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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF AN EFFICIENT TECHNOLOGY FOR THE PIPELINE TRANSPORTATION OF HIGH-PARAFFIN CRUDE OILS

Specialty: 3354.01 – "Construction and operation of oil and gas pipelines, bases and storage facilities"

Field of science: Technical sciences

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Baku – 2026

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GENERAL DESCRIPTION OF THE WORK

Relevance of the work. The formation of paraffin and inorganic salt deposits during the production and pipeline transportation of highly paraffinic crude oils is one of the major technological challenges in the oil and gas industry. When the oil temperature falls below the temperature at which paraffin crystals begin to form, paraffin hydrocarbons crystallize and accumulate on the inner surfaces of pipelines. As a result, hydraulic resistance increases, oil transportation becomes more difficult, energy consumption rises, and, under unfavorable conditions, complete pipeline blockage may occur. In this regard, improving the rheological properties of highly paraffinic crude oils under low-temperature conditions and increasing transportation efficiency are of particular importance. In recent years, the use of polymer-based additives has been extensively investigated as a promising approach to lowering the pour point of crude oil, regulating its viscosity, and improving its flow properties. Nevertheless, the development of depressants that are suitable for local conditions, economically efficient, and highly effective remains an important and relevant task.

The precipitation of inorganic salts during oil production, treatment, and transportation also adversely affects the reliability and operational performance of equipment. In particular, the accumulation of salts such as calcium carbonate and calcium sulfate on the inner surfaces of pipelines and process equipment reduces the flow area, impairs heat and mass transfer, and disrupts technological processes. The possibility of simultaneous paraffin and salt deposition during the pipeline transportation of highly paraffinic crude oils necessitates a comprehensive investigation of this problem. Although existing studies have yielded certain results concerning the application of polymer-based depressants, chemical inhibitors, and physical treatment methods, further scientific research is required to select these methods according to the properties of specific crude oils, determine optimal operating conditions, and evaluate the possibilities of their combined application. Such research is of considerable scientific and practical importance.

Object and Subject of the Research. The object of the research is the development of new methods to prevent the formation of asphalt-resin-paraffin deposits (ARPD) during the pipeline transportation of paraffinic crude oils. The subject of the research comprises the development of scientific and experimental foundations for the treatment, storage, and transportation of crude oil under complex operating conditions, including its movement through transportation pipelines.

Objective of the Research. The object of the research is to develop the scientific and experimental foundations for creating new technologies to mitigate complications occurring in oil pipelines, including paraffin and salt deposition, and to improve the efficiency of these technologies.

The main tasks of the research:

- Developing new technologies to mitigate complications arising during crude oil transportation through pipelines;
- Developing new salt deposition inhibitors;
- Developing new formulations of paraffin deposition inhibitors;
- Investigating the effectiveness of the developed salt and paraffin deposition inhibitors under laboratory conditions;
- Developing a new magnetic device to prevent deposit formation in transportation pipelines through the application of a magnetic field;
- Optimizing a dosing pump to ensure the optimal dosing of inhibitors into transportation pipelines.

Main Propositions Submitted for Defence

1. Development of new formulations based on carboxymethyl cellulose and mineral acids;
2. Preparation of new formulations based on nitrogen- and phosphorus-containing compounds;
3. Investigation of the effectiveness of the developed formulations against salt deposition;
4. Development of new formulations based on organic solvents and amphiphilic polymers;
5. Development of polymer-based additives to mitigate asphalt-resin-paraffin deposits in highly paraffinic crude oil;

6. Development of new formulations for breaking water-in-oil emulsions, preventing asphaltene, resin, and paraffin deposition, and protecting oilfield equipment against corrosion;
7. Development of a new-design magnetic device to prevent salt and paraffin deposition through the application of a magnetic field;
8. Development of an improved pump unit for the continuous dosing of inhibitors to prevent salt and paraffin deposition in transportation pipelines and equipment.

Scientific Novelty of the Research

- New formulations for preventing salt deposition have been developed, and their scientific foundations have been established;
- New polymer-based formulations have been developed to mitigate asphalt-resin-paraffin deposits in highly paraffinic crude oils;
- Solvents containing aromatic and polyaromatic compounds have been selected to improve the dissolution of asphalt-resin-paraffin deposits;
- For the first time, a new inhibitor formulation containing amphiphilic polymers has been developed to mitigate asphalt-resin-paraffin deposits;
- For the first time, a multifunctional inhibitor has been developed to break water-in-oil emulsions, prevent asphaltene-resin-paraffin deposition, and protect oilfield equipment against corrosion;
- A magnetic device with a new design has been developed to prevent salt and paraffin deposition through the application of a magnetic field;
- A structurally improved dosing pump has been developed to ensure the continuous and accurate delivery of inhibitors into pipelines, and the technical advantages of its application have been substantiated.

Theoretical and Practical Significance of the Research The problems of salt and paraffin deposition during the transportation of oil and gas through pipelines are primarily associated with operational complications occurring in flowlines and transportation pipelines. It is well known that the collection and transportation of paraffinic crude oils have been among the most complex and challenging problems in the oil industry for decades. At low temperatures, the flowability of paraffinic crude oil in pipelines may deteriorate, potentially resulting in a significant reduction in flow or a complete cessation of flow due to gel formation, which obstructs oil movement. These conditions may lead to non-Newtonian behavior of the oil and an increase in its effective viscosity as the temperature of paraffinic crude oil approaches the crystallization point of paraffin. Paraffin crystallization and solidification at or below the crystallization temperature can significantly alter the rheological behavior of crude oil, increase its effective viscosity, and impede flow through pipelines. Considering the aforementioned challenges, new salt and paraffin deposition inhibitors have been developed within the framework of this dissertation to mitigate complications arising during oil transportation through pipelines..

Approbation and Application. The principal statements and findings of the dissertation work were presented, discussed, and endorsed at the following international and national conferences and seminars:

1. Aliyev, C.R. Chemical Mitigation of Paraffin Deposition During Transportation of High Paraffinic Crude Oils // Practical Conference Society and Science: Interconnection. – 2025. – Vol. 2. – P. 44–45.
2. Gurbanov, A.N., Aliyev, C.R. Механизм образования и методы борьбы с асфальтено-смолистопарафиновыми отложениями в нефтепромысловом оборудовании // Надежность и безопасность транспортирования, хранения и распределения газа, нефти и нефтепродуктов. – 2025. – Vol. 1. – P. 100–101.
3. Aliyev, C.R. Methods for Combating Asphaltene-Resin-Paraffin Deposits in Oilfield Equipment // Research in Science and

Education: VIII Republican Scientific Conference. – 2025. – Vol. 3. – P. 165–168.

