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INVESTIGATION OF THE EFFECTS OF DIFFERENT METHODS ON THE RHEOLOGICAL PROPERTIES OF HIGH-PARAFFIN OIL

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For the first time, this article presents the results of comprehensive laboratory experiments investigating the individual and combined effects of physical and chemical methods on the rheological properties of a high-paraffin crude oil sample from SOCAR's Narimanov field. Ultrasound waves were employed as the physical method, while the chemical method involved the use of the depressant additive «Difron-3970.» The experiments demonstrated that the optimal exposure time for ultrasound waves was 15 minutes when used alone, and 10 minutes when combined with the chemical method. The optimal concentration of «Difron-3970» was 700 g/t when used independently and 500 g/t in combination. The effects of ultrasound waves and «Difron-3970,» both separately and in combination, on the oil's yield stress, dynamic viscosity, paraffin precipitation, and freezing point were evaluated. The highest efficiency was achieved when both methods were applied together. Under combined treatment, the dynamic viscosity of the oil decreased significantly, reaching its minimum value. Additionally, the freezing point dropped below zero, and the amount of asphaltene-resin-paraffin deposits was minimized. The study proposes the use of this economically and environmentally efficient combined physical-chemical method, specifically, the synergistic action of ultrasound waves with the «Difron-3970» depressant additive, for the treatment of high-paraffin oils under field conditions.

Keywords: ultrasound waves, physical-chemical method, optimal exposure time, optimal concentration, cold finger, efficiency.

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Introduction

In the present era, the complete exploitation of the world's largest light oil fields has led to a shift in the composition of oil reserves, resulting in an increased share of oils rich in heavy hydrocarbons, resins, and asphaltenes. Paraffinic and highly paraffinic oil dispersive systems lose fluidity even at positive temperatures due to the crystallization of paraffinic hydrocarbons. Various techniques, including thermal, mechanical, physical, and chemical methods, are available to address the challenges associated with the extraction and transportation of paraffinic oils. Currently, the use of ultrasonic waves for the pipeline transportation of oils with anomalous properties is being extensively studied and applied in the oil industry. The application of ultrasonic vibrations during oil extraction has been shown to improve permeability in reservoir zones, decrease oil viscosity, and alter key physicochemical characteristics through cavitation effects [1]. Research has demonstrated that ultrasonic fields can significantly increase reaction rates not only in water but also in organic media. For instance, studies [2] using decane samples revealed that exposure to ultrasound promotes molecular bond breakdown, followed by radical recombination. Acoustic impacts on dispersive systems cause changes in the structure, association sizes, and degree of dispersion of phase components, making acoustic methods widely applicable in oil transportation and processing. Ultrasonic waves affect both the rheological properties and the fractional composition of oils and petroleum products, leading to favorable adjustments in viscosity and flow characteristics.

According to modern scientific views, oil is a complex dispersive system with a unique internal structure that can change under external influences. Asphaltene aggregates, which can exist freely in oil, have a complex structural composition, making oil a dispersive system [3]. Among the effective methods for altering the viscoelastic properties of such systems, physical approaches, particularly those involving ultrasonic waves, are gaining importance [4]. Studies on the impact of ultrasonic waves on the rheological properties of dispersive oil systems are documented in ref. [5]. Results from studies [6] focusing on ultrasonic effects reveal significant cavitation developments in liquids with varying physicochemical properties. Moreover, the effectiveness of ultrasonic treatment in reducing the viscosity of heavy oils depends on the number and distribution of paraffin crystals. It has been demonstrated that the combined application of ultrasonic waves and chemical reagents further reduces oil viscosity, confirming the utility of this method. The authors of study [7] examined how ultrasonic waves influence the rheological characteristics of crude oil samples, noting a pseudoplastic flow behavior. They found that heavy components in oil decompose within 40 minutes of ultrasonic treatment, significantly reducing viscosity values [8]. Another study [8] explored the effects of ultrasonic waves at 25 and 68 kHz frequencies with powers of 100, 250, and 500 W on the viscosity of paraffin, synthetic oil, and kerosene in a smooth capillary tube, finding that viscosity decreases due to cavitation and heat generation within the liquid. The authors of studies [9,10] further demonstrated that the effectiveness of ultrasonic treatment depends on the oil's component composition: ultrasonic processing of high-paraffin and resin-containing oils reduced the freezing point by 16^{0}C and viscosity sixfold at 10^{0}C. Conversely, oils with high paraffin but low resin-asphaltene content showed increased viscosity, freezing point, and paraffin precipitation after ultrasonic treatment [3]. Study [3] reveals that ultrasonic processing for 15 minutes reduces the dynamic viscosity by 17 times and the freezing point by 20^{0}C in high-paraffin and resin-containing oils under low shear stress. Notably, chromatographic-mass spectrometry and IR spectroscopy analyses show that ultrasonic treatment does not significantly alter the oil's component composition.

