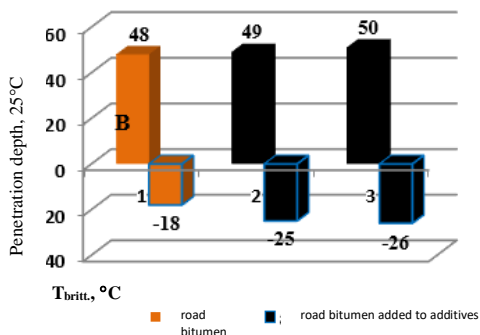


Fig. 8. Graphical representation of the dependence of penetration depth on brittleness temperature after the addition of 0.4% of amino esters synthesized from SPA and MEA, DEA, TEA to road bitumen

Note: 1 – road bitumen, 2 – amino ester synthesized from SPA:MEA, 3 – amino ester synthesized from SPA:TEA

Thus, amino esters synthesized from SPA and ethanolamines can be recommended for use as high-quality adhesion additives in road bitumen. In this case, the optimal variants are amino esters synthesized

at a 1:1 molar ratio of SPA:DEA and SPA:TEA, applied at a concentration of 0.4%.

Study of amidoamines and imidazolines synthesized from SPA+OSPA (oxy-synthetic petroleum acid) and PEPA as adhesion additives in road bitumen at various concentrations

Amidoamines (SPA+OSPA:PEPA=1:1÷6:1) and imidazolines (1:1 and 2:1) were synthesized based on SPA+OSPA and PEPA and used as high-performance adhesion additives for road bitumen.

It was determined that, similar to the amidoamines synthesized from SPA and PEPA, the best results were obtained with amidoamines synthesized at (SPA+OSPA):PEPA molar ratio of 3:1. In this case:

The softening point of the bitumen remained at 48°C.

The penetration depth increased from 48·0,1 mm to 52,5·0.1 mm after adding 0,6% amidoamine.

The ductility at 25°C increased from 75 cm (in the unmodified bitumen) to over 100 cm after modification.

The addition of amidoamine also positively influenced the brittleness temperature, decreasing it from -18°C to -25°C.

For all amidoamines studied, the adhesion score was 1 point.

When the imidazoline synthesized from SPA+OSPA and PEPA was added to road bitumen at 0,4%, all performance properties of the bitumen improved, except ductility: softening point: 48,5°C, penetration depth: 51·0,1 mm, brittleness temperature: -26°C, ductility, however, decreased to 60,8 cm.

Nevertheless, when imidazoline was added at a 0,6% concentration, the overall performance properties of the bitumen improved.

Preparation of Compositions Based on Metal Salts and Nitrogen Derivatives of SPA with Various Lubricating Oil Distillates and Study as Adhesion Additives in Road Bitumen

The compositions were prepared using various mineral oil distillates (AK-15, T-30, M-8B) in combination with nitrogen-containing derivatives and metal salts of SPA, and their performance

as additives in road bitumen was studied. The main objective was reducing the cost of the additive. Among the tested compounds, the best results were obtained from compositions based on amidoamines and amino esters of SPA and PEPA with AK-15 engine oil.

Compositions of amidoamines with AK-15 engine oil were prepared at various weight percentages (5-15%), and the performance properties of road bitumen samples modified with 0,4% and 0,6% of these compositions are presented in Tab. 8 and 9.

Table 8. Performance properties of road bitumen after the addition of 0,4% of compositions based on SPA and PEPA amidoamines with AK-15 engine oil

No.	Addition of synthesized additives to road bitumen	Softening temp., °C	Penetration depth, 0,1 mm, at 25°C	Ductility, cm	Britt. temp., °C	Adhesion points
				25°C		
1	Road bitumen	48	48	75	-18	3
2	A-1 95%+ AK-15 oil 5%	49	49	52	-19	1
3	A-1 90% +AK-15 oil 10%	47,8	49	51	-19	1
4	A-1 85%+ AK-15 oil 15%	47,6	51	58	-21	1
5	A-2 95%+ AK-15 oil 5%	48	49	65,5	-23	1
6	A-2 90% +AK-15 oil 10%	47,8	50	67	-23	1
7	A-2 85%+ AK-15 oil 15%	48,3	48	61,37	-25	1
8	A-3 95%+ AK-15 oil 5%	47,1	50	74,23	-24	1
9	A-3 90% +AK-15 oil 10%	46,8	50	85	-24	1
10	A-3 85%+ AK-15 oil 15%	46,4	51	73	-25	1
11	A-4 95%+ AK-15 oil 5%	47,5	48	88	-22	1
12	A-4 90%+ AK-15 oil 10%	47,1	51	>100	-24	1
13	A-4 85%+ AK-15 oil 15%	46,9	50	75	-27	1
14	A-5 95%+ AK-15 oil 5%	47	51	97	-24	1