4. Gurbanov, A.N., Aliyev, C.R., Ismayilov, G., Adigozelova, M., Abdullayev, E., Aliyev, I. Undesirable Consequences of Transporting Stable Oil Emulsions Mixed with Condensate // Conference Proceedings of the Seventh Eurasian Conference RISK-2025, Risk-Oriented Design and Operation of Infrastructure Systems: Sustainability Paradigm. – 2025. – Vol. 1. – P. 49.

Name of the Organization Where the Dissertation Was Carried Out.The dissertation was carried out at Azerbaijan State Oil and Industry University.

Personal Contribution of the Author.The author personally participated in formulating the research problems addressed in the dissertation, conducting the investigations, summarizing and interpreting the experimental results obtained, and preparing the scientific articles.

Total Length of the Dissertation in Characters, Indicating the Length of Each Structural Section Separately. The dissertation comprises 211 pages and consists of an introduction, four chapters, 32 figures, 44 tables, conclusions, and a list of 187 references. The dissertation is structured as follows: Total 225531 characters, Introduction (17,419 characters), Chapter I – 61,514 characters, Chapter II (21,827 characters), Chapter III (99,562 characters), Chapter IV (42,905 characters), Conclusion (2,822 characters) and List of references .

Publications. The main findings of the dissertation have been published in 9 scientific articles, 4 conference proceedings, and 2 patents. The journals in which the articles were published were selected in accordance with the requirements of the High Attestation Commission of the Republic of Azerbaijan. Three of these articles were published in internationally indexed journals.

THE MAIN CONTENT OF THE WORK

The Introduction of the dissertation substantiates the relevance of the research topic and presents the aim and objectives of the study, the problems to be addressed, the scientific novelty, the theoretical and practical significance of the work, the main propositions submitted for defence, and the structure and scope of the dissertation.

The first chapter presents a literature review of scientific studies addressing the problems encountered during the pipeline transportation of high-paraffin crude oils and the methods developed to overcome them. For this purpose, existing scientific sources were analysed concerning methods for improving the low-temperature properties of crude oil, the application of polymer-based pour point depressant additives, the mechanisms of formation of inorganic salt deposits and asphaltene–resin–paraffin deposits (ARPD), and methods for preventing and mitigating these deposits. The chapter also examines the structure of paraffin crystals, the role of intermolecular interactions in the crystallization process, and theoretical approaches to the effects of magnetic fields on the formation of paraffin deposits, salt deposits, and emulsions in petroleum systems. Based on the literature review, the capabilities and limitations of existing technologies were evaluated, and the scientific and technical challenges requiring further investigation to improve the efficiency of high-paraffin crude oil transportation were identified.

One of the major problems encountered during crude oil production, treatment, and pipeline transportation is the alteration of the physicochemical and rheological properties of high-paraffin crude oils under low-temperature conditions, as well as the formation of asphaltene–resin–paraffin deposits (ARPD) and inorganic salts on the internal surfaces of pipelines. These processes lead to increased hydraulic resistance in transportation systems, reduced throughput, higher energy consumption, and decreased operational reliability of technological equipment. In particular, the sensitivity of high-paraffin crude oils to temperature variations complicates their transportation

over long distances.[1] In particular, the sensitivity of high-paraffin crude oils to temperature variations complicates their transportation over long distances. In this regard, investigating paraffin crystallization, deposit formation mechanisms, and the low-temperature properties of crude oil, as well as analysing existing mitigation methods, is of considerable scientific and practical importance.

One of the main characteristics of high-paraffin crude oils is their significant content of high-molecular-weight saturated hydrocarbons. Paraffins consist primarily of C_{16}–C_{64} hydrocarbons and are present in dissolved form in crude oil under reservoir conditions. As the temperature decreases, paraffin solubility diminishes, and molecular association and crystallization begin. The growth and agglomeration of crystals lead to structuralization of the crude oil, an increase in viscosity, and a deterioration in flowability. As the temperature decreases, the solubility of paraffins diminishes, leading to molecular association and crystallization. Viscosity, the pour point of crude oil, yield stress, and structural-mechanical properties are also among the principal parameters affecting the transportation process. Thermal, mechanical, physicochemical, and chemical methods are used to improve the low-temperature properties of crude oil. Thermal methods include crude oil heating, thermal insulation of pipelines, and the installation of intermediate reheating systems at specified intervals. These methods improve crude oil flowability by inhibiting the formation of paraffin crystals. However, the implementation of thermal methods entails additional energy consumption, the installation of appropriate equipment, and increased operating costs. Mechanical methods, including pipeline cleaning, enable the removal of deposits that have already formed. One physicochemical method involves diluting crude oil with lower-viscosity hydrocarbons or suitable solvents. However, the use of diluents increases the demand for additional feedstock and solvents and may reduce the overall economic efficiency of the transportation process.

[1] Szuflita S., Pajda M., Kuśnierczyk J., Wojnicki M., Warnecki M. Studies on the Efficiency of the Impact of Paraffin Inhibitors on Lowering the WAT Temperature and Reducing the Amount of Paraffin Deposit // Energies. – 2020. – Vol. 13, No. 18.

The application of polymer-based compounds plays a particularly important role in improving the rheological properties of high-paraffin crude oils. These substances can adsorb onto crystal surfaces, hindering crystal growth and agglomeration and thereby improving crude oil flowability and low-temperature performance. The effectiveness of these compounds depends not only on their chemical composition but also on their dosage, the paraffin content of the crude oil, the temperature regime, and the distribution of the reagent throughout the oil. [2]

Salt deposition during oil production and transportation is another major factor adversely affecting equipment performance. Salt precipitation depends on the ionic composition and salinity of formation water, temperature and pressure conditions, and physicochemical changes occurring when different waters are mixed. These deposits accumulate on the internal surfaces of pipelines, pumps, and other process equipment, reducing the flow area, increasing hydraulic resistance, and impairing equipment performance. The mechanisms of scale inhibitors are primarily associated with retarding the crystallization process, restricting crystal growth, complexing ions, and reducing the adhesion of deposits to surfaces. Polymer-based compounds and surfactants also influence the formation of salt crystals and their deposition on surfaces. The effectiveness of inhibitors depends on the ionic composition and salinity of the water, temperature, and reagent concentration.

Research has also been conducted into the application of magnetic fields to address ARPD formation and salt deposition during the transportation of high-paraffin crude oils. The complex colloidal-dispersed nature of crude oil determines the interactions among asphaltenes, resins, paraffins, water, and mechanical impurities present in the system. Potential mechanisms under consideration include structural changes induced by magnetic fields and their influence on the behaviour of dispersed particles. In saline water

[2] F. Yang, Y. Zhao, J. Sjöblom, C. Li, K.G. Paso Polymeric wax inhibitors and pour point depressants for waxy crude oils: a critical review J Dispers Sci Technol, 36 (2015), pp. 213-225

systems, the electrical charges of dissolved ions make it relevant to investigate their sensitivity to external fields. [3]

The analysis of the reviewed literature indicates that the complications encountered during the transportation of high-paraffin crude oils result from interconnected physical, chemical, and hydrodynamic processes. In this regard, the comprehensive investigation of deposit formation mechanisms, the evaluation of reagent performance, the determination of optimal reagent dosages, and the combined application of physicochemical methods constitute key scientific and practical approaches to ensuring the reliable and economically efficient pipeline transportation of high-paraffin crude oils.