The present study experimentally investigates the individual and combined effects of ultrasonic waves and chemical reagents on the rheological properties of high-viscosity oil samples, with the aim of developing energy- and resource-efficient ultrasonic technologies for the transportation of high-paraffin oil. The objective is to examine the influence of ultrasonic waves and depressant additives, both separately and in combination, on the rheological characteristics of high-paraffin oils.

Experimental

In this study, the effects of ultrasonic waves and the depressant additive «Difron-3970,» both individually and in combination, were investigated. An oil sample with the physicochemical characteristics listed in Table 1 was used for the experiments.

Ultrasonic testing of the high-paraffin dispersive oil system was carried out at a temperature of 25–30^{0}C for 1–15 minutes using an ultrasonic device. The experimental setup included a PS-4/25 ultrasonic generator with 4 / kW power, an MST-2/22 magnetostrictive transducer with a resonance frequency of 22/ kHz, and a rod wave transmitter with a diameter of 12/ mm [11]. Before and after ultrasonic treatment, the oil sample was kept in a thermostat at 20^{0}C for 30 minutes. In the combined method, the chemical reagent was added first, followed by exposure of the oil sample to ultrasonic waves.

The process of paraffin precipitation in the oil sample was quantitatively assessed using the «cold finger» method under laboratory conditions. The freezing point of the oil was determined according to the RD 39-3-812-82 methodology. Viscometric studies were conducted using a «Reotest-2» rotational viscometer[1] [12].

Table 1

Physicochemical characteristics of the Narimanov oil sample

Characteristic	Value
density at 20^{0}C, kg/m^3	986.4
dynamic viscosity at 0^{0}C, mPa·s	1563
water content, wt.%	38
chloride salts content, mg/l	502
mechanical mixture content, wt.%	5.6
resin content, wt.%	9.2
asphaltene content, wt.%	4.24
paraffin content, wt.%	15.4
freezing (or pour) point temperature, ^{0}C	+18

[1] ASTM D97-09. Standard test method for pour point of petroleum products. ASTM International, 2009. 10 p.

Results and discussion

In the course of the research, the effects of ultrasonic waves, the «Difron-3970» depressant additive, and the combination of ultrasound+»Difron-3970" on the limit shear stress and dynamic viscosity of the oil sample were studied under various shear rates and temperatures. The duration of ultrasonic wave exposure was set at 15 minutes, and the concentration of the «Difron-3970» depressant was 700/ g/t. In the combined method, the ultrasonic exposure time was 10 minutes, and the depressant concentration was 500/ g/t.

The shear rates used ranged from 50 to 500 s^{-1}, specifically: 50, 100, 150, 200, 250, 300, 350, 400, 450, and 500 s^{-1}. The results obtained after 15 minutes of ultrasonic exposure at low and high temperatures are presented in Tables 2 and 3, respectively.

The results listed in Table 2 show that within the given shear rate interval and the specified temperatures (5^{0}C, 10^{0}C, and 15^{0}C), the dynamic viscosity of the oil sample decreases by 69.2%, 62.1%, and 59.7%, respectively. The results listed in Table 3 indicate that within the given shear rate interval and the specified temperatures (20^{0}C, 30^{0}C, 40^{0}C, 50^{0}C, and 60^{0}C), the dynamic viscosity of the oil sample decreases by 40%, 46.6%, 57.1%, 58.3%, and 57.5%, respectively.

Tables 4 and 5 present the results obtained after the addition of the optimal concentration of the «Difron-3970» depressant additive (700/ g/t) at low and high temperatures, respectively.

It can be seen from Table 4 that within the given shear rate interval and the specified temperatures (5^{0}C, 10^{0}C, and 15^{0}C), the dynamic viscosity of the oil sample decreases by 75.2%, 69.8%, and 66%, respectively.

The results given in Table 5 show that within the given shear rate interval and the specified temperatures (20^{0}C, 30^{0}C, 40^{0}C, 50^{0}C, and 60^{0}C), the dynamic viscosity of the oil sample decreases by 64.1%, 64.3%, 54%, 58.3%, and 47.5%, respectively.

Tables 6 and 7 present the results obtained after the combined effect of the «Difron-3970» depressant additive and ultrasonic waves at low and high temperatures, respectively.

As follows from Table 6, within the given shear rate interval and the specified temperatures (5^{0}C, 10^{0}C, and 15^{0}C), the dynamic viscosity of the oil sample decreases by 72.1%, 61.6%, and 66%, respectively.

