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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

ENHANCE OF RELIABILITY AND INDUSTRIAL SAFETY IN THE OPERATION PROCESSES OF OIL EQUIPMENT AND INSTALLATIONS

Speciality: 3313.02. – Machinery, equipment and processes

Field of science: Technical sciences

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Baku – 2025

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GENERAL CHARACTERISTICS OF THE WORK

Relevance and degree of development of the topic. The modern oil and gas industry of Azerbaijan is one of the decisive factors of its economy and forms the basis of the country's dynamic development. The discovery of large volumes of gas along with oil in the fields discovered and exploited in recent years has brought the Republic of Azerbaijan to a new position among gas exporting countries.

Although all types of logistics means (pipelines, sea and rail transport) are currently used to access the hydrocarbons produced in the country to the world market, the greater use of pipelines remains relevant [114][1].

The multi-branch pipeline system used to transport oil and gas produced in the Caspian Sea and the Absheron Peninsula, as well as the equipment and devices included in it, are operated in difficult and complex conditions. Thus, depending on their functional purpose, they are exposed to factors such as high pressure, dynamic loads, vibrations caused by well bottom depression, etc., as well as aggressive environments and various climate changes. In the manufacture of equipment and technical means applied in this field of industry, various brands of metals, rubber and polymers, as well as ceramics are used.

The intensification of corrosion processes in field equipment made of metals, including pipelines, installations, and metal structures, leads to a decrease in environmental and industrial safety [26][2].

Corrosion is one of the most important processes affecting the economy and ecological conditions of countries around the world. According to estimates, the volume of losses due to corrosion in developed countries is approximately 3-4% of national income, and 10% of metal products are completely destroyed.

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[1] Seyfullaev G.Kh. Operational characteristics of main and network gas pipelines operating in Azerbaijan // Oil industry of Azerbaijan, 2018. No. 5, pp. 35-40. [in Russian]

[2] Najafov E.A. Issues of ensuring environmental safety at oil and gas industry enterprises // Azerbaijan Oil Industry. 2016. No. 9, pp.57-62.[in Azerbaijani]

Currently, the consequences and financial costs caused by corrosion have become a global problem. In the neighboring Russian Federation, one of the largest oil and gas exporting countries in the world, the average annual metal losses due to corrosion are 1.5 million tons. On a global scale, this figure is 15–20% or 150–200 billion US dollars. 60–80 billion of this are related to corrosion processes occurring in the oil and gas transportation system, as well as in the chemical and oil extraction sectors [8].[3] For comparison, it can be noted that although this figure is less in Azerbaijan, the problem remains relevant. Thus, currently 70–85% of the causes of accidents occurring in equipment, installations and pipelines used in the oil and gas extraction, storage, processing and transportation system are related to corrosion processes. Every year, 20-25% of metal structures, oil drilling equipment (ODE), and main and inter-field pipeline systems in operation are renovated due to corrosion.

Although coating materials of various compositions is widely used among the methods protecting pipelines, as well as metal structures and equipment from corrosion, the issues that need to be resolved here have not lost their relevance.[89][4]

In this regard, the dissertation work is aimed at solving a pressing issue such as assessing the risks that may arise due to corrosion in the oil and gas transportation system and improving industrial and environmental safety.

The Oil and Gas Industry (OGI) is a set of units and systems necessary for the oil and gas industry, the development of oil fields, the production and transportation of oil. This includes drilling of oil and gas wells, as well as a wide range of production equipment, equipment and technical means used in the exploration of wells, repair and restoration work, as well as a multi-branch pipeline system, various structural volumes, technical means and others.

In order to prevent corrosion processes that cause various

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[3] Main transportation routes of energy resources. [Electronic resource] / URL: https://azerbaijan.az/related-information/133. [in Azerbaijani]

[4] Nasibullina O.A., Gareev A.G. Corrosion tests of corrosion inhibitors under low water cut conditions // Education and science in modern conditions: materials of the intra-university scientific-practical conference. Sterlitamak: Polygraphy, - 2016, - pp. 287–288 [in Russian]

fundamental failures in the mentioned equipment and facilities, and to increase their reliability during operation, and to increase industrial and environmental safety, extensive scientific research and scientific-practical work is being carried out in Azerbaijan, as well as in foreign countries. Among them, the works of S.H. Babayev, H.F. Miralemov, G.G. Ismayilov, Y.M. Bilalov, I.A. Habibov, F.A. Amirli, V.N. Pratasov and others can be cited.

Object and subject of research.

Methods for assessing and managing technical and environmental risks that may arise in pipelines and the equipment used in the oil and gas transportation system, as well as the results of the development and application of polymer-bitumen-based nanomaterials in increasing their reliability.

Goals and objectives of the study.

The purpose of the dissertation is to assess and develop management methods for technical and environmental risks that may arise during the operational processes of oilfield equipment and facilities, as well as to increase their reliability and industrial safety by developing and applying polymer-bitumen-based nanomaterials.

In order to achieve the goal in the dissertation, the following main issues were raised and resolved:

-analysis of operating conditions of pipelines, equipment and facilities used in the gas transportation system, investigation of existing reliability and safety problems;

-analysis of the reasons for failures in the oil and gas production and transportation system and the losses associated with them;

-development of a method for assessing environmental risks in the pipeline system;

-Development of a point and interval assessment method for gas losses in order to ensure operational safety and manage risks in oil and gas pipelines, as well as the equipment used there;

-study of the nature of changes in pipeline reliability parameters based on the theory of dynamic systems;

-development of a polymer-bitumen-based nanocomposite material with low water permeability and high adhesion for corrosion protection of equipment and metal structures included in the pipeline system;

-development of a model that allows predicting changes in the operational performance of metal structures and pipelines;

- justification of the choice of material for the manufacture of the gas regulator membrane and determination of its rational thickness.

Research methods . To solve the goals and problems set in the research work, the foundations of mathematical statistics and probability theory, nonlinear dynamic systems and oilfield equipment systems, and the theories of ensuring operational and environmental safety were used.

At the same time, the issues of risk assessment and prediction have been solved by applying computer technologies.