Chapter Two. In the experimental part of the research, laboratory studies were conducted to evaluate the physicochemical and rheological properties of high-paraffin crude oils, the component composition of asphaltene–resin–paraffin deposits (ARPD), and the effectiveness of reagents used to prevent salt deposition. The experimental work involved determining the main characteristics of crude oil and water samples, modelling the paraffin deposition process, evaluating inhibitor performance, and applying various analytical methods. To ensure the accuracy and reproducibility of the results, methodologies based on relevant standards and appropriate laboratory equipment were used.

The density of crude oil samples was determined using the hydrometric method under thermostatically controlled conditions, and the results were calculated at a reference temperature of 20°C. A Stabinger SVM3001 viscometer was used to determine kinematic viscosity. To evaluate the rheological behaviour of crude oil under different temperature and flow conditions, a Brookfield rotational rheometer, a EuroPhysics Rheo 2000 instrument, and a thermostatically controlled measurement system were used. These instruments were used to measure apparent viscosity and shear stress and to investigate the flow properties of the crude oil. The pour point

[3] Gao C. Experimental Research on Paraffin Deposition with Cold Finger Devices – A Review // Improved Oil and Gas Recovery. – 2025. – Vol. 9. – P. 1–20

of the crude oil was determined by gradually cooling a heated sample and identifying the temperature at which it ceased to flow.

To evaluate the rheological behaviour of crude oil under different temperature and flow conditions, a Brookfield rotational rheometer, a EuroPhysics Rheo 2000 instrument, and a thermostatically controlled measurement system were used. These instruments were used to measure apparent viscosity and shear stress and to investigate the flow properties of the crude oil. The pour point of the crude oil was determined by gradually cooling a heated sample and identifying the temperature at which it ceased to flow.

The cold finger method was used to evaluate the effectiveness of paraffin deposition inhibitors. During the experiments, a 400–500 g crude oil sample was mixed using a magnetic stirrer, and a temperature difference was established between the crude oil medium and a cooled stainless-steel surface. The crude oil temperature was maintained above the onset temperature of paraffin crystallization, while the temperature of the cooled surface was kept below this value. The experiments lasted up to 5 hours. After each test, the deposits formed on the cooled surface were washed off with a solvent. Following evaporation of the solvent, the mass of the deposits was measured.

The temperature of the crude oil was maintained above the onset temperature of paraffin crystallization, while the temperature of the cooled surface was maintained below this value. Crude oil samples without an inhibitor and those containing an inhibitor were compared under identical conditions. The effectiveness of the inhibitor in reducing ARPD formation was calculated by comparing the masses of the deposits. The inhibition efficiency was calculated using the following formula[4]:

$$K = [(C2-C1)/C2] \times 100\%,$$

where: (K) – inhibition efficiency against ARPD formation, %; (C1) – mass of ARPD deposited on the cold finger after the addition of the inhibitor, g;(C2) – mass of ARPD deposited on the cold finger in the absence of an inhibitor, g.

[4] Gao C. Experimental Research on Paraffin Deposition with Cold Finger Devices – A Review // Improved Oil and Gas Recovery. – 2025. – Vol. 9. – P. 1–20



Figure 1. Experimental apparatus for evaluating the effectiveness of paraffin deposition inhibitors

The water content of the crude oil samples was determined using the distillation and measurement method with a Dean–Stark (Figure 2) apparatus. For this purpose, the sample was mixed with a solvent and heated, allowing the separated water to accumulate in the receiver, where its volume was measured. The water content of the crude oil was calculated based on the volume of the collected water and the mass or volume of the original sample.

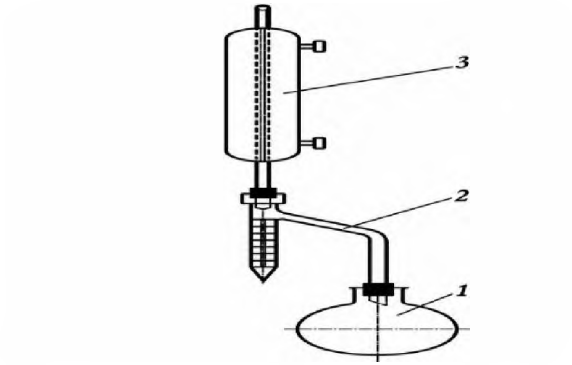


Figure 2. Dean–Stark apparatus for determining water content under laboratory conditions: 1 – flask; 2 – receiver-trap; 3 – condenser.

To evaluate the effectiveness of scale inhibitors, laboratory tests were conducted using model water samples designed to form calcium carbonate ($CaCO_3$) and calcium sulfate ($CaSO_4$). Aqueous solutions of the reagents at a concentration of 2% were prepared and added to the model systems at various dosages ranging from 10 to 200 g/t. The prepared samples were maintained at 80°C for 5 hours and then cooled, after which the resulting precipitates were separated by filtration. The concentration of calcium ions remaining in the solution was determined by complexometric (trilonometric) titration. The results obtained were compared with those for the initial solution and the inhibitor-free control sample to evaluate the effectiveness of the reagents in preventing salt deposition.

The first section of **chapter three** of the dissertation is devoted to the development of scale inhibitors and their laboratory testing. The dissertation involved comprehensive studies aimed at developing various chemical formulations, comparatively evaluating their performance under laboratory conditions, and selecting optimal inhibitor compositions to prevent inorganic salt deposition in oilfield equipment and transportation systems. The studies were conducted using carbonate and sulfate model formation waters, and the inhibitory effects of various reagents against the formation of calcium carbonate and calcium sulfate deposits were evaluated. At the initial stage, the effectiveness of sodium carboxymethylcellulose (NaCMC-600) as a scale inhibitor was investigated (Table 1). It was established that, although the reagent demonstrated high efficiency in preventing the precipitation of sulfate salts, its effect on carbonate deposits was very limited. Subsequent studies were conducted using inhibited hydrochloric acid. It was found that, in contrast, this reagent effectively prevented the formation of carbonate-type deposits at higher dosages but did not provide sufficient inhibition against sulfate salts. Thus, the selective effects of the two reagents on different salt systems demonstrated that their separate application was insufficient and that the development of new complex formulations was necessary. It was established that mixtures of these components exhibited higher inhibition efficiency than the individual components used separately (Table 2).

Table 1.