The results presented in Table 7 show that the

Table 2

Values of some rheological parameters of oil after 15 minutes of ultrasonic treatment at low temperatures

Shear rate, s^{-1}	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s
	5^{0}C		10^{0}C		15^{0}C	
50	52	1040.0	23	460.0	11	220.0
100	63	630.0	30	300.0	15	150.0
150	76	506.6	38	253.3	18	120.0
200	83	415.0	42	210.0	21	105.0
250	92	368.0	48	192.0	25	100.0
300	104	346.0	54	180.0	28	93.3
350	112	320.0	61	174.0	31	88.6

Table 3

Values of some rheological parameters of oil after 15 minutes of ultrasonic treatment at high temperatures

Shear rate, s^{-1}	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s
	20^{0}C		30^{0}C		40^{0}C		50^{0}C		60^{0}C	
50	2.0	40.0	0.9	18.0	0.7	14.0	0.6	12.0	0.4	8.0
100	3.8	38.0	1.7	17.0	1.2	12.0	1.0	10.0	0.6	6.0
150	5.2	34.7	2.4	16.0	1.5	10.0	1.2	8.0	0.8	5.3
200	6.6	33.0	3.0	15.0	1.8	9.0	1.4	7.0	1.0	5.0
250	7.8	31.2	3.6	14.0	2.0	8.0	1.6	6.4	1.2	4.8
300	9.1	30.3	4.0	13.0	2.2	7.3	1.8	6.0	1.3	4.3
350	10.3	29.4	4.2	12.0	2.4	6.8	2.0	5.7	1.4	4.0
400	11.0	27.5	4.4	11.0	2.6	6.5	2.2	5.5	1.5	3.7
450	11.6	25.7	4.6	10.2	2.8	6.2	2.4	5.3	1.6	3.5
500	12.0	24.0	4.8	9.6	3.0	6.0	2.5	5.0	1.7	3.4

dynamic viscosity of the oil sample decreases by 72.1%, 52.5%, 53.3%, 60.0%, and 66.6%, respectively, within the given shear rate interval and the temperatures indicated.

The effect of ultrasonic waves and the «Difron-3970» depressant additive, both individually and in combination, on asphaltene-tar-paraffin deposits forming in the oil volume and precipitating using the «cold finger» method was studied under laboratory conditions. During the process, the amount of paraffin deposits accumulated on the tube surface was measured at time intervals of 0, 20, 40, 60, 80, 100, and 120 minutes using an analytical balance. Experiments were conducted at tube surface temperatures of 0^0C, 5^0C, 10^0C, 15^0C, 20^0C, 25^0C, and 30^0C. Initially, experiments were carried out without any external influence on the oil, and the results are presented in Fig. 1.

Table 4

Values of some rheological parameters of oil after the effect of the optimal concentration (700 g/t) of «Difron-3970» additive at low temperatures

Shear rate, s^{-1}	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s
	5^0C		10^0C		15^0C	
50	49	980	26	520	10	200
100	55	550	35	350	13	130
150	61	407	38	253	15	100
200	70	350	42	210	17	85
250	76	304	46	184	19	76
300	83	277	53	177	22	73
350	85	243	55	157	24	68

Table 5

Values of some rheological parameters of oil after the effect of the optimal concentration (700 g/t) of «Difron-3970» additive at high temperatures

Shear rate, s^{-1}	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s
	20^0C		30^0C		40^0C		50^0C		60^0C	
50	1.7	34.0	0.7	14.0	0.5	10	0.3	6.0	0.2	4.0
100	3.0	30.0	1.0	10.0	0.8	8.0	0.5	5.0	0.3	3.0
150	3.6	24.0	1.2	8.0	1.1	7.3	0.6	4.0	0.4	2.6
200	4.0	20.0	1.4	7.0	1.3	6.5	0.7	3.5	0.5	2.5
250	4.5	18.0	1.6	6.4	1.5	6.0	0.8	3.2	0.6	2.4
300	4.8	16.0	1.8	6.0	1.7	5.6	0.9	3.0	0.7	2.3
350	5.2	14.8	2.0	5.7	1.9	5.4	1.0	2.8	0.8	2.2
400	5.5	13.7	2.2	5.5	2.0	5.0	1.1	2.7	0.9	2.1
450	5.8	12.9	2.4	5.3	2.2	4.8	1.2	2.6	1.0	2.1
500	6.1	12.2	2.5	5.0	2.3	4.6	1.3	2.5	1.1	2.1

Table 6

Values of some rheological parameters of oil after the combined effect of «Difron-3970» depressant additive and ultrasound at low temperatures (ultrasound time of 10 minutes and reagent concentration of 500 g/t)

Shear rate, s^{-1}	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s
	5^0C		10^0C		15^0C	
50	42	840	16	320	5.0	100
100	50	500	21	210	7.0	70
150	57	380	27	180	9.0	60
200	64	320	34	170	10.0	50
250	70	280	37	148	11.0	44
300	78	260	40	133	13.0	43
350	82	234	43	123	14.0	40

Table 7

Values of some rheological parameters of oil after the combined effect of «Difron-3970» depressant additive and ultrasound at high temperatures (ultrasound time of 10 minutes and reagent concentration of 500 g/t)