The main provisions put forward for defense:

- a methodology capable of assessing environmental and industrial risk based on statistical data collected during the transportation of oil and gas through pipelines, as well as the operation of the OGFE used here;

- polymer-bitumen-based nanocomposite coating material that can be used to protect metal structures and pipelines from corrosion;

-Development of a dynamic model based on initial data and allowing to forecast changes in the leading indicators of the coating material.

Scientific novelty of the study:

- An environmental risk assessment methodology has been developed based on data collected on losses caused by various types of accidents in metal structures, field equipment and pipeline systems;

-The average number of losses occurring in pipelines was determined by estimating the distribution density of losses as close to reality as possible;

-A dynamic model has been developed that allows to predict the reliability indicators of equipment and pipelines according to their changing order;

-A nano-based polymer-bitumen composite material has been developed for the corrosion protection of metal structures and gas pipelines, and its optimal compositional parameters have been determined;

-the effectiveness of using polymer-bitumen-based nanocomposite material has been confirmed;

- the choice of the thickness of the regulating membrane used in gas distribution is justified.

Theoretical and practical significance of the research. The results of the dissertation work allow to solve the following practical problems:

- The use of methods for assessing losses in field equipment and pipeline systems creates opportunities for assessing risks in the oil and gas transportation process based on statistical data.

- Polymer-bitumen-based nanocomposite coating material has high quality indicators and helps to increase the longevity of pipelines and equipment operated in aggressive environments by 35-40%.

-The simplicity of the technology of using the proposed composite coating material allows it to be used in any conditions.

-The thickness of the gas regulating membrane has been determined to be a rational value.

Approval and implementation. The results of the dissertation work were discussed at the following conferences and seminars: "Khazarneftgazyatag-2014" Scientific and Technical Conference, 2014, Baku, XIII International Scientific and Practical Conference "Scientific Reviews of Physical, Mathematical and Technical Sciences in the XXI Century", 2015, Moscow, IV International Scientific and Technical Conference of the Faculty of Science and Technology "Safety Problems in Emergency Situations" , Baku, 2018, "I International Scientific Conference of Students and Young Researchers" dedicated to the 97th anniversary of the birth of the National Leader H. Aliyev by the Baku Higher Oil School, Baku, 2020, 11th Scientific Conference "Intelligent systems for industrial automation," WCIS-2020, held in Tashkent, Uzbekistan, 2020, " Modern Problems of Macromolecular Compounds Technology" dedicated to the 60th anniversary of the Department of "Technology of Organic Substances and High-Molecular Compounds" of the Azerbaijan State Oil and Industry University , Baku, 2024, as well as at the scientific seminar of the “Engineering and Computer Graphics” department of ASOIU, at the seminar of the “Reliability and

Efficiency of Oil Equipment Operating on Land and Offshore" problem laboratory of the "Geotechnological Problems of Oil, Gas and Chemistry" Research Institute, and at the scientific-practical conference on ""Green" Development of Technical Safety" of the "Azerbaijan State Labor Protection and Safety Engineering", Baku, 2024, Research Institute.

Name of the organization where the dissertation work was carried out. The dissertation work was carried out in the laboratory of the Research Institute of "Geotechnological Problems of Oil, Gas and Chemistry" under the Azerbaijan State Oil and Industry University, "NB Group" company (Paint Plant), "AzINMASH" and "Oil Gas Scientific Research Project" Institute, as well as the "Technology of Organic Matters and High Molecular Compounds" Department of the Azerbaijan State Oil and Industry University.

The results have been obtained due to researches carried out in accordance with the Work Plan of the "Reliability and Efficiency of Oil Equipment Operating on Land and Offshore" problem laboratory and the topics of scientific research of the "Engineering and Computer Graphics" department of ASOIU.

The total volume of the dissertation, indicating the volume of the structural sections of the dissertation separately. The dissertation consists of an introduction, five chapters, conclusions, a list of 156 references and appendices (4 appendices), including 22 figures, 21 tables and 10 graphs.

The content of the dissertation consists of an introduction of 7 pages and 12065 characters, the first chapter of 28 pages and 37715 characters, the second chapter of 17 pages and 24690 characters, the third chapter of 24 pages and 31595 characters, the fourth chapter of 23 pages and 30490 characters, the fifth chapter of 27 pages and 30740 characters, the conclusions of 2 pages and 1905 characters, and a list of 156 used literature of 15 pages.

The dissertation consists of 148 pages of computer-written text, with a total volume (excluding tables, pictures, graphs and bibliography) of 169200 characters.

MAIN CONTENT OF THE WORK

The introduction reflects the relevance of the dissertation work, its purpose, the main issues to be considered, scientific innovations, the main provisions put forward for defense, the practical significance of the work, its structure and scope, as well as comments on the application of the results obtained.

The first chapter examines the characteristics of the operating conditions of Azerbaijan's main and inter-field gas pipelines and facilities, and provides an analysis of the main prospective directions. As a result of the theoretical analyses, the pipeline systems branching out from the Caspian Sea to the Absheron Peninsula and then throughout the country's geographical areas, the territories they pass through, the ecological status of these territories, the compositional indicators of water and soil here, and the situation affecting the reliability and longevity of the pipeline system were examined.

In the second chapter, at the initial stage, the issue of developing a recipe for composite materials that can be used to protect main gas pipelines from corrosion has been resolved.

The following stages reflect the discussion of the results of tests on their use in field conditions. In the research work, a mechanical method was used to prepare nanofiller compositions. In order to ensure uniform distribution of nano copper in the polymer matrix, as well as to prevent aggregation, sonochemistry technology - the effect of ultrasound waves (USW) on the liquid medium was used.[5] In the research work a specially designed and manufactured device was used to evaluate the effect of gas flow rate on the durability of the coating layer.

The tests were carried out in gas condensate fields produced in the Bulla-Deniz and 28 May fields, which have different physicochemical parameters in terms of aggressiveness. The general scheme of the test facility is given in Figure 1.