15	A-5 90% +AK-15 oil 10%	46,9	52	>100	-25	1
16	A-5 85%+ AK-15 oil 15%	46,7	51	94	-27	1
17	A-6 95%+ AK-15 oil 5%	46,9	50	70	-20	1
18	A-6 90% +AK-15 oil 10%	46,7	51	75	-22	1
19	A-6 85%+ AK-15 oil 15%	46,2	52	67	-25	1

Table 9. Performance properties of road bitumen after the addition of 0.6% of compositions based on SPA and PEPA amidoamines with AK-15 engine oil

No.	Addition of synthesized additives to road bitumen	Softening temp., °C	Penetration depth, 0.1 mm, at 25°C	Ductility, cm	Britt. temp., °C	Adhesion points
				25°C		
1	Road bitumen	48	48	75	-18	3
2	A-1 95%+ AK-15 oil 5%	48,8	49	46	-19	1
3	A-1 90% +AK-15 oil 10%	48,4	50	46	-20	1
4	A-1 85%+ AK-15 oil 15%	47,6	51	51	-21	1
5	A-2 95%+ AK-15 oil 5%	48,1	49	61	-25	1
6	A-2 90% +AK-15 oil 10%	47,5	50	62	-26	1
7	A-2 85%+ AK-15 oil 15%	47,9	49	57	-24	1
8	A-3 95%+ AK-15 oil 5%	46,7	51	62	-28	1
9	A-3 90% +AK-15 oil 10%	46,6	51	78	-27	1
10	A-3 85%+ AK-15 oil 15%	46,5	51	61	-28	1
11	A-4 95%+ AK-15 oil 5%	47,2	51	80	-21	1
12	A-4 90% +AK-15 oil 10%	47	52	85	-22	1
13	A-4 85%+ AK-15 oil 15%	46,7	51	72	-24	1
14	A-5 95%+ AK-15 oil 5%	48	52	90	-23	1

15	A-5 90% +AK-15 oil 10%	46,7	52	95	-24	1
16	A-5 85%+ AK-15 oil 15%	46,4	53	90	-26	1
17	A-6 95%+ AK-15 oil 5%	46,7	51	67	-21	1
18	A-6 90% +AK-15 oil 10%	46,4	52	70	-24	1
19	A-6 85%+ AK-15 oil 15%	46	53	63	-27	1

Based on both tables, it can be stated that the addition of small amounts of the synthesized compounds to road bitumen significantly improves its quality parameters.

Table 10. Performance properties of road bitumen after the addition of 0.4% of compositions based on amino esters synthesized from SPA and MEA, DEA, and TEA with AK-15 engine oil

№	Addition of synthesized additives to road bitumen	Softening temp.e, °C	Penetration depth, 0.1 mm, at 25°C	Ductility, cm	Britt. temp., °C	Adhesion points
				25°C		
1	Road bitumen	48	48	75	-18	3
2	N-1 95%+ AK-15 oil 5%	48	49	87	-20	1
3	N-1 90% + AK-15 oil10%	47,9	49	89	-21	1
4	N-1 85%+ AK-15 oil15%	47,8	50	88	-23	1
5	N-2 95%+ AK-15 oil 5%	48	49	90	-22	1
6	N-2 90% + AK-15 oil10%	48,2	52	97	-24	1
7	N-2 85%+ AK-15 oil 15%	47,4	51	99	-25	1
8	N-3 95%+ AK-15 oil 5%	47,5	51	> 100	-25	1
9	N-3 90% + AK-15 oil10%	49,5	54	99	-24	1
10	N-3 85%+ AK-15 oil 15%	49	54	96,3	-25	1

The results of the effect of adding compositions of amino esters synthesized from SPA with MEA, DEA, and TEA in various concentrations (respectively 5-15%) in combination with AK-15 engine oil at dosages of 0,4% and 0,6% to road bitumen on the

performance properties of the bitumen are presented in Tab. 10 and 11.