Shear rate, s^{-1}	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s	τ, Pa	μ, mPa·s
	20^0C		30^0C		40^0C		50^0C		60^0C	
50	1.4	28.0	0.4	8.0	0.3	6.0	0.2	4.0	0.2	3.0
100	2.0	20.0	0.6	6.0	0.5	5.0	0.3	3.0	0.3	2.8
150	2.4	16.0	0.8	5.3	0.7	4.6	0.4	2.6	0.4	2.6
200	2.6	13.0	1.0	5.0	0.8	4.0	0.5	2.5	0.5	2.5
250	3.0	12.0	1.2	4.8	1.0	3.9	0.6	2.4	0.6	2.2
300	3.2	10.6	1.4	4.6	1.1	3.7	0.8	2.3	0.7	2.0
350	3.4	9.7	1.6	4.5	1.2	3.5	0.9	2.1	0.8	1.8
400	3.6	9.0	1.7	4.2	1.3	3.2	1.2	2.0	0.9	1.6
450	3.7	8.2	1.8	4.0	1.4	3.0	1.3	1.8	1.0	1.3
500	3.9	7.8	1.9	3.8	1.6	2.8	1.4	1.6	1.2	1.0

Experiments using the cold finger were continued by exposing the oil sample to ultrasonic waves for 15 minutes, and the results are presented in Fig. 2.

Subsequently, experiments using the cold finger continued with the application of the optimal concentration of the «Difron-3970» depressant additive (700 g/t) to the oil sample, and the results are presented in Fig. 3.

Subsequently, experiments with the cold finger continued, subjecting the oil sample to the combined effect of the «Difron-3970» depressant additive and ultrasonic waves. The results are shown in Fig. 4.

Based on the results of multiple cold-finger experiments under laboratory conditions, the effects of ultrasonic waves, the «Difron-3970» depressant additive, and their combined application on paraffin sedimentation were calculated as percentages and plotted in graphs.

Figure 5 shows the effect of ultrasonic waves on paraffin sediments after exposure times of 5, 10, and 15 minutes. The effectiveness of ultrasonic waves in reducing paraffin sedimentation increases with longer exposure times. Specifically, ultrasound treatment reduced the amount of sediment by 36% after 5 minutes, 42% after 10 minutes, and 55% after 15 minutes.

Figure 6 illustrates the effect of varying concentrations of the «Difron-3970» depressant additive (200, 300, 400, 500, 600, and 700 g/t) on paraffin sedimentation. As shown, the effectiveness of the additive in inhibiting paraffin deposition increases with its concentration, up to a certain threshold. Specifically, the additive demonstrates increasing efficiency within the range of 200–700 g/t. Although not depicted in the graph, further increases beyond 700 g/t do not result in significant improvements. Therefore, the optimal concentration of the «Difron-3970» additive is determined to be 700 g/t. The observed effectiveness at different concentrations is as follows: 38% at 200 g/t, 48% at 300 g/t, 60% at 400 g/t, 68% at 500 g/t, 78% at 600 g/t, and 85% at 700 g/t.

Figure 7 presents the results of the combined effect of the «Difron-3970» depressant additive and ultrasonic waves on paraffin sedimentation in high-paraffin oil samples. In the combined method, the optimal ultrasound exposure time was set at 10 minutes, and the optimal concentration of the depressant additive was 500 g/t. As seen in the figure, under a constant ultrasound exposure time of 10 minutes, the effectiveness of the depressant in reducing paraffin sedimentation increased with its concentration: 52% at 100 g/t, 68% at 200 g/t, 75% at 300 g/t, 88% at 400 g/t, and 96% at the optimal concentration of 500 g/t.

Furthermore, the study examined the impact of ultrasonic waves, the «Difron-3970» depressant additive, and their combined application on the freezing point of the investigated oil sample, following the established methodology. The experimental results are presented in Tables 8, 9, and 10.

The synergistic effect observed from the combined application of ultrasonic waves and the «Difron-3970» depressant additive on high-paraffin oil can be attributed to complementary physicochemical mechanisms. Ultrasonic treatment generates cavitation, causing intense local shear forces and microstreaming that disrupt paraffin crystal nucleation and aggregation [13]. This process increases the surface area and alters the morphology of paraffin crystals, facilitating more effective adsorption of the depressant additive molecules onto crystal surfaces. Consequently, the additive further inhibits crystal growth and aggregation by modifying