Inhibition Efficiency of NaCMC-600 against Salt Deposition in "Carbonate" and "Sulfate" Model Formation Waters

Reagent consumption (g/t)	Reagent Consumption and Scale Inhibition Efficiency	
	Scale inhibition efficiency (%) in carbonate water	Scale inhibition efficiency (%) in sulfate water
5	–	20.5
10	–	35.0
15	–	50.0
20	–	60.0
25	–	70.0
30	–	80.0
40	–	90.0
50	–	100.0

Table 2.

Physicochemical Properties of Formulations Prepared from Mixtures of Orthophosphoric Acid, NaCMC, and Water

Formulation	H_3PO_4 (%)	NaCMC (%)	Water (%)	Density at 20°C (kg/m^3)	Viscosity at 20°C (mm^2/s)	Pour point (°C)
I	5	0.5	94.5	1,020	3.025	−3
II	5	1.0	94.0	1,050	3.300	−3
III	5	1.5	93.5	1,080	3.520	−3
IV	5	2.0	93.0	1,100	5.030	−4
V	5	3.0	92.0	1,2030	5.075	−4

Table 3.

Inhibition Efficiency of the Developed Formulations against Salt Deposition

Formulation	Dosage (g/t)	Inhibition efficiency against $CaCO_3$ deposition (%)	Inhibition efficiency against $CaSO_4$ deposition (%)
I	25	43.0	32.0
	50	62.0	47.0
	75	81.0	65.0
	100	100.0	90.0
II	25	48.0	45.0
	50	67.0	65.0
	75	83.0	80.0
	100	100.0	100.0
III	25	40.0	45.0
	50	63.0	67.0
	75	85.0	82.0
	100	100.0	100.0
IV	25	58.0	50.0
	50	74.0	83.0
	75	90.0	100.0
	100	100.0	100.0
V	25	48.0	90.0
	50	65.0	100.0
	75	85.0	100.0

As a continuation of the research, new formulations designated as “DÇİ” were developed based on ammophos, NaCMC, sulfanol, and inhibited hydrochloric acid. The homogeneity, long-term stability, and physicochemical properties of the prepared formulations were evaluated, after which their inhibitory effects against salt deposition were determined. Laboratory tests demonstrated that the DÇİ-1, DÇİ-2, and DÇİ-3 formulations exhibited higher efficiency than the other compositions and almost completely prevented the formation of

carbonate- and sulfate-based deposits at relatively low reagent dosages. The results confirmed the presence of a synergistic effect among the components (Figures 3 and 4).

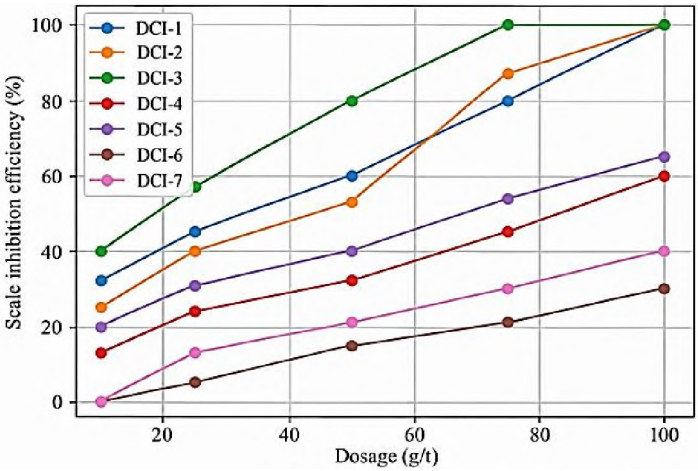


Figure 3. Inhibition Efficiency of DÇİ-1 to DÇİ-7 Formulations against $CaCO_3$ Deposition as a Function of Dosage

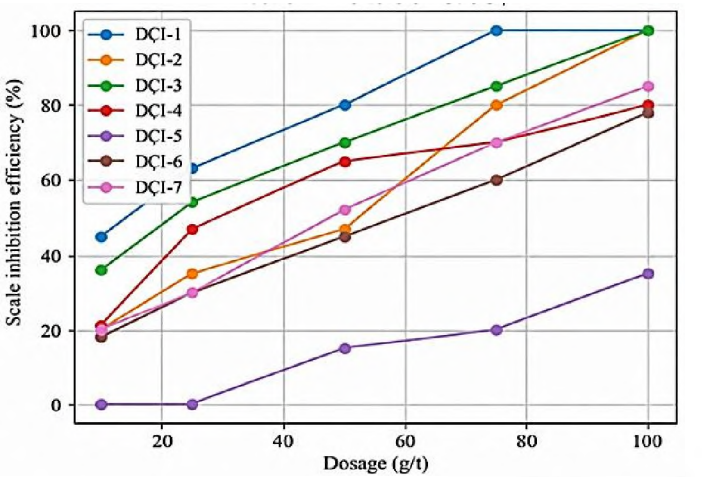


Figure 4. Inhibition Efficiency of DÇİ-1 to DÇİ-7 Formulations against $CaSO_4$ Deposition as a Function of Dosage

It was established that the developed formulations demonstrated high inhibition efficiency even at low dosages, effectively restricted the formation of carbonate- and sulfate-type deposits, and could be applied over a wide temperature range owing to their low freezing points.

The research was continued by identifying suitable solvents and other components for dissolving and preventing asphaltene–resin–paraffin deposits (ARPD) during the transportation of high-paraffin crude oils and developing pour point depressant additives. The studies were conducted using crude oil samples collected from the Sangachal–Duvanny–Khara–Zira field operated by the N. Narimanov Oil and Gas Production Department (OGPD) (Table 4).

Table 4.

ARPD Samples Collected from Production Wells in the Fields Operated by "Azneft" PU (OGPDs)

Oil and Gas Production Department (OGPD)	Mechanical impurities (%)	Asphaltenes (%)	Resins (%)	Paraffins (%)	Losses (%)
Narimanov OGPD	1.35	7.83	18.86	70.53	1.43
Neft Dashlari (Oil Rocks)	1.85	11.54	9.42	75.87	1.32

Gasoline fractions with boiling ranges of 80–180°C, kerosene, stabilized gas condensate, light catalytic cracking distillate (LCC), liquid pyrolysis resin, and other aromatic solvents were used in the study. The dissolution capacity of asphaltene–resin–paraffin deposits (ARPD) was investigated at temperatures of 20 and 40°C using a specially designed experimental apparatus. The dissolution capacity, i.e., the effectiveness of the selected solvent, was determined using the following formula:

$$E= [(m_0+m)- (m_s+m)/ m_0 +m]100\%$$

where:(m_0) – initial mass of the selected ARPD sample, g; (m) – mass of the selected ARPD sample after the experiment, g; (m_s) – mass of the selected metal mesh, g.