The test pipe exploitation line includes the following: 1- Test pipe; 2- Tank filled with oil products brought from the field; 3- Stopcock

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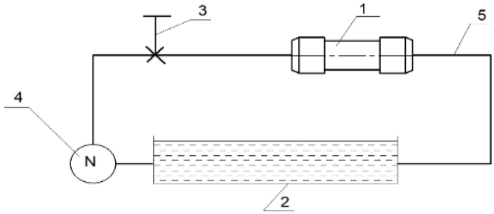
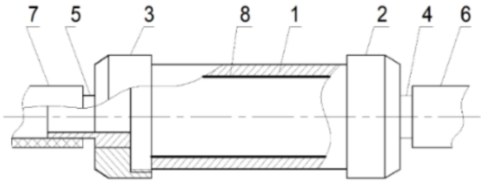
[5] Application of ultrasound in the production of nanomaterials. [Electronic resource] / URL: https://utinlab.ru/articles/primenenie-ultrazvuka-pri-proizvodstve-nanomaterialov. [Application of ultrasound in the production of nanomaterials. [in Russian]

designed to regulate pressure in the system; 4- Injection pump, 5- connecting pipes (Figure 1, a). The test pipe includes: 1- test pipe with coated inner surface; 2, 3- test pipe stoppers; 4,5 - fittings; 6,7- rubber pipes for fluid circulation in the system; 8 – coating layer



a)



b)

Figure 1. Stand for evaluating the resistance of the coating material to environmental influences (Δm):
a) Test pipe exploitation diagram; b) Test pipe

The assessment of the resistance capacity (Δm) of coatings was evaluated by determining their weights before and after exposure to the environment.

$$\Delta m = \frac{Q_t - Q_0}{Q_0} \cdot 100\ \%$$

Where Δm is the resistance of the coating material; Q_t is the weight of the sample tested in the operating environment (gr), Q_o is the initial weight of the test sample (gr).

As it can be seen from the analysis of Table 1, the corrosion resistance (Δm) of the deposits from which test samples were taken is ranked as follows: Bulla Deniz > 28 May deposit. As a result of the tests conducted over a period of 48 months, the ratio of resistance indicators is 0.198:0.085=2.32.

From the oilfield equipment and facilities the RDUK-2 type gas pressure regulator and pipes with diameters (16”) 306 mm and (20”) 508 mm were accepted.

Table 1.

The nature of the change in corrosion resistance (Δm) of coating materials applied to the inner surface of the pipeline of test samples taken from the Bulla-Deniz and 28 May fields

The name of the bed and chemical indicators	Test comp.	Character of change in resistance (Δm) by months								
	K-5	3	6	12	18	24	30	36	42	48
May 28th Bed M=25mg/l, T=1.15 mgKOH/100ml, K= 0.20 %	-	-	-	-	0.008	0.015	0.033	0.051	0.062	0.085
Bulla sea M=70 mg/l, T=2.6 mgKOH/100ml, K=0.29%	-	-	-	0.017	0.024	0.066	0.085	0.121	0.144	0.198

In the third chapter, five different polymer-bitumen-based nanocomposite coating materials were developed and the results of their testing were presented in order to protect the external surfaces of oilfield equipment and facilities from corrosion. The composition of the composite materials used in the experimental and testing works is reflected in Table 2.

Table 2.

Content of test compositions

No.	Components, Gr	Content of the composition, (kh)				
		K-1	K-2	K-3	K-4	K-5
1.	Bitumen (BNB70/30)	54	54	54	54	54
2.	UK	10	10	-	-	-
3.	BNK -40	-	-	10	10	10
4.	FFO	10	-	-	-	-
5.	KFFO	-	10	-	-	1
6.	MFFO	-	-	10	-	-
7.	ED-20	-	-	-	10	85
8.	Dispersant (MPA-60X)	0.5	0.5	0.5	0.5	0.5
9.	TK	6	6	6	-	-
10.	Talc (Persitalc ISW)	-	-	-	6	32
11.	Copper nanoparticles %	2.0	2.0	2.0	2.0	2.0
12.	Urotropin	10	10	10	-	-
13.	PEPA	-	-	-	10	23.2
14.	Gasoline, ml	100	10 0	-	100	-
15.	Acetone, ml	3	3	3	-	-
16.	Benzene, ml	-	-	100	-	100
17.	Xylene, ml	-	-	-	-	150

In the selection of the content parameters of the composite material, a polymer-bitumen mixture was adopted as the matrix. The use of extruded bitumen (from which light fractions and oil fractions were removed) in the composition plays an important role in improving its physical and mechanical properties (plasticizer, high water impermeability). The ED-20 epoxy oligomer added to the composition has high adhesion, as well as resistance to abrasion, chemical effects and moisture. In order to eliminate or reduce the brittle properties of bitumen, various rubbers were used in the composition of the compositions.

In order to test the water impermeability of the compositions, the degree of water impermeability, characterizing their resistance in a wide range of environments, was tested. Oil, sea and field waters, as well as distilled water, were taken as test environments. The choice is justified by the fact that main oil and gas pipelines mainly pass through these categories of areas. The results of the tests on the assessment of the water impermeability of the compositions are shown in Table 3.

Table 3.

Dependence of water impermeability on environmental changes

No.	Test environment	Material group	Probation period, months.					
			3	6	9	12	15	18
1	Distilled water	K-1	-	-	0.60	0.63	0.66	0.71
		K-2	-	-	0.40	0.45	0.51	0.62
		K-3	-	-	0.32	0.34	0.38	0.41
		K-4	-	-	-	0,	0.27	0.31
		K-5				22	0.01	0.01
2	Oil	K-1	-	0.90	0.95	0.98	1.02	1.05
		K-2	-	0.7 0	0.72	0.76	0.77	0.80
		K-3	-	-	0.48	0.52	0.59	0.65
		K-4	-	-	-	0.12	0.14	0.19
		K-5	-	-	-	-	0.01	0.01
3	Sea water	K-1	-	1.93	2.11	2.18	2.23	2.30
		K-2	-	1.87	1.95	2.01	2.12	2.11
		K-3	-	1.55	1.65	1.73	1.78	2.05
		K-4	-	-	-	0.1	0.1 2	0.1 5
		K-5	-	-	-	0-	0.01	0.01
4	Mineral water	K-1	-	3.10	3.89	4.32		5.24
		K-2	-	2.77	2.97	3.33		4.32
		K-3	-	2.52	2.83	2.91		3.51
		K-4	-	-		0.11		0.18
		K-5	-	-	-	-		0.0 1

It was found that the adhesive properties and water impermeability of the compositions of components IV and V are higher than the indicators of the first three compositions. The fifth composition has higher physical and mechanical properties compared to the fourth composition. As it can be seen from the analysis of the obtained results, field and sea waters demonstrate the highest aggressiveness to the coating material. At the same time, it was found that the composition K-5 practically did not change its weight during the testing period (18 months). The weakest protective ability was observed in the composition K-1. Considering that the composition can also create environmental problems, only the compositions of components K-4 and K-5 were used in the subsequent stages of the research work. It was found that the ratio of the matrix to the hardeners in the content of the compositions by mass fraction has a significant impact on their leading properties. Figure 1 shows the effect of the ratio of the matrix and hardener in the content of the compositions K-4 and K-5 on the adhesion and penetration indicators. Table 4 presents the final results of the composite material tests.

