EXPERIMENTAL STUDIES OF ANTICORROSION COATING EFFICIENCY

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Abstract
The huge expenses of oil companies associated with corrosion of metal pipes led to the creation of metal pipes with high corrosion resistance. Coating of pipelines is performed for protection against corrosion, mechanical damage and other external impacts. There are several basic methods of coating pipelines, and the choice of method depends on the operating conditions, type of pipes, protection requirements and cost. The introduction of certain components into the metal and the observance of a certain technology of continuous steel casting makes it possible to obtain metal that is pure in terms of the content of impurities. Such a metal is distinguished by its strength, plastic and corrosion-resistant characteristics. The anticorrosive coating proposed by the authors effectively reduces the corrosion rate of stainless steel and provides a high degree of protection in salt media at various pH and temperature variations. The purpose of this section is to comprehensively evaluate the anticorrosive effectiveness of alkyd-urethane varnish and microsilica coating developed using examples of various types of tubular steels. Methods of simulation of aggressive corrosion conditions are used in the work, which make it possible to reproduce the actual operational factors and objectively assess the protective properties of coatings.

Keywords: Bitumen, oxygen, aggressive substances, pyrolysis distillate, thermal decomposition, anti-corrosion, composite, bonds, bitumen-polymer matrix, elasticity, crack resistance, adhesion strength, oxidation-polymerization processes.

I. INTRODUCTION
The reliability and durability of oil and gas pipelines is mainly determined by the effectiveness of corrosion protection, since metal corrosion is one of the main causes of accidents, leaks and premature retirement of the pipeline system. Aggressive factors of the external and internal environment - moisture, soil electrolytes, dissolved salts, hydrogen sulfide, carbon dioxide, as well as changes in temperature and pressure significantly accelerate the processes of corrosion and reduce the operational properties of pipelines. Tests of anticorrosive coatings for corrosion resistance, adhesion and water permeability are the most important stages of their scientific and practical

justification [1]. Corrosion resistance characterizes the ability of the coating to maintain protective properties in aggressive environments; adhesion determines the bond strength of the coating to the metallic surface of the pipeline and its tensile strength; water permeability reflects the ability of the coating to prevent moisture and electrolytes from entering the metal, which directly affects the rate of corrosion processes. The purpose of these tests is to obtain objective and repeated information on the effectiveness of protection of anti-corrosion coatings, their compliance with the requirements of regulatory technical documentation and the possibility of using oil and gas pipelines in operating conditions. The test results will optimize the composition and coating technologies, increase the reliability of pipeline systems, and reduce the risk of accidents and economic losses [2].

II. MATERIALS AND METHODS

Consideration of traditional and modern corrosion protection methods.

Traditional corrosion protection methods. The most common passive method of protecting pipelines is coatings that prevent metal from contacting an aggressive medium. Classical bitumen mastics and packaging materials (for example, bitumen-polymer tapes) have been used since the middle of the 20th century. They have good dielectric and waterproof properties, but lose plasticity over time, break and collapse. Disadvantages: resistance to UV, oxygen, temperature changes, poor adhesion to a wet surface [3]. Cathodic Protection (CP)

Electrochemical protection method (tread or PSR), based on the transfer of the potential of steel to a safe field by connecting an external current source to it. It is used as a primary or auxiliary means, especially in areas with a high risk of soil corrosion [4]. Sacrificial anodes: Zn, Al, Mg. DC source: transformer-rectifier devices. Disadvantages: requires constant monitoring, the presence of a conductive medium, the lack of reliable insulation.

Inhibitory protection. Introduction into the working environment of substances (inhibitors) that reduce the corrosion rate. Most effective in closed systems (tanks, internal walls of pipelines).Types of inhibitors: anode (passivating metals) - nitrates, phosphates; cathodes (slow down hydrogen reduction) - organic ammonia compounds; mixed fatty amines, oxygen complexions [5].

Modern and innovative protection methods

Multilayer polymer coatings. Combined insulation systems: powder epoxy (FBE), polyethylene/polypropylene (3PE/3PP) and their combinations with an adhesive layer. Standardized by international standards (API 5L2, ISO 21809). Advantages: high chemical resistance, resistance to mechanical damage, excellent adhesion. Disadvantages: high cost, complexity of application [5].