The results obtained showed that, among the solvents used, liquid pyrolysis resin exhibited the highest dissolving capacity. Specifically, its ARPD dissolution efficiency was 57.15% at 20°C and 55.88% at 40°C. For comparison, the corresponding values for the light catalytic cracking fraction (LCC) were 31.88% and 45.92%, respectively; for gasoline, 9.89% and 21.95%; and for kerosene, 7.29% and 27.75%. Stable gas condensate exhibited the lowest dissolving capacity. (Table 5). To enhance the effectiveness of the solvents, a non-ionic surfactant was added to each formulation at a concentration of 0.5%. The addition of the surfactant increased the dispersing capacity of all the solvents. The best results were obtained with the mixture of liquid pyrolysis resin and the non-ionic surfactant. These findings indicated the presence of a synergistic effect between aromatic hydrocarbons and non-ionic surfactants, demonstrating that their combined application significantly improved ARPD dissolution.

Table 5.

Dissolving Effect of Various Solvents on ARPD at Different Temperatures

Solvents	Temperature , ^{0}C							
	20				40			
	m_0,q	m,q	∇_m,q	%	m_0,q	m,q	∇_m,q	%
Kerosene	7,820	7,25	0,570	7,29	7,820	5,650	2,17	27,75
Gasoline	5,745	5,17	0,567	9,89	5,745	4,485	1,26	21,95
Light catalytic cracking distillate	7,840	5,34	2,50	31,8	7,840	4,235	3,60	45,92
Condensate	6,754	6,53	0,217	37,2	6,754	6,124	0.63	9.33

Table 6.

Effect of Solvent and Non-Ionic Surfactant (Flexoil) Mixtures on ARPD Dissolution at Different Temperatures

Solvent + surfactant (Flexoil)	Temperature, ^{0}C							
	20				40			
	$m_{0,q}$	m,q	$\nabla_{m,q}$	%	$m_{0,q}$	m,q	$\nabla_{m,q}$	%
Kerosene	7.82	7.01	0.80	10,2	7.820	6.750	1.07	13.7
Gasoline	5.74	5.01	0.79	13.7	5.745	4.735	1.01	17.6
Condensate	6.75	6.43	o.31	4,5	6.754	6.153	0.6	8.9
Light catalytic cracking distillate	7.84	5.02	2.82	36,0	7.840	4.650	3.39	43.2
Liquid pyrolysis resin	7.83	4.01	3,81	39.0	7.830	2.25	5.48	70.0

At the next stage of the research, a new inhibitor formulation based on an amphiphilic polymer combined with solvents was developed to not only dissolve existing asphaltene–resin–paraffin deposits (ARPD) but also prevent their subsequent formation. The developed composition consisted of 2% amphiphilic polymer, 8% non-ionic surfactant, and 90% aromatic solvent. Laboratory studies showed that increasing the reagent dosage gradually reduced the amount of ARPD deposited and increased the inhibition efficiency. At a dosage of 100 g/t, the inhibition efficiency was 59.61%; at 150 g/t, it reached 74.23%; and at dosages of 200 and 250 g/t, it was 74.61%. At the same time, the pour point of the paraffinic crude oil gradually decreased from the initial value of +21°C to +3°C at dosages of 200–250 g/t. It was established that the reagent not only prevents paraffin deposition but also significantly reduces crude oil viscosity. Specifically, the kinematic viscosity decreased from 280.27 mm²/s to 66.33 mm²/s, while the dynamic viscosity decreased from 250.45 mPa·s to 58.7 mPa·s (Table 7).

Table 7

Effect of Adding a Polymer-Based Additive on ARPD Formation and the Properties of Crude Oil

Reagent dosage (g/t)	ARPD deposited on the cold finger (g)	Inhibition efficiency against ARPD (%)	Pour point of ARPD-containing crude oil (°C)	Crude oil density at 20°C	Viscosity, 20^0C	
					Dynamic mPa s	Kinematic mm^2/s
0	13,0	-	+21	0,893	250,45	280,27
10	11,24	13,54	+19	0,893	247,32	276,92
25	10,30	20,76	+10	0,892	231,53	259,56
50	8,72	32,92	+7	0,891	226,76	254,41
100	5,25	59,61	+5	0,889	202,45	227,73
150	3,35	74,23	+4	0,887	140,56	158,47
200	3,30	74,61	+3	0,885	90,0	101.65
250	3,30	74,61	+3	0,885	58,7	66,33