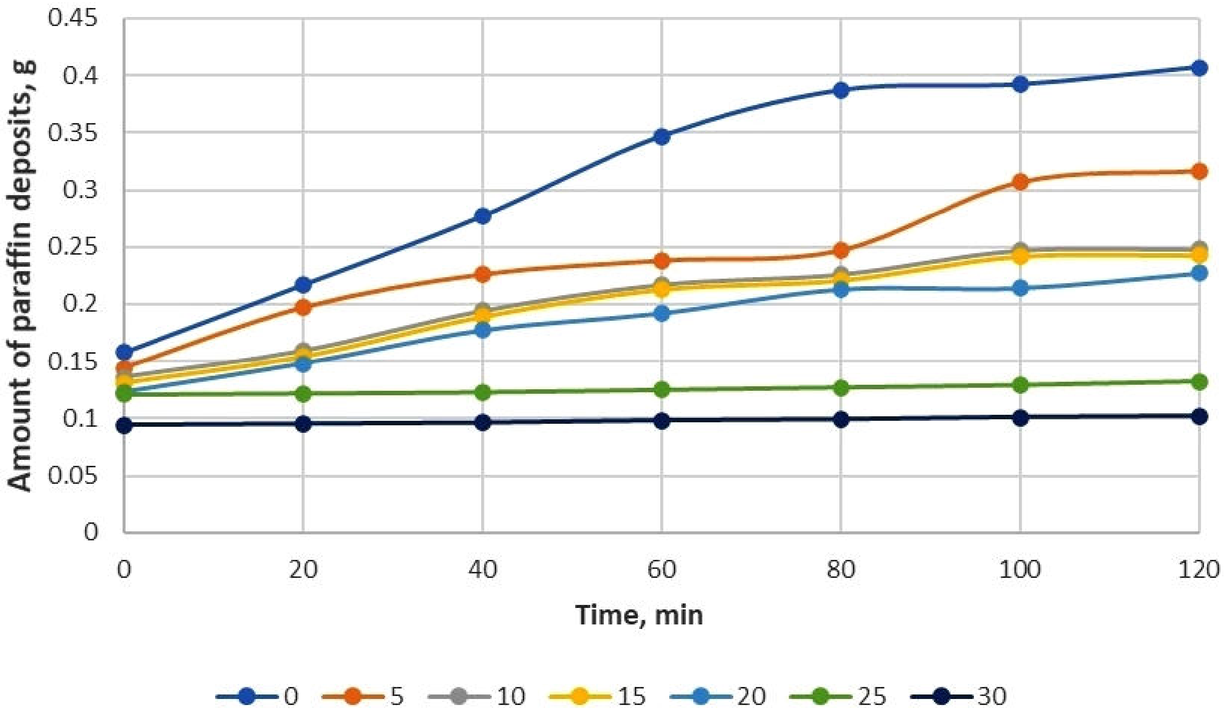

Fig. 1. Amount of sediment accumulated on the surface of the cold finger from the investigated oil sample without external influence

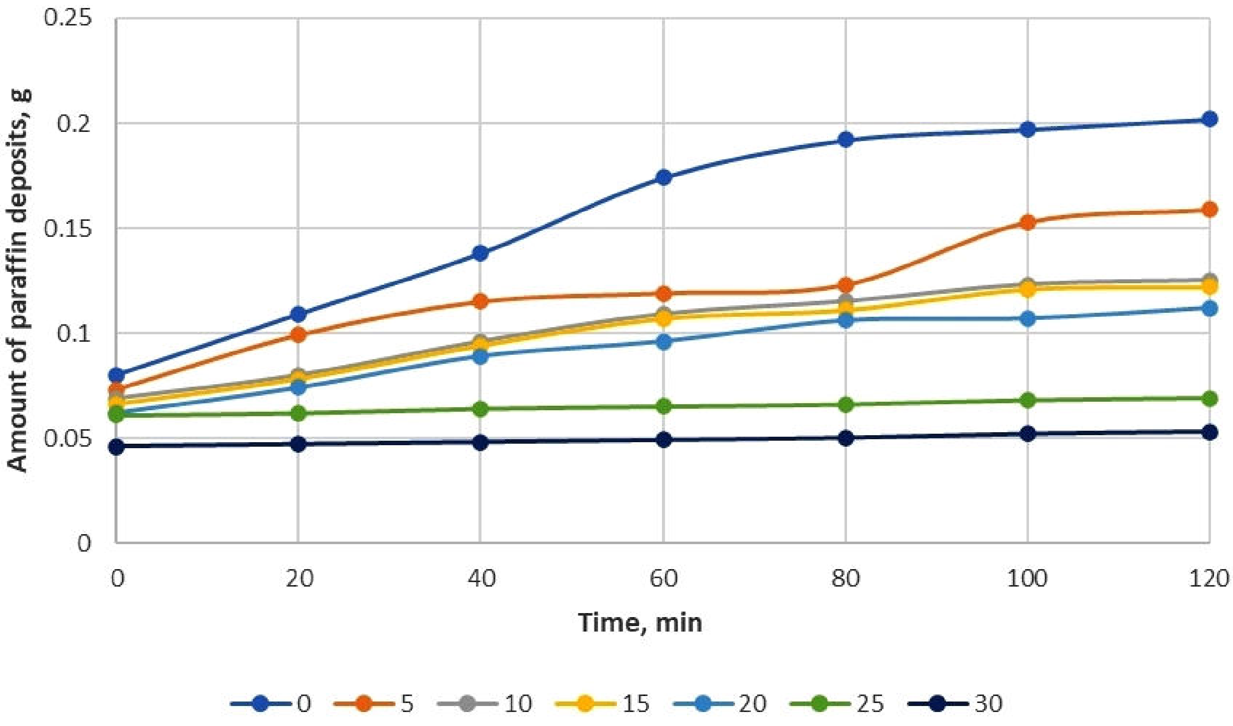

Fig. 2. Amount of paraffin sediment collected on the surface of the cold finger after ultrasonic treatment (15 min exposure)