Table 4.

Physical and mechanical properties of bitumen-based compositions

Composition symbol	Water Impermeability, %	Adhesion, MPa	Penetration 25 ^{0}C, 0.1mm	Softening temperature, ^{0}C
K-1	0.6-5.24	12.3-14.1	28-30	75
K-2	0.4-4.32	16.4-18.6	26-27	75
K-3	0.32-3.51	20.1-22.8	2 4-25	75
K-4	0.18-0.22	2 2 ,4-2 5 ,3	21- 2 3	80
K-5	0.01	33.5-38.2	18 - 20	80

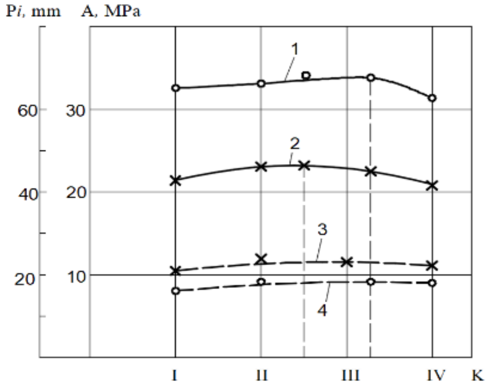
It was found that the adhesive properties and water impermeability of the IV and V component compositions are higher than those of the first three compositions.

The fifth composition has higher physical and mechanical properties compared to the fourth composition.

ED-20 resin, which has a certain adhesive ability, plays a key role in the formation of a network structure during chemical curing, which further increases its adhesion strength.

When studying the physical and mechanical properties of the resulting coating, it was determined that the adhesive properties and water impermeability of the composition containing modified FFO were relatively higher than those of the composition containing unmodified FFO oligomer.

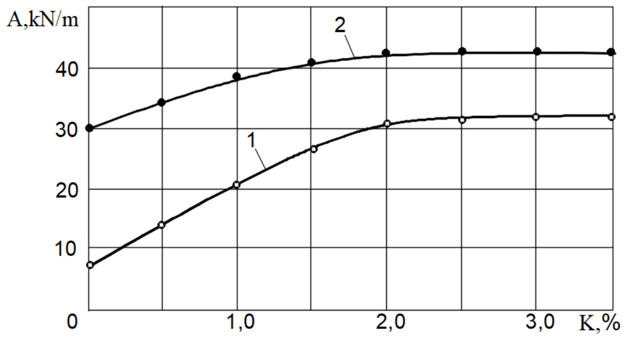
From the analysis of Graph 1, it is clear that the change (increase) in the volume of the hardener in the content of the composition leads to an increase in their adhesion strength and penetration index at the initial stage.



Graph 1. The effect of the ratio of matrix and hardener in the content of the composition on the adhesion strength and penetration index: 1,2 - adhesion in K-5 and K-4 composite materials, respectively; 3,4 - change in the penetration index in K-4 and K-5 composite materials, respectively.

In the subsequent stages, i.e., in cases of increasing the amount of hardener, a decrease in these factors is observed. Finally, the graph of the dependence of the adhesion strength of the coating composition (K-5), which is recommended as a coating material, on the amount and size of the nanoparticles added to its composition shows that the addition of nanoparticles (nanomis (60-80 nm)) to the composition leads to an improvement in its adhesion properties.

The amount of nanoparticles in the composition (Graph 1) increases monotonically starting from 0.5%, leading to an increase in its adhesion ability. In the range of the amount of nanoparticles from 0.5 to 1.75 (2.0) %, the adhesion strength increases from 31.2 MPa to 42.7 MPa, after which stabilization is observed. Thus, an increase in the amount of copper nanoparticles in the composition from 0.5 to 2.0% accelerates their penetration into the molecules of the polymer matrix, creating connecting bridges between them, which creates a serious basis for strengthening the physical and mechanical indicators. A further increase in the amount of copper nanoparticles (above 2.0%) significantly reduces the adhesion ability of the coating material to the metal surface. This is explained by the effect of the amount of nanoparticles on the formed structure. Graph 2 shows dependence of the size of the nanoparticle on its leading properties.



Graph 2. Dependence of the leading properties of the coating composition on the size of the nanoparticles: 1 -80 nm; 2 - 60 nm.

According to the test results, as the size of the nanoparticles in the composition increases, the value of the adhesion strength decreases (Figure 3, graph 1, for *l* =80 nm). At small values of the nanoparticles (at 60 nm), the value of the adhesion strength (Graph 2, for *l* =60 nm) is higher. In analogous dependences, the water impermeability and impact resistance indicators of the coating material were determined.

The analysis of Table 5, shows that the water impermeability and impact resistance of the coating material with copper nanoparticles added to its composition is higher than that of the composite material without nanoparticles. It was found that in the first case (with nanoparticles), the water impermeability is 1.39 - 2.12 times less, and the impact resistance is 1.15 -1.3 times more. As a continuation of the research work, the issue of assessing the effect of gas flow rate on the durability of the coating material was studied.