Polyurethane and epoxy composites. Liquid compositions classified in situ and forming a dense protective structure. Used for external and internal insulation.

Use of bitumen-polymer compositions with pyrolysis distillate. A promising area that combines the low cost of bitumen with improved plastic, adhesive and hydrophobic properties due to the addition of pyrolysis components. Such compositions provide reliable protection against moisture and aggressive ions, adapt to soil deformations and allow adaptation to operating conditions (pH, temperature, humidity) [6].

Nanostructured Inhibitors and Container Coatings. Development of smart coatings containing inhibitory microcapsules or self-healing components (e.g. based on silicates or organic polymers). When the coating is damaged, the inhibitor is removed and suppresses corrosion [7].
Plasma and ion-plasma treatment. With the help of high-temperature ion handles or plasma treatment, protective layers can be applied to the metal, which makes it possible to obtain hard, strong and dense coatings, often with the addition of titanium, chromium, zirconium (Table1) [8].

Table 1- Technical characteristics of alkyd-urethane varnish [9]

Standard	**Application**
API RP 5L2	Steel pipes with anti-corrosion coatings
NACE SP0169	Cathodic Protection of Underground/Subsea Pipelines
ISO 21809	Multilayer coatings for pipelines (FBE, 3PE)
GOST 51164-98	Steel pipes. Anticorrosion coatings
STO Gazprom	Internal and external coating of pipelines of Gazprom

The following methods were used in the studies: tests in the salt area in accordance with GOST 9.402-2004, providing a prompt assessment of the corrosion resistance of coatings in an environment with a high content of chlorides; resistance to water and moisture, determined by changes in physical and adhesive characteristics after prolonged exposure to a moist environment; electrochemical investigation methods, including polarization measurements and electrochemical impedance (EISA) spectroscopic analysis, allow for real-time estimation of corrosion rate and protective effect properties; morphological analysis of the coating surface and steel after tests by optical and scanning electron microscopy, as well as energy dispersion analysis (EDA) to detect corrosion products and degradation of the coating material.
In the course of experimental studies, the composition and structure of alkyd-urethane and micro silica compositions, application methods and conditions of use for the degree of corrosion protection of tubular steels were studied [8]. To assess the effectiveness of the developed bitumen-pyrolysis coatings, a comparative check of their anti-corrosion resistance was carried out with industrial coatings used in the pipeline network (for example, bitumen-polymer and epoxy coatings).
Samples and test methods. Samples of pipes coated with the developed compositions and industrial analogues fell into the salt area (study according to GOST 9.402-2004) with a duration of 240 to 1000 hours. Additional tests for relative humidity of 100% and resistance to humidity at 40 °C were performed within 30 days.Electrochemical methods, including potential dynamic polarization and electrochemical impedance spectroscopic analysis, have been used to estimate the corrosion rate and properties of the protective layer (Table2).

Table 2-Benchmarking results

Indicator	**Developed coatings**	**Bitumen-polymer coatings [4]**	**Epoxy coatings [5]**
Time to corrosion, hour	>1000	~700	~900
Corrosion rate, mm/year	0.02	0.05	0.03
Decrease in adhesion after testing, %	8	20	15
Change in coating thickness, %	<5	10	7

The developed coatings "maintained integrity and adhesion during long-term tests under aggressive conditions and showed high resistance to corrosion." Their anti-corrosion properties are superior to bitumen-polymer analogues and provide high elasticity and heat resistance compared to epoxy coatings. The high corrosion resistance of the developed compositions is associated with the optimal compatibility of the bitumen matrix and pyrolysis distillate, as well as with the introduction of fillers and polymer modifiers that prevent the penetration of coating density, adhesion and aggressive ions. Comparative analysis confirms the prospects of the developed coatings in the pipe industry, especially in conditions of high temperature and high humidity [9].

Electrochemical testing

Electrochemical studies using methods of potential dynamic polarization and electrochemical impedance spectroscopic analysis (EISA) were carried out for a deep understanding of the mechanisms of corrosion protection and a quantitative assessment of the protective properties of the developed coatings of alkyd-urethane varnish and micro silica.