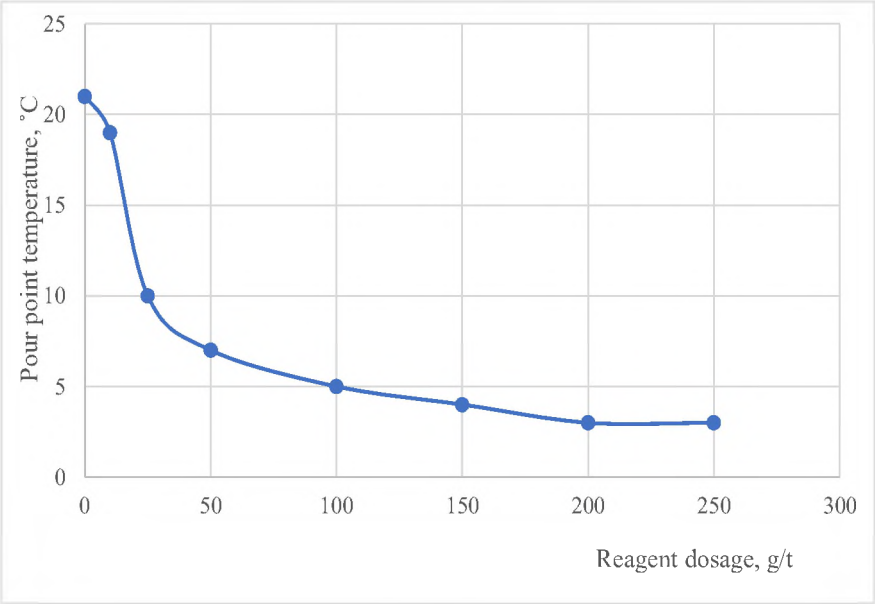


Figure 5. Dependence of Pour Point on Reagent Dosage

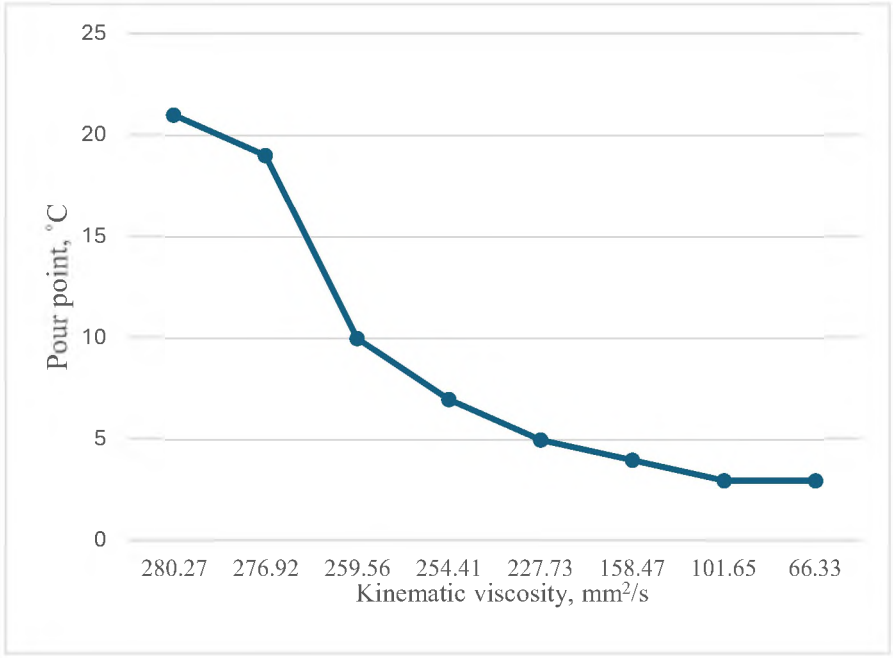


Figure 6. Variation in Kinematic Viscosity

The effects of solvents and polymers on the low-temperature properties of high-paraffin crude oils were investigated, and depressant compositions were formulated based on the results obtained. Laprol 4202-2B-30 and Laprol 3603-2-12 were used as non-ionic surfactants, the light catalytic cracking distillate (LCC) was used as the solvent, light pyrolysis resin was used as a co-solvent, and an ethylene-vinyl acetate (EVA) copolymer was incorporated as an additional component.

The effectiveness of the developed pour point depressants was investigated using a high-paraffin crude oil sample. The test crude oil contained 23% paraffin, 2.75% asphaltenes, and 5.4% resins, with an initial pour point of +31°C. The tests conducted at additive concentrations of 0.01 and 0.02 wt.% demonstrated that all the formulated compositions exhibited a certain degree of pour point depressant activity (Table 8).

Table 8.

Effect of Pour Point Depressants on ARPD-Containing Crude Oils

Formulation №	Additive concentration in crude oil (wt.%)	Pour point temperature of crude oil, (°C)	Temperature change (°C)
1	0,01 0,02	-10 -13	41 44
2	0,01 0,02	-7 -11	38 42
3	0,01 0,02	-6 -15	37 46
4	0,01 0,02	2 6	29 25
5	0,01 0,02	8 10	23 21
6	0,01 0,02	13 11	18 20
7	0,01 0,02	0 2	31 29
8	0,01 0,02	-3 -5	34 36
9	0,01 0,02	1 -1	30 32
10	0,01 0,02	4 2	27 29
11	0,01 0,02	-13 -15	44 46
12	0,01 0,02	-10 -15	41 46
13	0,01 0,02	-23 -27	54 58
14	0,01 0,02	10 2	21 29

Continuation of Table 8

15	0,01 0,02	-14 -17	45 48
16	0,01 0,02	-18 -21	49 52
17	0,01 0,02	-12 -17	43 48
Without additives	0,01 0,02	13 5	18 26

At the next stage of the research, a new multifunctional composition was developed for breaking water-in-oil emulsions, preventing asphaltene–resin–paraffin deposit (ARPD) formation, and protecting oilfield equipment against corrosion. The composition consisted of a Laprol-based block copolymer, an imidazoline compound obtained through the condensation of natural petroleum acids with polyethylene polyamines, and an aromatic solvent. The physicochemical properties of the developed formulations were determined, and their demulsifying, anticorrosion, and anti-ARPD performance was comprehensively evaluated. The proposed formulations were investigated in terms of their demulsification activity, corrosion inhibition, protection against asphaltene, resin, and paraffin deposits, and residual oil content in petroleum products. The studies were conducted using a stable crude oil emulsion with a density of 910 kg/m³, containing 40% water, 19.8% paraffins, 4.65% asphaltenes, and 7.4% resins.

Laboratory tests demonstrated that the new compositions effectively separated water-in-oil emulsions (Table 9). In corrosion tests conducted in an H_2S-containing environment, the corrosion inhibition efficiency reached 95% at a dosage of 50 g/t. The ARPD removal efficiency was 92% within 30 seconds, while the deposit cleaning efficiency reached 92–93%. It was established that the principal formulations achieved rapid emulsion separation at dosages of 50–100 g/t and reduced the residual water content to 1–2%. These results demonstrated that the composition simultaneously performed the functions of a demulsifier, corrosion inhibitor, and ARPD dispersant.

Table 9

Performance of Demulsifier Formulations in Relation to ARPD

№	Residual water content (wt.%)		Corrosion inhibition efficiency (%)				ARPD prevention efficiency			
			H_2S content (mg/L				Oil film washing rate		Average size of dispersed particles (mm)	ARPD removal from the surface (%)
			100		200					
	Reagent dosage,g/t		Reagent dosage,g/t				%/s	rate		
	25	50	25	50	25	50				
1	0,48	0,18	81	86	73	78	82/30	good	1	84
2	0,45	0,17	83	87	74	79	84/30	good	1	86
3	0,43	0,16	86	90	78	83	91/30	excellent	1	90
4	0,41	0,15	89	93	81	86	85/30	excellent	1	93
5	0,50	0,19	79	84	70	76	78/30	good	1	80
6	0,42	0,15	88	92	80	85	85/30	excellent	1	92
7	0,40	0,15	91	95	83	88	92/30	excellent	1	93
8	0,49	0,18	80	85	71	74	80/30	good	1	82
9	0,41	0,16	89	94	82	87	91/25	excellent	1	92

Chapter Four is devoted to the application of reagent-free physicalmethods to prevent the formation of asphaltene–resin–paraffin deposits (ARPD), inorganic salts, and mechanical impurities in oilfield equipment and transportation systems. In the course of the research, the designs of existing magnetic devices were analysed, and a new magnetic device was developed taking their limitations into account. The calculations took into account the geometric parameters of the pipeline and the internal magnetic conduit, the fluid flow velocity, pressure, and temperature. A comparison of different magnetic configurations revealed that the geometric shape of the magnets significantly affects the variation pattern of the magnetic field and the magnetic field strength gradient.

In the design of the “MA-Azneft” magnetic device, the magnetic system is positioned on the outer surface of the pipeline and protected by a hermetically sealed protective casing, which also serves as a magnetic flux conductor. Designing the device as an integral

section of the pipeline enables its application in oil gathering and transportation systems, as well as in oilfield equipment. Based on the developed design, the treatment of fluid flow within the magnetic field generated by permanent magnets and the selection of the magnetic field parameters were investigated.