Table 5

The effect of nanoparticles added to the composition on its properties

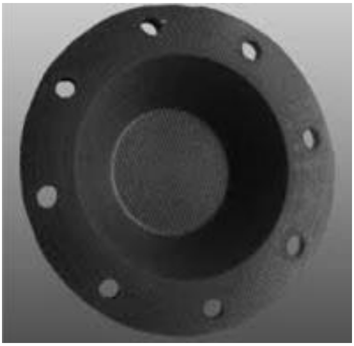
Nanofiller	Quality indicators	Amount of nanofiller, %					
		0.5	1.0	1.5	2.0	2.5	3.0
Copper nano-filled coating	Water Impermeability, %	0.042	0.034	0.025	0.019	0.022	0.031
	Impact resistance, mm	300	400	450	500	430	380
Nano-filler - free coating	Water impermeability, %	0.053	,041	0.032	0.045	0.057	0.065
	Impact resistance, mm	260	350	420	435	400	325

Thus, polymer-bitumen-based nanocomposite material can be successfully applied to protect pipelines used for transporting oil and gas, as well as equipment and metal structures used along main lines, from corrosion.

The other part of the study shows the results of material selection and thickness for the preparation of the gas regulating and controlling membrane.

Figure 2 shows the membrane of the RDUK-2 type gas pressure regulator, which is the object of research.

In regulators, membranes are usually made of rubber or rubberized fabric. The properties of membrane materials are mainly determined by the elements that make them up - reinforcing fabric and elastomeric coating. The properties of the membrane layer, as well as its service life, are determined by the safety of the rubber layer. As a result of research conducted to study the causes of failures in 100 gas regulators, it was determined that the shutdowns occurring in them during the year can be classified as follows (Table 6).



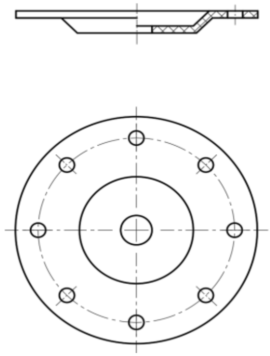


Figure 2. Membrane of the low pressure regulator Q

Table 6

Reasons for failure of the gas regulator

No.	Reason for refusal	Location and volume in construction	
		In the drawing Position (see Fig. 2.3)	In general refusal volume, %
1.	The gas regulator membrane Disintegration	4	51-53
2	Leakage in the control regulator membrane	10	26-28
3	Adjustment spring release	12	10-12
4	Steering column and saddle eating	6, 7	7-9
5	Others	-	2

As it can be seen from the analysis of Table 6, failures due to the breakdown of the gas regulator membrane predominate. Rubber-nylon composite materials are used in the manufacture of modern membranes.

Currently, a large number of rubber mixtures based on butadiene-nitrile, ethylene-propylene, fluorine - rubbers are recommended for the production of technical membranes. At the same time, the tightening of operating conditions for hermetic and regulated devices and fittings leads to increased requirements for sensitive elements of devices and power elements of regulators.

As the basis of the composite material, polyamide fabrics (nylon) are most often used. In addition, polyester (lavsan), polyurethane, tetrafluoroethylene, high-strength, high-modulus fabrics (teflon), fiberglass are used. At the same time, membranes are porous, non-porous, fibrous, hybrid and other types. The main leading properties are high water impermeability and vapor permeability.

For this reason, the type of fabric material was determined at the initial stage, taking into account the working environment.

The reliable operation of the membrane depends on the correct selection of its material, and the determination of a rational value for the thickness dimension is equally important.

The most important stage of the technological process is the issue of ensuring the required adhesion strength of the rubber-fabric system. For this purpose, an active substance adhesive is used between the layers that make up the composition. Thus, butadiene nitrile rubber used for this purpose is distinguished by high results, unlike chloroprene rubbers. The reason can be explained as the absence of crystallization

In order to provide the required strength properties of the adhesive compounds during the preparation process, a BNK-based adhesive composition was used. For this purpose, ЭХ-1 quinol ether was used in the research work.

The vulcanization process was carried out in the following technological mode: temperature – 150 ^{0} C, pressure - 50-60 MPa), vulcanization time - 30 minutes. The results of the test work are given in Table 6 and Graph 3. As it can be seen from the analysis of the obtained results, the change in the thickness of the polyamide fabric included in the membrane within the limits of 70-150 μm allows adjusting the adhesion strength to 8.15-8.05 kN/m. The value of the breaking load required for the membrane to collapse is 380-130 N.

Depending on the value of the gas regulation pressure (low – 0.05 kg/cm^2, medium – 0.05 -3 kg/cm^2 and high 3-12 kg/cm ^{2} (0.3-1.2 MPa), the thickness of the membrane is determined. Usually h_{mem} =0.9-3.0 mm is accepted in the interval.

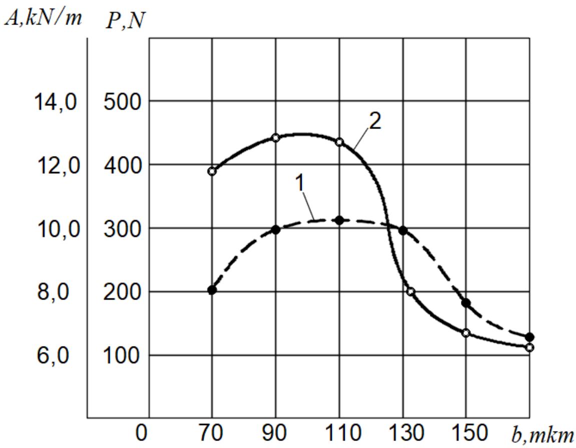
Determination of the thickness of the gas regulator membrane is shown below.

Table 7.

Dependence of test parameters on membrane thickness

Test indicators	Membrane thickness, mm				
	0.9	1.2	1.5	2.0	3.0
Thickness of polyamide fabric, μm	70	125	130	135	150
Adhesion strength, kN/m	8.15	10.33	10.55	10,11	8.08
Breaking load, H	380	435	443	243	131

The analysis of Graph 3, shows that the optimal thickness of the polyamide fabric included in the membrane is 125-130 μm.



Graph 3. Dependence of adhesion strength (1) and breaking load (2) on the thickness of the polyamide fabric.

To ensure the required strength characteristics of the membrane, a BNK-based adhesive composition and ЭХ-1 quinol ether are used, and favorable results are obtained. The nominal thickness of the membrane of the gas regulator is h_{mem} = 1.2-1.5 mm interval is recommended.