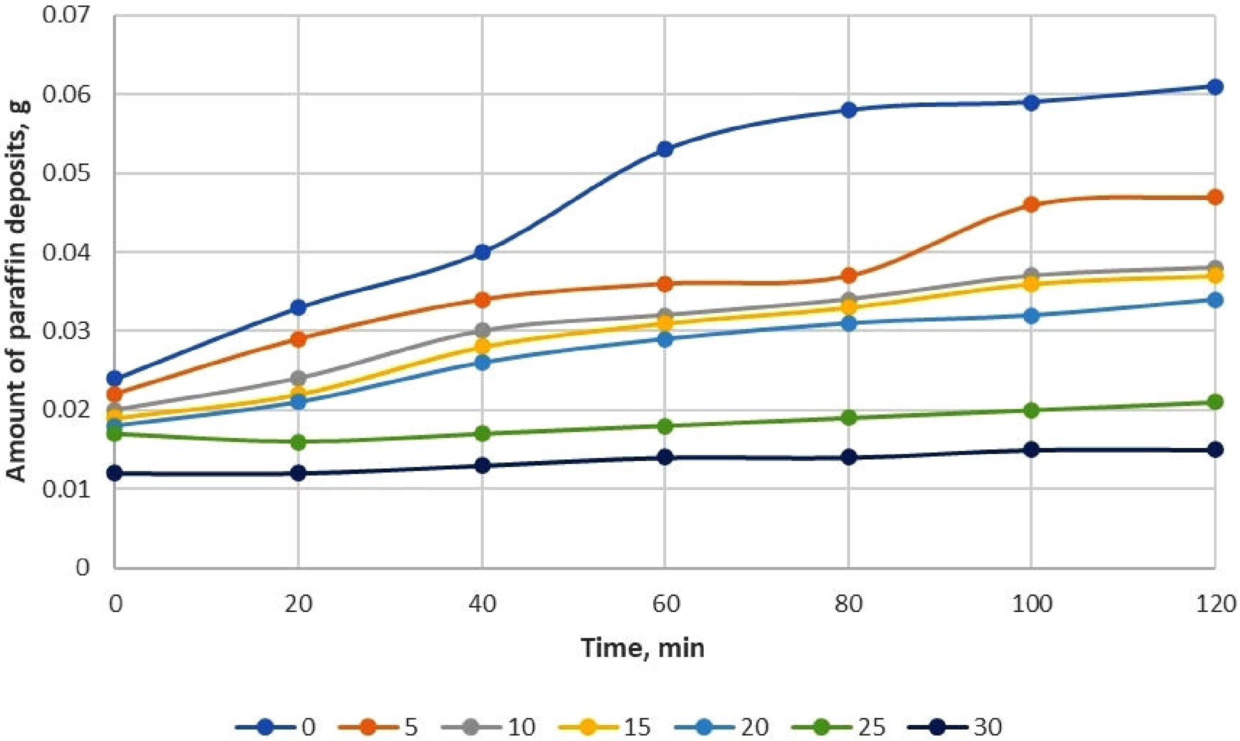

Fig. 3. Amount of paraffin sediment collected on the surface of the cold finger after applying the optimal concentration (700 g/t) of the «Difron-3970» additive