As can be seen from the tables, the compositions based on amino esters also significantly improve the performance properties of the bitumen.

Table 11. Performance properties of road bitumen after the addition of 0,6% of compositions based on amino esters synthesized from SPA and MEA, DEA, TEA with AK-15 engine oil

No.	Addition of synthesized additives to road bitumen	Softening temp., °C	Penetration depth, 0.1 mm, at 25°C	Ductility, cm	Britt. temp., °C	Adhesion points
				25°C		
1	Road bitumen	48	48	75	-18	3
2	N-1 95%+ AK-15 oil 5%	47,9	49	75	-21	1
3	N-1 90% + AK-15 oil10%	47,8	51	90	-22	1
4	N-1 85%+ AK-15 oil15%	47,7	52	92	-24	1
5	N-2 95%+ AK-15 oil 5%	48,6	51	94	-23	1
6	N-2 90% + AK-15 oil10%	48,1	51	99	-25	1
7	N-2 85%+ AK-15 oil 15%	48	52	>100	-24	1
8	N-3 95%+ AK-15 oil 5%	49	53	>100	-25	1
9	N-3 90% + AK-15 oil10%	49	53	>100	-26	1
10	N-3 85%+ AK-15 oil 15%	48,5	53	>100	-27	1

Note: N-1 – SPA:MEA; N-2 – SPA:DEA; N-3 – SPA:TEA amino esters synthesized in a 1:1 molar ratio.

Development of Multicomponent Systems Based on SPA Derivatives and Study as Adhesion Additives for Road Bitumen

In addition, amidoamines synthesized from SPA and PEPA, metal salts of SPA and the AK-15 mineral oil distillate were used along with amidoamines, amino esters and AK-15 oil distillate, to

form three-component systems. The effects of these systems on the performance properties of road bitumen were studied.

It was determined that when these three-component systems are added to road bitumen at concentrations of 0,4% and 0,6%, they demonstrate a significantly higher additive effect compared to their individual components. Specifically, the addition of these compositions results in all quality parameters of the bitumen meeting the requirements of the GOST standard. In this case: the softening point increases to 52°C, the penetration depth reaches 55·0,1 mm, The brittleness temperature improves to -28°C, the adhesion score reaches 1 point.

Conclusions

1. Amidoamines were synthesized by a known method using mixtures of synthetic petroleum acid (SPA), obtained via liquid-phase oxidation of naphthene-paraffin hydrocarbons (isolated from the diesel fraction of Azerbaijani crude oil) in the presence of transition metal salts as catalysts, with PEPA (polyethylene polyamine) at various molar ratios (SPA:PEPA = 1:1 ÷ 6:1). The physicochemical properties of the resulting amidoamines were studied and their effectiveness as adhesion additives in road bitumen was evaluated. It was determined that the best performance was observed at a molar ratio of SPA:PEPA = 3:1, when 0,6% of the synthesized amidoamine was added to bitumen. In comparison to a 0,4% addition, the performance properties of the bitumen significantly improved: softening point – 47,5°C, penetration at 25°C – 50·0,1 mm, ductility >100 cm, and brittleness temperature – -26°C [1, 3, 4, 6, 7].
2. Imidazoline was also synthesized using SPA and PEPA at molar ratios of 2:1 exhibited higher additive effectiveness: softening point – 48,2°C, penetration at 25°C – 48 mm, ductility – 75 cm, brittleness temperature – -23°C. In both cases (amidoamines and imidazolines), adhesion reached the highest rating of 1 point [2, 5].
3. Metal salts of SPA (Ba, Al, Ca, Mn) were synthesized and added to road bitumen at concentrations of 0,4% and 0,6%. It was found

that although the addition of these salts improved penetration depth and brittleness temperature, other parameters fell below standard limits, and the adhesion rating decreased from 3 to 2 [14].