The fourth chapter is devoted to the distribution density of leaks occurring in the main gas pipeline and the assessment of environmental risks in the process of gas transportation. In order to maintain the safe operation and reliable performance of the gas pipeline system, it is necessary to determine their actual technical condition using modern diagnostic tools.

To estimate the distribution density of the number of failures resulting in gas leaks of the MGP, we used the histogram estimation of the density, which is a special case of the root estimate of the density . The method of root estimation of the distribution density of a random quantity is based on describing the probability density (called the psi-function, analogous to the wave function in quantum mechanics) as the square of the modulus of any function.

$$\psi_X(x) = |f(x)|^2$$

To construct a density histogram, it is assumed that the distribution is given in a finite stage. For variables given in an infinite interval, it is appropriate to cut off the "tails" by taking the minimum and maximum values as boundaries.

Let's divide the entire range of variation of the variable into a finite number of intervals. The points $x_0, x_1, ..., x_{s-1}$ divide the entire range of variation of the s random variable X into a finite number of grouping intervals.

At large values of $x = \tilde{x}$, x and $\bar{x}$. In this case, we can expect that P(x) >P ($\bar{x}$) then the value of the mathematical expectation for risk will change accordingly

$$M[R(X)] > M[R(\tilde{X})]$$

A maximum similarity (MS) model was defined to determine the density of this function. Let’s show the application of the explained method to the estimation of the distribution density of the statistical data depicted in Figure 4.

8, 4, 3, 2, 19, 12, 13, 9, 25, 18, 20, 14, 26, 21, 25, 18, 25, 23, 23, 21, 23, 22, 21, 19, 17, 20, 18, 18, 15, 14, 18, 17, 14, 13, 17, 15, 12, 12, 16, 14, 11, 11, 16, 14, 10, 9, 15, 14. (n=48)

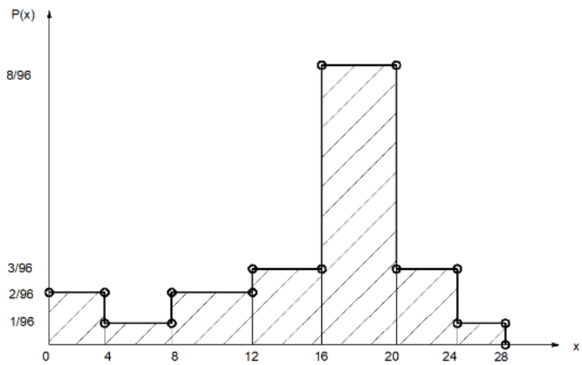
Let's write the variation order corresponding to the given option values

2, 3, 4, 8, 9(2), 10, 11(2), 12(3), 13(2), 14(6), 15(3), 16(2), 17(3), 18(4), 19(2), 20(2), 21(3), 22, 23(3), 25(3), 26.

$$R(x) = P(x) \cdot Q(x),$$

is understood as the quantity, where $P(x)$ - is the probability of the X event occurring, $Q(x)$ is a function of the costs incurred to eliminate the damage or consequences of the event X .

Let us show the application of the explained method to the estimation of the distribution density of the statistical data depicted in Figure 4. By writing the data for the full period of years, first for January, then for February, etc. up to the data for December, we obtain the following set of values of the random quantity (X number of gas leaks) (Figure 4):

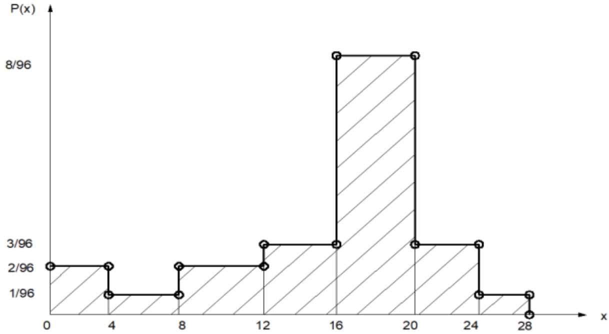


Graph 4. Histogram estimation of the distribution density of a $\tilde{X}$ random variable.

Let us construct the statistics for a random variable in which distribution $\tilde{X}$ is equal to the distribution of the random variable $R(\tilde{X})$

$$T_{\tilde{s}(\tilde{n})}(R(\tilde{X})) = \frac{1}{\tilde{s}(\tilde{n})} \sum_{i=0}^{s(\tilde{n})-1} g(\bar{\tilde{x}}_i)$$

Here $\tilde{s}(\tilde{n}) = 7$, $g(\bar{\tilde{x}}_i) = R(\bar{\tilde{x}}_i) \cdot f(\bar{\tilde{x}}_i)$, is the $f(\bar{\tilde{x}}_i)$ value of the histogram of the distribution density of the random variable $\tilde{X}$ at a point $\bar{\tilde{x}}_i$. The statistic is the $R(\tilde{X})$ empirical mean value of the risk, $R(\tilde{X})$ approximating the mathematical expectation for the random variable $M[R(X)]$.



Graph 5. $\widetilde{X}$ Histogram estimation of the distribution density of a random variable.

It can be seen from Graph 4 and Graph 5 that the random variables X and $\tilde{X}$ at large values of x and $\tilde{x}$, when $x = \tilde{x}$, $P(x) > P(\tilde{x})$ then the value of the mathematical expectation for risk will change accordingly $M[R(X)] > M[R(\tilde{X})]$.