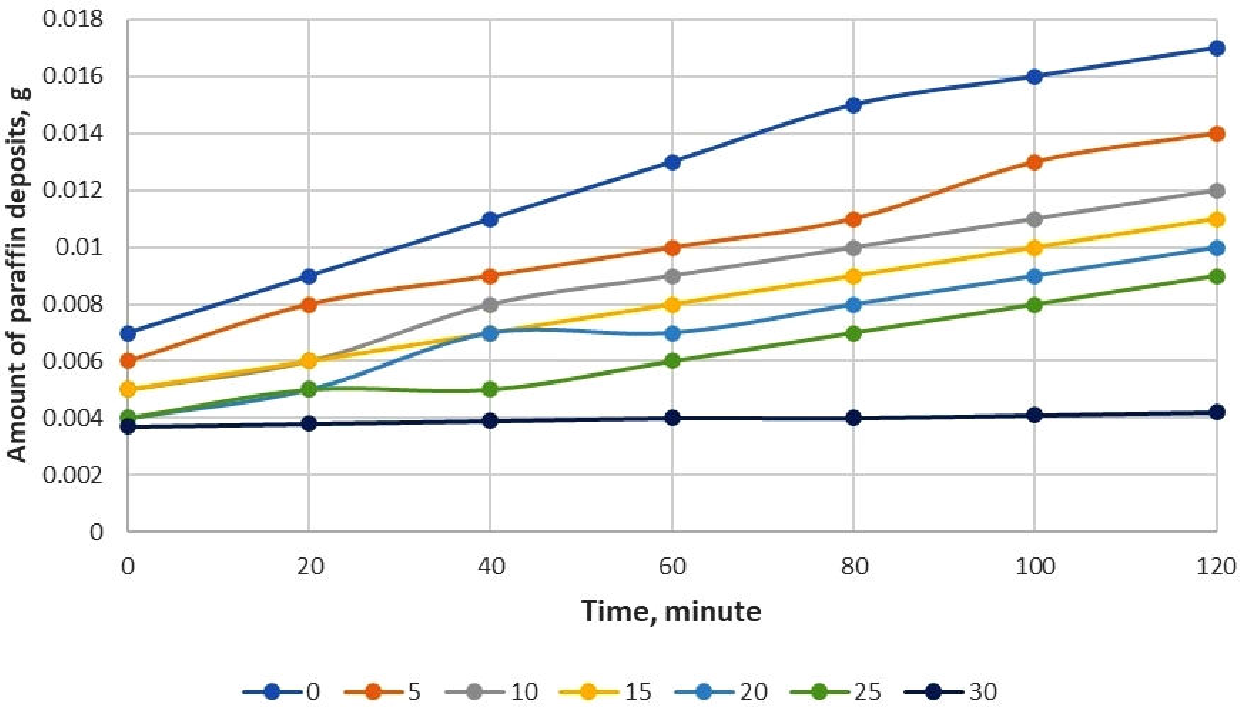

Fig. 4. Amount of paraffin sediment collected on the surface of the cold finger after combined treatment with the «Difron-3970» additive (500 g/t) and ultrasound (10 min)

crystallization kinetics. This combined physical-chemical action leads to more efficient prevention of paraffin deposition than either method alone.

Thus, a comparative analysis of the results obtained from the individual and combined effects of physical and chemical methods on key rheological parameters of the high-paraffin oil sample under laboratory conditions demonstrates that the combined physical-chemical approach is significantly more effective and economically advantageous than the application of these methods separately.

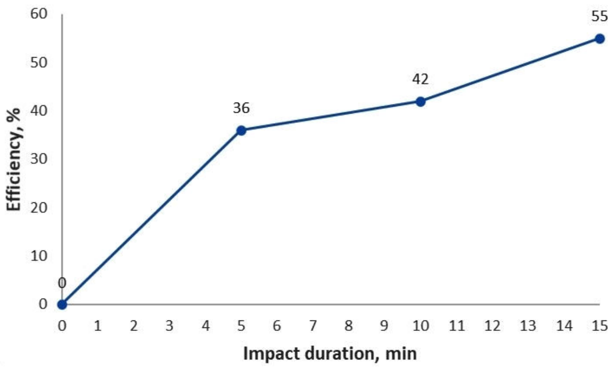

Fig. 5. Effect of ultrasonic wave exposure duration on paraffin sedimentation

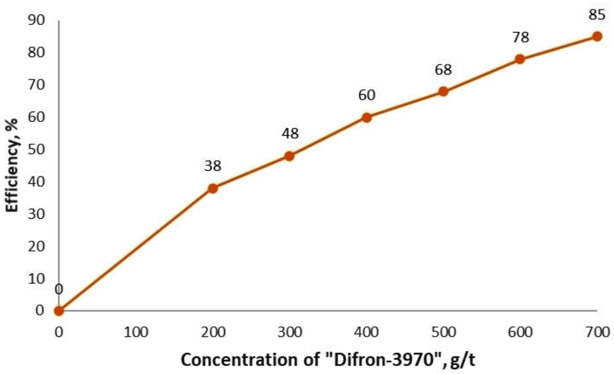

Fig. 6. Effect of the «Difron-3970» depressant additive on paraffin sedimentation

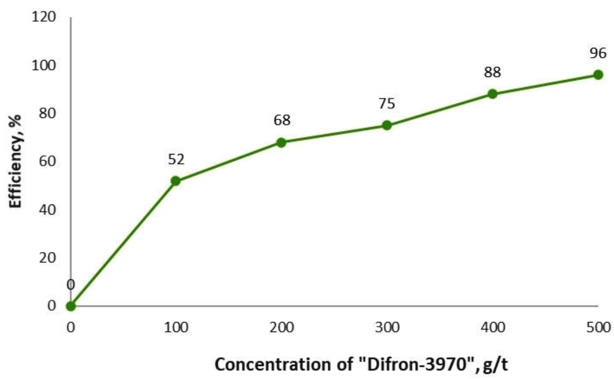

Fig. 7. Combined effect of the «Difron-3970» depressant additive and ultrasonic waves on paraffin sedimentation in high-paraffin oil samples (reagent concentration of 500 g/t and ultrasound exposure of 10 minutes)

Conclusions

1. For the first time, the effects of physical and chemical methods, both individually and combined, on the rheological properties of a high-paraffin oil sample were investigated under laboratory conditions. Ultrasound waves served as the physical method, while the «Difron-3970» depressant additive was employed as the chemical method. Based on extensive experimental data, the optimal exposure times and additive concentrations were identified. The optimal ultrasound exposure time is 15 minutes for individual treatment and 10 minutes for combined treatment, whereas the optimal depressant dosage is 700 g/t for