4. Amino esters were synthesized from SPA and ethanolamines (MEA, DEA, TEA) at a molar ratio of 1:1 using a known method. The structure was confirmed by IR spectroscopy. When added to road bitumen at concentrations of 0,4% and 0,6%, they improved the operational characteristics of the bitumen, including increased adhesion. The best results were obtained using the amino ester synthesized from SPA and TEA at 0.4% concentration: softening point – 48,5°C, penetration at 25°C – 50·0,1 mm, ductility >100 cm, brittleness temperature – -24°C, adhesion rating – 1 point [15, 17].
5. Compositions were prepared by mixing amidoamines (synthesized at SPA:PEPA molar ratios of 1:1 to 6:1) with lubricating oils such as AK-15, Aftol, and T-30 at 5%, 10%, and 15% concentrations. These were added to road bitumen to evaluate their effect on bitumen properties and adhesion. It was found that AK-15-based compositions gave the best additive effect: softening point – 48°C, penetration – 52·0,1 mm, ductility – 96 cm, brittleness temperature – -23°C, adhesion improved from 3 to 1 point. Additionally, the use of such oils in additive formulations was deemed economically favorable [8-13].
6. Compositions of SPA metal salts (Ca, Mn, Ba, Al) with mineral oil distillates were prepared. The addition of these compositions to bitumen as adhesion additives resulted in better performance compared to the use of the metal salts alone.
7. Compositions of amino esters (synthesized from SPA and MEA, DEA, TEA at 1:1 molar ratio) with AK-15 engine oil were prepared in various concentrations (85-95% amino ester and 5-15% AK-15). These compositions were added to road bitumen at 0,4% and 0,6% to evaluate performance. It was demonstrated that compositions with AK-15 improved bitumen quality more significantly than the amino esters alone. The best results were obtained using the SPA-TEA amino ester (90%) with AK-15

(10%), added at 0,4%: softening point – 49,5°C, penetration – 54·0,1 mm, ductility – 99 cm, brittleness temperature – -24°C, adhesion rating – 1 point [16].

8. Three-component systems were developed from amidoamines (synthesized from SPA and PEPA in molar ratios of 1:1 to 6:1), SPA metal salts (1:1 mass ratio with the amidoamines, total 85-95%), AK-15 mineral oil distillate (5-15%). These systems were added to road bitumen at 0,4% and 0,6%. It was proven that these combinations showed higher efficiency than the individual components alone. Furthermore, a multicomponent system comprising amidoamines (SPA:PEPA = 1:1÷6:1), amino esters (SPA:TEA = 1:1), and AK-15 yielded the best performance at both concentrations: softening point – 52°C, penetration – 55·0,1 mm, ductility >100 cm, brittleness temperature – -28°C, adhesion rating – 1 point.

The main content of the dissertation has been published in the following scientific works:

1. Afandiyeva, L.M., Aliyeva, L.I., Hasanov, E.K., Musaly, V.Kh., Babayeva, B.A., Abbasov, V.M. Synthesis of additives for bitumen based on amidoamines of synthetic petroleum acids // International scientific conference on "Current issues of modern natural and economic sciences" dedicated to the 96th anniversary of national leader Heydar Aliyev. – Ganja, May 2–3, 2019, pp. 195–197.
2. Abbasov, V.M., Aliyeva, L.I., Afandiyeva, L.M., Musaly, V.Kh., Hasanov, E.K., Babayeva, B.A. Investigation of imidazolines as an additive to bitumen obtained on the basis of synthetic petroleum acids // The International Scientific Conference “Actual Problems of Modern Chemistry”. – Baku, October 2–4, 2019, p. 20.
3. Musaly, V.Kh. Study of amidoamines synthesized from synthetic petroleum acids as additives to road bitumen // Baku Higher Oil School. I Republican Student Scientific Conference dedicated to the 96th anniversary of national leader Heydar Aliyev. – Baku, April 15–19, 2019, pp. 22–23.
4. Aliyeva, L.I. Nitrogen derivatives of synthetic naphthenic acids as additives for road bitumen / L.I. Aliyeva, L.M. Afandiyeva, V.Kh. Musaly, E.K. Hasanov, Ch.K. Salmanova // Uzbek Chemical Journal, 2020, No. 4, pp. 85–89.
5. Musaly, V.Kh. Investigation of nitrogen derivatives of synthetic petroleum acids as additives to bitumen // Young Researcher, Scientific-Practical Journal, 2020, Vol. 6, No. 2, pp. 17–22.
6. Afandiyeva, L.M. Study of amidoamines obtained from synthetic petroleum acids as additives to road bitumen / L.M. Afandiyeva, L.I. Aliyeva, V.Kh. Musaly, E.K. Hasanov, B.A. Babayeva // Sumgayit State University, Scientific News, 2020, Vol. 20, No. 4, pp. 30–34.
7. Afandiyeva, L.M., Aliyeva, L.I., Musaly, V.Kh., Hasanov, E.K., Cherepnova, Yu.P., Abbasov, V.M. Investigation of nitrogen derivatives of synthetic petroleum acids as an additive to road bitumen // 9th Rostock International Conference: “Technical