Therefore, we can expect that $M[R(X)] > M[R(\tilde{X})]$ Indeed, for example, if the loss function $Q(x) = A \cdot x$ is linear in the form of $A = const$, the empirical average risks $\bar{R}(X)$ and $\bar{R}(\tilde{X})$ will be equal to the following quantities:

$$\bar{R}(X) = \frac{167}{48}A \text{ and } \bar{R}(X) = \frac{153}{24}A$$

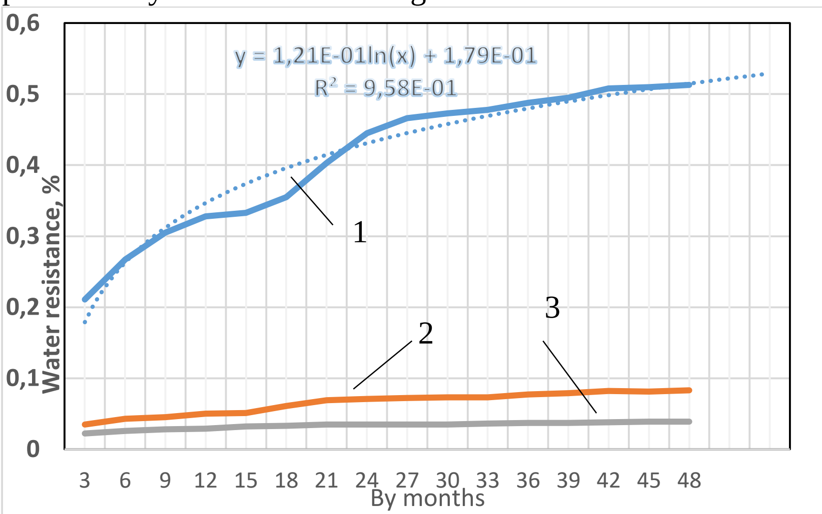
So,

$$\bar{R}(X) > \bar{R}(\tilde{X})$$

The fifth chapter is devoted to predicting the water impermeability capacity and adhesion strength of coatings based on the construction of a dynamic model due to time series. **Analysis of the results of the survey** on the assessment of the condition of gas pipelines showed that the pipeline system passes through areas with different relief. The soils on these routes are diverse and differ in varying degrees of humidity and salinity. In this process, to assess the condition, studies were conducted on the potential difference of the pipes in the pits and the specific resistance of the soil. In addition, ultrasonic measurements of the thickness of the pipe wall and an assessment of the condition of the anti-corrosion protection of the gas pipeline are carried out.

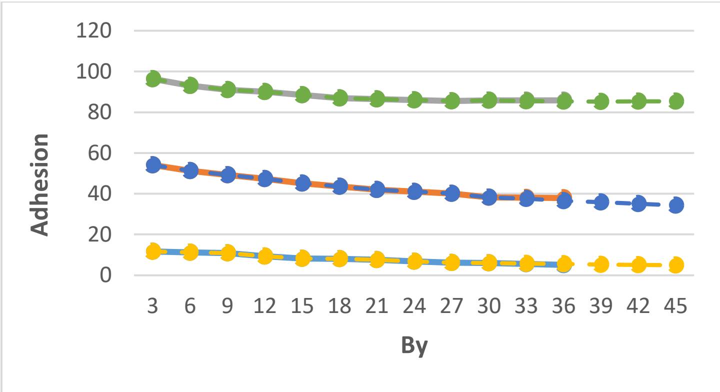
Taking into account the importance of predicting the insulation capacity of the coating material and the real operating conditions of the MGPS, the results of research on the development of a dynamic model of its aging (wear) based on time series and the predictive assessment of the water impermeability capacity and adhesion strength of the coatings are presented below.

Table 8, as well as graphs 6 and 7, show the initial data (for the last 6 months) and forecast (retro and future) values of the water impermeability and adhesion strength of the tested materials.



Graph 6. Water impermeability of the covering material, in %.

As it can be seen from their analysis, the actual values of the water impermeability indicators of the materials considered in the last 36th month of observation and the corresponding predicted values in the 45th month were as follows: 2.1; 1.0 and 0.1 % between BNB 70/30, BNB + KFFO + ED-20 + BNK-40 and nanosized BNB + ED-20 + KFFO + BNK-40 + Cu. For adhesion strength indicators, a decrease of 0.3 MPa was observed during the operation period.



Graph 7. Adhesion strength of the coating material.

Table 8.

Water impermeability and adhesion strength in coating materials

Name of the coating material	Water impermeability in cover material for months, %				
	Retro		Forecast		
	33	36	39	42	45
BNB 70/30	0, 481	0, 491	0.5 03	0.5 11	0.5 12
BNB+ED-20 +KFFO +B N K - 40	0.072	0.082	0.082	0.082	0.083
Nanosized BNB + ED -20 +KFFO + BNK-40+ Thu	0.0 41	0.0 41	0.0 42	0.04 2	0.0 42
BNB 70/30	Adhesion strength of coating material by month, MPa,				
	5.61	5.46	5.26	5.03	4.91
BNB+ED-20 +KFFO +B N K - 40	37.90	37.80	37.73	37.60	37.48
Nanosized BNB + ED -20 +KFFO + BNK-40+ Thu	85.68	85.62	85.48	85.40	85.31

As a result of the research work, for the practical evaluation of the results obtained, along with experimental testing, industrially significant inspections were conducted. These works were carried out at the “AzComposite” company, the “Baku Oil and Gas Equipment” enterprise, in the administratives of “N. Narimanov Oil and Gas Production Plant” of SOCAR, and the **“**Industrial Safety”.

The testing was carried out at SOCAR's "N. Narimanov Oil and Gas Production Plant" and in stages by applying it to the outer surface of a pipe with a diameter of 20" (508 mm) and a length of l=50 meters, which is on the balance of the enterprise. In the first stage, the testing work covered the period from 10.01.2020 to 23.09.2021.

The coating materials were applied to the test samples manually (using a brush) outdoors.

Measurements were taken in open-air conditions characterized by high humidity and monitored once every 3 months. As a result of visual observation of the pipelines, it was determined that there were no cases of rupture, disintegration or swelling of the coating material on them.

Although the test results were validated, the monitoring work continued until the end of 2023. No changes were observed in the coating material during this period.

A calculation of the weight of coating material ($Q_{coating}$) required to be applied to the outer surface of a pipe with a diameter of 20” (508 mm) and a length of l=50 meters is given bellow.

Thus, the amount of coating material required to coat one pipe will be as follows:

$Q_{coating} = V_{coating}$ xlx $\rho = \pi(D^2 - d^2)$ xlx $\rho = 3.14\ (5.12^2 - 5.08^2)$ x1000 x 1.22=1532.2 gr =1.53 kg.

Then the amount of coating material required for L=50 meters (taking into account 5 pipes) will be determined as follows: $Q_{total} = 5 \times 1.53 = 7.66$ kg.