Table 8

Effect of ultrasound treatment on the freezing temperature of oil

Ultrasound exposure time, min	Freezing temperature of the oil, ^{0}C
0	18
5	11
10	9.6
15	7.2

Table 9

Effect of «Difron-3970» additive on the freezing temperature of oil

Concentration of "Difron-3970", g/t	Freezing temperature of the oil, ^{0}C
0	18
200	10.2
300	8.3
400	6.7
500	4.8
600	3.9
700	2.8

Table 10

Effect of «Difron-3970» additive combined with ultrasound treatment on the freezing point of oil

Concentration of "Difron-3970", g/t	Freezing temperature of the oil, ^{0}C
0	18
100	7.6
200	4.8
300	2
400	–3
500	–6

individual use and 500 g/t for combined application.

2. It was established that the greatest reduction in dynamic viscosity of the oil sample at both low and high temperatures occurs during the combined application of ultrasound waves and the depressant additive, compared to their separate effects.

3. The effectiveness of ultrasound waves in reducing paraffin deposition at the optimal exposure time is 55%, with a 60% reduction in the oil's freezing point. The «Difron-970» additive, at its optimal dosage, achieves 85% effectiveness against paraffin deposition and 84.4% effectiveness in lowering the freezing point. Under combined treatment conditions, these values increase significantly to 96% and 165%, respectively.

4. The enhanced effectiveness observed during combined treatment is likely due to synergistic physicochemical effects: ultrasound promotes dispersion and reduces paraffin crystal size, facilitating the depressant's action by improving its interaction with paraffin molecules and inhibiting crystal growth more efficiently.

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ДОСЛІДЖЕННЯ ВПЛИВУ РІЗНИХ МЕТОДІВ НА РЕОЛОГІЧНІ ВЛАСТИВОСТІ ВИСОКО-ПАРАФІНОВОЇ НАФТИ

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У статті вперше представлено результати комплексних лабораторних експериментів, у яких досліджено індивідуальний та комбінований вплив фізичних і хімічних методів на реологічні властивості зразка високо-парафінової сирої нафти з Наріманівського родовища ДК SOCAR. Як фізичний метод використовували ультразвукові хвилі, а як хімічний – депресорну присадку «Difron-3970». Результати експериментів показали, що оптимальний час дії ультразвуку становив 15 хвилин при окремому застосуванні та 10 хвилин у комбінації з хімічним методом. Оптимальна концентрація «Difron-3970» становила 700 г/т при самостійному застосуванні та 500 г/т у комбінації. Оцінювався вплив ультразвукових хвиль і «Difron-3970» – окремо та в поєднанні – на межу плинності, динамічну в'язкість, випадання парафіну та температуру застигання нафти. Найвища ефективність була досягнута при їх одночасному застосуванні. За умов комбінованої обробки динамічна в'язкість нафти значно зменшилася, досягнувши мінімального значення. Крім того, температура застигання знизилася до від'ємного значення, а кількість асфальтено-смоло-парафінових відкладень була мінімізована. У дослідженні запропоновано застосовувати цей економічно та екологічно ефективний комбінований фізико-хімічний метод, зокрема, синергічну дію ультразвукових хвиль з депресорною присадкою «Difron-3970», для обробки високо-парафінових нафт у польових умовах.

Ключові слова: ультразвукові хвилі; фізико-хімічний метод; оптимальний час дії; оптимальна концентрація; метод «холодного пальця»; ефективність.

INVESTIGATION OF THE EFFECTS OF DIFFERENT METHODS ON THE RHEOLOGICAL PROPERTIES OF HIGH-PARAFFIN OIL

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For the first time, this article presents the results of comprehensive laboratory experiments investigating the individual and combined effects of physical and chemical methods on the rheological properties of a high-paraffin crude oil sample from SOCAR's Narimanov field. Ultrasound waves were employed as the physical method, while the chemical method involved the use of the depressant additive «Difron-3970.» The experiments demonstrated that the optimal exposure time for ultrasound waves was 15 minutes when used alone, and 10 minutes when combined with the chemical method. The optimal concentration of «Difron-3970» was 700 g/t when used independently and 500 g/t in combination. The effects of ultrasound waves and «Difron-3970,» both separately and in combination, on the oil's yield stress, dynamic viscosity, paraffin precipitation, and freezing point were evaluated. The highest efficiency was achieved when both methods were applied together. Under combined treatment, the dynamic viscosity of the oil decreased significantly, reaching its minimum value. Additionally, the freezing point dropped below zero, and the amount of asphaltene-resin-paraffin deposits was minimized. The study proposes the use of this economically and environmentally efficient combined physical-chemical method, specifically, the synergistic action of ultrasound waves with the «Difron-3970» depressant additive, for the treatment of high-paraffin oils under field conditions.

Keywords: ultrasound waves; physical-chemical method; optimal exposure time; optimal concentration; cold finger; efficiency.

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