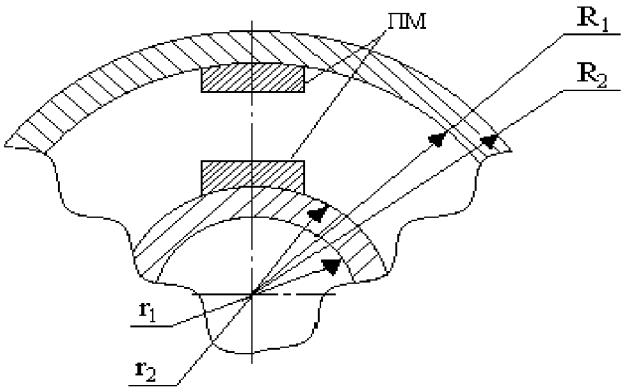


Figure 7. Schematic diagram of the device.

A methodology for calculating the magnetic field generated by permanent magnets was developed for the design of the new magnetic device. The calculations took into account the geometric dimensions of the pipeline and the inner magnetic tube, fluid flow velocity, pressure, and temperature. In the computational model of the device, the fluid flows through an annular channel between two concentric ferromagnetic tubes equipped with permanent magnets. The radii of the tubes were taken as (r_1=0.1) m, (r_2=0.108) m, (R_1=0.546) m, and (R_2=0.562) m, respectively. Taking into account the remanent magnetic induction of permanent magnets used in industrial applications, a magnetic induction value of 0.5 T was adopted for the calculations.

The calculations were performed for wavelengths of 0.2 and 1.0 m and initial magnetic field strengths of 200 and 1000 A/m. The results confirmed that the geometric shape of the magnets significantly affects the variation and gradient of the magnetic field. It was established that flat-surfaced magnets are more suitable for generating a uniform magnetic field, whereas magnets with parabolic surfaces are more appropriate for producing a field distribution approaching a trapezoidal profile. Furthermore, the ratio of magnet length to the distance between adjacent magnets was found to influence whether the magnetic field exhibits a steady or pulsating character.

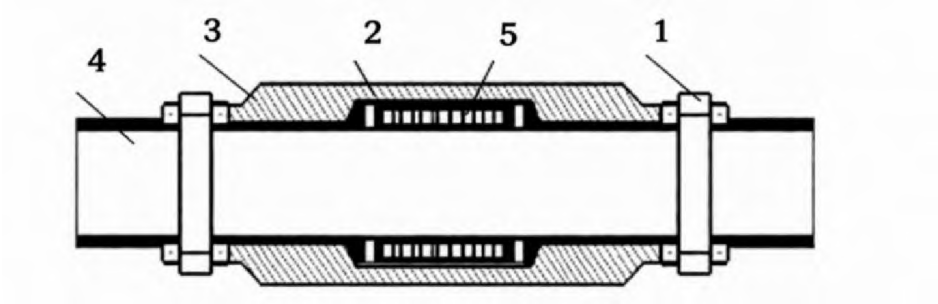


Figure 8. Schematic diagram of the "MA-Azneft" apparatus. 1 – pipe coupling; 2 – retaining connectors; 3 – protective casing; 4 – apparatus housing; 5 – magnetic system

Cədvəl 10.

Maqnit sahəsinin dəyişməsinin bəzi formalarını almaq üçün maqnit qurğularının parametrlərinin nümunələri

Magnet Surface Geometry / H Variation Pattern	H_{in}=1000 A/m λ=0,2 m	H_{in}=200 A/m λ=0,2 m	H_{in}=200 A/m λ=1,0 m	H_{in}=1000 A/m λ=1,0 m
Düz/Unipolar	H_{fact}=1028 M=0,006m h=0,02m T=0,006m	H_{fact}=208 M=0,003m h=0,05m T=0,003m	H_{fact}=278 M=0,004m h=0,005m T=0,005m	H_{fact}=1018 M=0,009m h=0,01m =0,008m

Continuation of Table 10

Circular cylinder / Unipolar	H_{fact}=1019 M=0,006m h=0,02m T=0,006m R=0,001m	H_{fact}=207 M=0,003m h=0,05m T=0,003m R=0,001m	H_{fact}=275 M=0,004m h=0,005m T=0,005m R=0,001m	H_{fact}=1015 M=0,009m h=0,01m T=0,008m R=0,001m
Parabolic cylinder / Unipolar	H_{fact}=938 M=0,006m h=0,02m T=0,006m R=0,001m	H_{fact}=207 M=0,003m h=0,05m T=0,003m R=0,001m	H_{fact}=275 M=0,004m h=0,005m T=0,005m R=0,001m	H_{fact}=1007 M=0,009m h=0,01m T=0,008m R=0,001m
Flat / Bipolar	H_{fact}=1009 M=0,007m h=0,028m T=0,007m	H_{fact}=212 M=0,025m h=0,05m T=0,005m	H_{fact}=271 M=0,004m h=0,004m T=0,005m	H_{fact}=1015 M=0,009m h=0,01m T=0,008m
Circular cylinder / Bipolar	H_{fact}=999 M=0,007m h=0,028m T=0,007m R=0,001m	H_{fact}=210 M=0,025m h=0,005m T=0,005m R=0,001m	H_{fact}=269 M=0,004m h=0,005m T=0,005m R=0,001m	H_{fact}=1007 M=0,009m h=0,01m T=0,008m R=0,001m
Parabolic cylinder / Bipolar	H_{fact}=998 M=0,007m h=0,028m T=0,007m R=0,001m	H_{fact}=208 M=0,025m h=0,005m T=0,005m R=0,001m	H_{fact}=268 M=0,004m h=0,004m T=0,005m R=0,001m	H_{fact}=1006 M=0,009m h=0,01m T=0,008m R=0,001m

In the dissertation, the technology of continuous inhibitor dosing was investigated and its application justified to prevent salt and paraffin deposition in pipelines during oil transportation and treatment at the N. Narimanov Oil and Gas Production Department (OGPD). It was established that the stable and precise dosing of chemical reagents into the system reduces the rate of deposit formation, increases pipeline throughput, ensures the stability of technological processes, and extends the operating period of equipment between repairs.

An analysis of the technical condition of the dosing units in operation revealed several design and operational deficiencies. The

main problems identified included the low throughput capacity of filter elements, the failure of electrically contact pressure gauges to meet process requirements, the lack of corrosion protection for the reagent tank, the unreliable design of the tank cover, the absence of a vent pipe, the lack of check and leakage valves, the malfunctioning of some high-pressure gate valves, and the absence of a thermal overload relay for motor protection. These deficiencies adversely affected the continuous supply of reagents and the long-term operation of the equipment

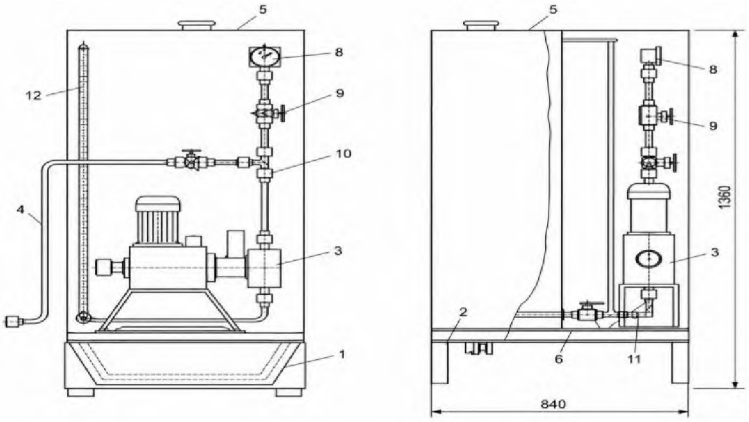


Figure 9. UDE metering electric pump unit: 1 – frame; 2 – storage tank; 3 – pump; 4 – common housing; 5 – filling neck; 6 – filters; 7 – valve; 8 – pressure gauge; 9, 10, 11 – valves; 12 – level gauge.