Sample preparation. Coated steel samples and untreated controls were mechanically ground, degreased and dried. The samples were fixed in a 3.5%sodium chloride solution simulating an aggressive seawater environment. The active area of the sample was about 1 sm^2.

Potential dynamic polarization method. The tests were carried out using a three-electrode cage with a comparative Ag/AgCl electrode and a platinum auxiliary electrode. The scan speed of the potential was 1 mV/s. From the obtained polarization curves: Corrosion potential (Ecorr); Corrosion current density (characterizing corrosion rate I_corr); Characteristics of the volt-ampere for evaluation of the inhibitory effect of the coating.

Electrochemical impedance spectroscopic analysis (EISA) EISA was carried out in the frequency range from 100 kGs to 10 mGs with an alternating voltage amplitude of 10 mV. Impedance spectra analysis showed corrosion resistance (Rst) and double layer capacitance (Cdl). High Rst value and low Cdl indicate the formation of a strong protective coating layer and the influence of an effective barrier.

Results

A significant decrease in the corrosion current density for coatings confirms the high efficiency of the protective barrier. Corrosion resistance increases 20 times compared to untreated metal, which indicates low permeability of aggressive ions. The corrosion potential turns into a positive region, which indicates a decrease in the corrosion activity of the surface (Table3) [9].

Table 3-Results and their interpretation

Parameter	Uncoated metal	Recommended coating	Industrial equivalent
Corrosion potential, E corr, V	-0.55	-0.32	-0.38
Corrosion current density, I_corr, μA/sm²	12.5	0.8	1.5
Corrosion resistance, R_st, Kom·sm ²	1.2	25	15

Electrochemical test conclusions

The developed electrochemical methods have confirmed the high anti-corrosion efficiency of bitumen-pyrolysis coatings. Their protective properties are superior or consistent with industrial analogues, providing long-term protection of steel pipes under aggressive conditions.

Salt chamber and outdoor tests

Tests were carried out to assess the durability of the developed alkyd-urethane varnish and micro silica coatings under the conditions of artificial corrosion in the salt district chamber, as well as in the conditions of a real atmosphere in the open air [10].

Tests in the chamber of the Sollinsky district. Tests on NSS (Neutral Salt Spray) equipment were carried out in accordance with GOST 9.402-2004. The coated samples were placed in a chamber with salt cloud conditions at +35 ± 2 °C and a NaCl concentration of 5%. The duration of the tests ranged from 240 to 1000 hours, the condition of the coatings was periodically checked. Rust, coating failure, discoloration and surface integrity were evaluated.

Outdoor tests. For 6-12 months, samples were demonstrated outdoors in temperate climatic conditions with changes in temperature, humidity and atmospheric exposure. Regular visual inspection, measurement of adhesion and thickness of coatings, as well as assessment of damage from corrosion were carried out. Particular attention was paid to the resistance of the coating to ultraviolet radiation and precipitation (Table 4).

Table 4-Test results

Parameter	Developed coatings	Industrial coatings
Time to corrosion, hour	>1000	700–800
Coating damage rate, % after 1000 hours	<5	15–20
Change in adhesion after experiments, %	<10	20–25
Degree of corrosion after 12 months outdoors, %	3	10

The developed coatings showed high salt mist resistance, low corrosion and good adhesion after prolonged exposure. In the open air, the coatings retained their integrity and protective properties, which indicates weather resistance and suitability for use in various climatic zones. The high corrosion resistance of the developed compositions is associated with the optimal compatibility of the bitumen matrix and pyrolysis distillate, as well as with the introduction of fillers and polymer modifiers that prevent the penetration of coating density, adhesion and aggressive ions. Comparative analysis confirms the prospects of the developed coatings in the pipe industry, especially in conditions of high temperature and high humidity [11].

Tests have confirmed that modified alkyd-urethane lacquer and micro silica coatings reliably protect metal surfaces from corrosion in conditions of high humidity and aggressive salt aerosols. Their resistance to the atmosphere is higher than that of standard coatings, and they can be used by pipeline transport.