- Thermodynamics: Thermophysical Properties and Energy Systems”, Rostock, Germany, October 15, 2020, p. 54.
8. Efendiyeva, L.M. Study of compositions based on amidoamines of synthetic petroleum acids and M-8B motor oil as additives to road bitumen / L.M. Efendiyeva, L.I. Aliyeva, V.Kh. Musaly, E.K. Hasanov, A.P. Musayeva, Yu.P. Cherepnova, T.A. Mazamova // *Oil Refining and Petrochemistry*, 2021, No. 6, pp. 22–25.
 9. Abbasov, V.M. The study of compositions prepared on the basis of amidoamines and mineral oil distillates of synthetic petroleum acids as an additive to bitumen / V. Abbasov, L. Aliyeva, L. Afandiyeva, V. Musaly, E. Hasanov // *Processes of Petrochemistry and Oil Refining*, 2021, Vol. 22, No. 1, pp. 172–179.
 10. Afandiyeva, L.M., Musaly, V.Kh., Nasibova, G.Q., Asgarova, S.Y., Mammadova, Kh.R., Isgandarova, V.R. Investigation of compositions based on amidoamines of synthetic petroleum acids and AK-15 motor oil as bitumen additives // *Materials of the Republican Scientific Conference "Modern Problems of Chemistry"*, Sumgayit, April 15–16, 2021, pp. 215–219.
 11. Afandiyeva, L.M., Aliyeva, L.I., Musaly, V.Kh., Nasibova, G.Q., Asgarova, S.Y., Abbasov, V.M. Investigation of compositions based on amidoamines of synthetic petroleum acids and M-8B (Aftol) motor oil as additives for road bitumen // *International Scientific Conference on "Current Issues in Natural and Economic Sciences"*. – Ganja, May 6–7, 2021, pp. 92–95.
 12. Afandiyeva, L.M., Aliyeva, L.I., Musaly, V.Kh., Hasanov, E.K., Musayeva, A.P., Abbasov, V.M. Investigation of compositions based on amidoamines of synthetic petroleum acids and mineral oil distillates as additives to bitumen // *10th Rostock International Conference: "Technical Thermodynamics: Thermophysical Properties and Energy Systems"*. – Rostock, Germany, September 9–10, 2021, p. 74.
 13. Abbasov, V.M., Afandiyeva, L.M., Musaly, V.Kh., Mammadova, Sh.R., Chingiz, F.Ch., Hasanova, T.Ch., Isgandarova, V.R. Investigation of compositions based on nitrogen derivatives of

- synthetic petroleum acids and T-30 mineral oil as additives for road bitumen // Proceedings of the 2nd International Conference of Azerbaijan State Oil and Industry University. – Baku, February 24–25, 2022, Vol. 24, No. 2, pp. 146–150.
14. Musaly, V.Kh. Synthesis of metal salts of synthetic petroleum acids and their study as additives for road bitumen // Sumgayit State University, Scientific News, 2023, Vol. 23, No. 1, pp. 53–58.
 15. Abbasov, V.M. Multifunctional additive for road bitumen, Patent i2023 0103, Republic of Azerbaijan / T.A. Ismayilov, E.K. Hasanov, L.M. Afandiyeva, E.A. Gasimzadeh, V.Kh. Musaly.
 16. Abbasov, V.M., Afandiyeva, L.M., Aliyeva, L.I., Musaly, V.Kh., Mammadova, Sh.R., Pashayeva, J.R. Investigation of compositions based on amino esters of synthetic petroleum acids and AK-15 motor oil as additives for road bitumen // International Scientific Conference on “Modern Problems of Petrochemical and Lubricant Technologies” dedicated to the 100th anniversary of academician M.A. Mammadjarov. – Baku, September 26–27, 2024, pp. 196–197.
 17. Abbasov, V.M. Synthesis of amino esters of synthetic petroleum acids and study as additives for road bitumen / V. Abbasov, L. Afandiyeva, L. Aliyeva, N. Aliyeva, A. Mammadov, V. Musaly // Processes of Petrochemistry and Oil Refining, 2025, Vol. 26, No. 1, pp. 5–16.



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