In parallel with the N. Narimanov Oil and Gas Production Department, experiments were conducted at the oil company's " Industrial Safety" department on 10.01.2019 - 10.01.2020. Test works were carried out on the 260-meter-long pipelines of the Garadagh Bahar main gas pipeline passing through the coastal area. Operating conditions and laying of the coating material were carried out in the same manner. Here, too, 26 pipes with a diameter of 508 mm passing through areas close to the seacoast were covered with the presented coating material in open air conditions. 40 kg of material was used in the process. At the end of the test period, visual observation of the external surfaces of the pipelines showed that they were of the same nature as the results of the previous control works, that is, no cases of rupture, collapse and swelling of the coating material were identified on them. Based on this, the commission noted that the presented coating material is suitable for protecting the external surfaces of inter-field pipelines from corrosion and recommended its widespread application. Taking into account current market prices, the cost of 1 kg of coating material is M = 6.61 AZN (Table 9).

Table 9.

Prices of components set by manufacturing companies

Components, gr	Price of components, Manat			The price of the composition,				
	Kg	Liter	500mg	K-1	K-2	K-3	K-4	K-5
Bitumen (BNB70/30)	0.53	-	-	0.028	0.028	0.028	0.028	0.028
UK	25.4	-	-	0.25	0.25	-	-	-
BNK -40	33.66	-	-	-	-	0.34	0.34	0.34
FFO	-	-	0.99	0.099	-	-	-	-
KFFO	-	-	0.752	-	0.07	-	-	0.007
MFFO	-	-	0.88	-	-	0.088	-	-
ED-20	0.023	-	-	-	-	-	0.0002	0.002
DisperserMPA-60X	-	-	6	0.045	0.045	0.045	0.45	0.045
TK	5	-	-	0.03	0.03	0.03	-	-
Talk Per - sitalc ISW	3.40	-	-	-	-	-	0.002	0.10
Nanometer, %	1.7	-	-	0.26	0.26	0.26	0.26	0.26
Urotropin	9.35	-	-	0.093	0 ,093	0.093	-	-
PEPA	13.2	-	-	-	-	-	0.08	0.42
Gasoline, ml	-	2	-	0.2	0.2		0.2	
Acetone, ml	-	6.54	-	0.02	0.02	0.02	-	
Benzene, ml	-	0.75	-	-	-	0.075	-	0.075
Xylene, ml	-	1.9	-	-	-		-	0.28
Total 100 kh	-	-	-	1,025	0.996	0.97	1,360	1,323
Only 1 kg	-	-	-	5.12	4.98	4.9	6.68	6.61
Total 20kg	-	-	-	87.13	84.66	82.45	115.6	112.4

Table 10 shows the selling prices of some coating materials currently used by the “Azerigas” PU to protect pipelines from corrosion, and a price comparison with the prepared coating material (K-5) is provided.

Table 10.

Some coating materials used to protect pipelines from corrosion

No.	Brand	2.5 (lt), in manats	20 (lt) , in manats
1	FAB	20	136
2	Rocol	20	136
3	Sobplus	22	149.6
4	Star paint	22	149.6
5	Betek	28	190.4
6	Panda	20	136
7	K-5	16.54	112.4

As it can be seen from the analysis of Table 8 and Table 9, the cost of the proposed coating materials is 12-15% lower than that of existing materials. This confirms the high performance of the coating materials as well as their economic efficiency.

Main results

1. Increasing the corrosion resistance of equipment and facilities used in the oil and gas production, storage, and transportation system is of great importance, as it is a decisive factor in increasing the level of reliability and technical safety.

2. A formulation of a polymer-bitumen-based nanocoating composite material with high conductive properties for corrosion protection of equipment and facilities used in the oil and gas production, storage, and transportation system has been developed based on locally produced components and subjected to laboratory and industrial testing [12][6].

3. It was found that the recommended nano-sized polymer-bitumen based composite coating material has high quality indicators. Unlike analogues, the water permeability of this coating material

[6]Habibov, I.A. Development of bitumen-polymer based coating materials for corrosion protection of oil and gas pipelines. / I.A. Habibov, K.B. Iravanli // Azerbaijan journal of chemical news. - Baku: - 2020, Vol. 1, No. 1, - pp. 30–35.

changed by 0.01% during the observation period, the adhesion strength by an average of 1.1 MPa, and the impact resistance by 1.12 times [15][7].

4. During the test period and in the subsequent time interval of the tests, there were no significant changes in the physical and mechanical properties of the K-5 composite material recommended as a coating material. At 33 months, the retro value of the adhesion capacity of the composite material was 85.62 MPa, the water impermeability capacity was 0.0221 mg, at 45 months, the predicted value of the adhesion capacity was 85.31 MPa, the predicted value of the water impermeability capacity was 0.0224 mg);

5. An environmental risk assessment methodology has been developed based on data collected on losses caused by various types of accidents in the oil and gas production, storage and transportation system .

6. In order to ensure the reliability and industrial safety of the gas regulator, the thickness of the polyamide fabric in the membrane was selected to be 90-110 μm, and the rational value of the total membrane wall thickness was determined to be 1.2-1.5 mm . At these thicknesses, the adhesion strength is within the limits of 10.33-10.55 kN/m, and the force expended on the breaking load is within the limits of 435-443 kN/m [16][8].

7. The cost of the proposed coating materials is 12-15% lower than existing materials. This confirms the high performance of the coating materials as well as their economic efficiency.

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[7] Habibov, İ.A. The results of usıng new polymer-bitumen based coating materials in corrosion protection of mine gas pipelines./ I.A. Habibov, I.G.. Abdullayeva. S.M. Abasova, K.B. Iravanli. // PPOR, - Baku: - 2023, No. 2, Vol. 24, - pp. 333-340.

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The dissertation defense will be held on May 16, 2025 at 14^{00} hrs at the meeting of the Dissertation Council ED 2.02 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan State Oil and Industry University, PRH.

Address Az 1010, Baku, Azadlig Ave. 20.

Dissertation is accessible at the library of the Azerbaijan State Oil and Industry University, PRH.

Electronic version of the abstract is available on the official website of the official website of the Azerbaijan State Oil and Industry University, PRH.

Abstract was sent to the required addresses on Aprel 11, 2025.

Signed for print: 07.04.2025

Paper format: A5

Volume: 36815

Number of hard copies: 20