To address the identified problems, the design of the dosing unit was improved. (Figure 9,10)The proposed modifications included applying a special protective coating to the internal surface of the tank, replacing copper pipelines with corrosion-resistant materials, installing high-capacity filter elements, introducing a control system that automatically shuts down the pump at minimum and maximum pressure limits, upgrading measuring instruments, and installing check valves, leakage valves, and a vent pipe.

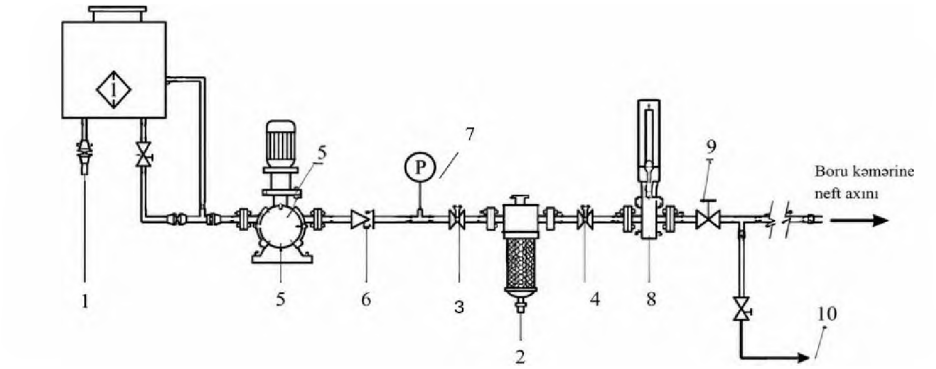


Figure 10. Process flow diagram continuous inhibitor dosing pumping system: 1 – inhibitor tank; 2 – suction filter; 3, 4 – valves; 5 – metering pump; 6 – check valve; 7 – pressure gauge; 8 – control valve; 9 – valve; 10 – drain line.

The implementation of the improved dosing system resulted in reduced reagent consumption and increased inhibitor effectiveness. When metering pumps were used, reagent consumption decreased from 180–220 g/t to 90–120 g/t, while dosing accuracy improved from ±35% to ±2%.

CONCLUSIONS AND RECOMMENDATIONS

1. It was established that the inhibitors designated DK-1, DK-2, and DÇİ, formulated based on the sodium salt of carboxymethylcellulose, mineral acids, ammophos, and surfactants, exhibited high efficiency in preventing salt deposition. The DK-1 inhibitor achieved an inhibition efficiency of 100% at a dosage of 500 g/t, while DK-2 achieved 93%. The DÇİ-1 to DÇİ-3 formulations completely prevented the formation of $CaCO_3$ and $CaSO_4$ salts at dosages of 75–100 g/t. [7]
2. Multicomponent scale inhibitors based on sodium naphthenate, whey, isopropyl alcohol, sodium carboxymethylcellulose, and tripolyphosphate were developed, and their effectiveness against salt deposition was investigated. The tripolyphosphate-based formulation with combined functionality demonstrated a scale inhibition efficiency of 90–98% at low dosages of 10–25 g/t, while its corrosion protection efficiency against salt-induced corrosion reached 80–85%.
3. Various solvents suitable for dissolving asphaltene, resin, and paraffin deposits and for developing multifunctional inhibitor formulations were experimentally selected. The investigations established that light pyrolysis resin exhibited a dissolution capacity for asphaltene–resin–paraffin deposits (ARPD) that was 35–80% higher than that of other solvents, depending on temperature. By combining light pyrolysis resin with non-ionic surfactants, it was possible to dissolve up to 90% of ARPD. [2, 3, 9]
4. A polymer-based additive was developed to mitigate asphaltene–resin–paraffin deposits in high-paraffin crude oil, and the effect of amphiphilic polymers on paraffin deposition was investigated. At an additive dosage of 200 g/t, the polymer-based inhibitor achieved an inhibition efficiency of 74.6%. [1, 4, 5, 13]
5. A new multifunctional formulation was developed for breaking water-in-oil emulsions, preventing asphaltene–resin–paraffin deposit formation, and protecting oilfield equipment and pipelines against corrosion. The formulation, consisting of glycerol-based block copolymers of ethylene oxide and propylene oxide, a

solvent, and imidazoline compounds, demonstrated effective demulsifying, anti-ARPD, and corrosion protection properties. These findings indicate its potential application as a multifunctional chemical agent in oil production and transportation processes. [6, 15]

6. It was established that magnetic field treatment of crude oil reduced the formation of asphaltene–resin–paraffin deposits by up to 90% and salt deposits by up to 45%. In addition, the probability of hydrate plug formation decreased by a factor of 3–5, while the corrosion rate was reduced by up to 50%. The application of the newly developed magnetic device reduced hydraulic resistance in the system, minimized the risk of blockage, and improved operational reliability. [7]
7. The design and operational deficiencies of the dosing pumps used at the N. Narimanov Oil and Gas Production Department (OGPD) were analysed, and technical solutions were developed to address them. Implementation of the proposed improvements enhanced pump reliability and operational efficiency, improved the stability and accuracy of inhibitor dosing, and had a positive effect on reagent consumption and the efficiency of the technological process. [12, 14]

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

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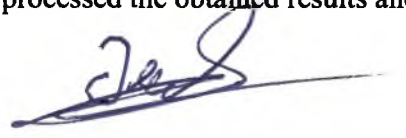
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The Author's Personal Contribution to the Published Works:

The works listed under references **[3, 4, 5, 9, 13]** were carried out independently by the author.

For the works listed under references **[1, 2, 6, 7, 8, 14, 15]**, the applicant developed the research concept and methodology, processed the obtained results, and analysed the data.

For the works listed under references **[10, 11, 12]**, the applicant processed the obtained results and analysed the data.



The defense will be held on 17 November 2026 at 11:00 at the meeting of Dissertation council FD 2.03 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the Azerbaijan State Oil and Industry University PLE.

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Abstract was sent to the required addresses on 16 October 2026.

Signed for print: 14.10.2026
Paper format: A5
Volume: 39011
Number of hard copies: 20