Adhesion, cracks and resistance to atmosphere

Adhesion Method.The adhesion properties of the coatings were evaluated using adhesive tape extraction methods (GOST 28507-90) and shear strength, as well as the microenvironment method, followed by measurement of the separation force. Available samples of bitumen-pyrolysis compositions and industrial analogues were used for comparative analysis [12].

Adhesion test results. The average adhesion strength of the developed coatings was 2.4-2.8 MPa, which is higher than the indicators of traditional bitumen-polymer coatings (1.5-2.0 MPa). The use of polymer additives and surfactants improved the moistening of the metal surface and the formation of a strong interfacial layer.

Rupture resistance tests. Thermal cycling from -40 °C to +80 °C, number of cycles up to 50 and mechanical tensile tests were used to evaluate the tensile strength of the coatings. Microstructure control was performed by optical and scanning electron microscopy. The results showed that there were no microcracks and breaks, and the elasticity of the coatings remained after a full test cycle. The addition of flexible fillers (rubber scraps, PET) significantly increased the resistance to mechanical and thermal loads [13].

Weather resistance of coatings. Weathering was evaluated during long-term (up to 12 months) outdoor and UV testing. Changes in thickness, adhesion and appearance "showed that the coatings retain their protective properties and appearance."

The use of polymer stabilizers and antioxidants ensured high resistance of the bitumen matrix to photochemical disturbances.

Evaluation of service life based on accelerated tests. To predict the stability of the developed bitumen-pyrolysis coatings, a set of accelerated tests was carried out to simulate the processes of degradation and corrosion in a shorter time compared to natural conditions of use.

Accelerated test procedure. Salt chamber tests were carried out 9.402-2004 in accordance with GOST and increased the exposure time (up to 1000 hours or more), which corresponds to the long-term influence of aggressive corrosion. Thermocycling and humidity effects modeled repeated temperature fluctuations and humidity fluctuations that lead to mechanical and chemical wear of coatings.

• Ultraviolet radiation (UV) was used for rapid photography to determine the degradation of the bituminous matrix and polymer additives. During the tests, electrochemical monitoring made it possible to evaluate the changes and protective properties of the coating over time [14].

Consideration of traditional and modern corrosion protection methods

Corrosion protection of steel pipes is the main task in the design, construction and operation of trunk, underground and process pipeline systems. The effectiveness of corrosion protection depends on the corrosiveness of the environment, the conditions of use, the properties of the materials and the methods used. All existing methods can be conditionally divided into passive, active, as well as combined, including the latest achievements in the field of materials science, electrochemistry and nanotechnology(Table5) [15].

Table 5-Main results

Parameter	Pre-test value	Cost after accelerated tests	Predicted service life, year
Adhesion	2.6	2.1	>15
Coating thickness, μm	150	140	>15
Corrosion rate, mm/year	0.02	0.03	>15

Despite the strong impact, the coatings retained their basic protective properties. Data extrapolation shows a service life of at least 15 years under standard operating conditions.

III. CONCLUSIONS

Thus, the developed anticorrosive material has a set of protective properties that ensure an increase in the service life of oil and gas equipment in an aggressive environment and a sharply continental climate. As a result of experimental studies of the effectiveness of anticorrosive bitumen-pyrolysis coatings, the following was established: The developed coatings are superior in their protective properties to their industrial counterparts and have high corrosion resistance. Electrochemical methods (potential dynamic polarization and spectroscopic analysis of electrochemical impedance) have confirmed a significant decrease in corrosion current and an increase in corrosion resistance, which indicates the formation of a strong and reliable protective barrier. Tests carried out in the chamber of the salty area and in the open air showed the resistance of coatings to salty aerosols, atmospheric humidity and ultraviolet radiation, provided durable protection of metal surfaces. High adhesion, tear resistance and weather resistance make the coating reliable for use in difficult climatic and mechanical conditions. Accelerated tests confirmed the high stability of the developed bitumen-pyrolysis coatings. The data obtained allow them to be used to protect pipelines in aggressive and climatically diverse conditions with a guarantee of a long service life.

Thus, the studies carried out confirm the effectiveness and prospects of using bitumen-pyrolysis coatings for corrosion protection of steel pipes, and also provide a scientific basis for their implementation in industrial practice.All ingredients used are available on the domestic market of Uzbekistan at relatively low prices, which ensures the economic feasibility of creating local anti-corrosion coatings and reduces dependence on imported raw materials. The conducted set of studies makes it possible to recommend optimal compositions for practical use on oil and gas pipelines, taking into account operational conditions and technological requirements, and also serves as a basis for the further development of new modified coatings.

References

1. G. Ajayi et al., 2015. Bitumen in Coating Corrosion Protection of Steel (AJER, 4(12))
2. Corrosionpedia Editorial. Bituminous Coating – Definition & Applications, 2024. Description of the technologies and applications of bituminous pavements. corrosionpedia.com..
3. EJT, 2025. Physicochemical Analysis of Composite Bitumen Mastics with Pyrolysis Distillate (vol. X).
4. ScienceDirect Topics, 2024. Bituminous Coating, sciencedirect.com, paper 11.3.4, p. 109.
5. Matcor, 2024. Pipeline Corrosion and Prevention—A Comprehensive Guide, matcor.com.
6. Gladkykh I.F., Cherkasov N.M., Kraikin V.A., Sigaeva N.N., Ionova LA., Zaikov G.E., Monakov Yu. B. Heat- and thermostability of asphaltoresinous oligomers // Journal of the Balkan tribo logical association. -2001. -Vol. 7. -l3-4. -P-P. 147-155.
7. Cherkasov N., Kolosnitsin V., Gladkykh I., Monakov Yu. Asmol Innovation anti-corrosive material // The summary of technologies. Russian technological review. -2001. -Ns 2 (6). -P. 28-30.
8. Niu L., Cheng Y.F. Development of Innovative Coating Technology for Pipeline Operation Crossing the Permafrost Terrain // Construction and Building Materials. 2008. Vol. 22, Issue 4. P. 417-422. DOI: 10.1016/j.conbuildmat.2007.06.001
9. Wong J.F., Hassan A., Chan J.X., Kabeb S.M. Plastics in Corrosion Resistant Applications // Encyclopedia of Materials: Plastics and Polymers. 2022. Vol. 4. P. 136-148. DOI: 10.1016/B978-0-12-820352-1.00072-9.
10. Samimi A., Zarinabadi S. Application Polyurethane as Coating in Oil and Gas Pipelines // International Journal of Science and Engineering Investigations. 2012. Vol. 1, No. 8. P. 43-45.
11. Popoola A., Olorunniwo O.E., Ige O.O. Corrosion Resistance through the Application of Anti-Corrosion Coatings // Developments in Corrosion Protection: in Book. 2014. P. 241270. DOI: 10.5772/57420.
12. Shirazi M., Ayatollahi Sh., Ghotbi C. Damage evaluation of acid-oil emulsion and asphaltic sludge formation caused by acidizing of asphaltenic oil reservoir. Journal of Petroleum Science and Engineering. 2018, vol. 174, pp. 880-890. DOI: 10.1016/j.petrol.2018.11.051 29.
13. UrinovA. Study of water influence on waterproofing material "Polyisol-M". The American Journal of Engineering and Technology (ISSN – 2689-0984) Volume 05 Issue 09 -2023. Pp. 21-27. 11.
14. Straka P., Maxa D., Staš M. A novel method for the separation of high-molecular-weight saturates from paraffinic petroleum based samples. Organic Geochemistry. 2019, vol. 128, pp. 63-70. http://www.sciencedirect.com/science/article/pii/S0146638018302699.
15. Alexander I.V, Ragulin V.V., Telin A.G. Development and Introduction of Heavy Organic Compound Deposition Diagnostics, Prevention and Removing. SPE International Symposium on Oilfield Chemistry, 2005. DOI: 10.2118/93128-MS
16. A Ivanova I.K., Semenov M.E. Choice of the Effective Solvent to Remove Paraffin Deposits in Conditions of Abnormally Low Reservoir Temperatures. Conf. Series: Earth and Environmental Science, 2020, vol. 459. DOI: 10.1088/1755-1315/459/3/032006.