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The effect of formation temperature and constituent components on rheological parameters of water-oil emulsions

Wpływ temperatury złożowej i elementów składowych na parametry reologiczne emulsji wodno-ropnych

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ABSTRACT: This article investigates the correlation between freezing temperature, viscosity, and oil deposit levels in samples from the Muradkhanli and Surakhany fields, as well as in model oils created under laboratory conditions, both in commodity and emulsion forms. The focus is on the influence of asphaltene-resin-paraffin compounds, the primary components of these samples. Laboratory experiments were conducted at temperatures of 10°C, 20°C, 40°C, and 60°C, utilizing crude oil samples with dilution levels ranging from 5% to 40% for emulsified oil. Freezing temperatures and viscosity values were determined using established standard methods, while the amount of paraffin deposits was assessed through the "Cold finger test" method. Analysis of numerous experiments revealed that freezing temperature, viscosity of water-oil emulsions, and paraffin deposit levels formed on cold surfaces primarily hinge on the temperature of emulsion formation and the water content percentage. It was also observed that water content affects the rheological properties of emulsions formed at 10°C and 20°C, while freezing temperature undergoes minimal changes. An increase in water content leads to heightened viscosity. However, in water-oil emulsions formed at 40°C and 60°C, rheological parameters exhibit different trends. Emulsions formed at 40°C demonstrate maximum freezing temperatures, accompanied by increased asphaltene-resin-paraffin deposits and viscosity across the temperature spectrum. Conversely, water-oil emulsions formed at 60°C exhibit minimal freezing temperatures, deposit content, and viscosity values. Thus, the analysis of water-oil emulsion group composition indicates that these emulsions are mainly stabilized and rendered stable by the presence of asphaltene-resin components.

Key words: Muradkhanli and Surakhany oil fields, model oil, asphaltene, resin, paraffin, emulsion, freezing temperature.

STRESZCZENIE: W artykule przeanalizowano zależność temperatury krzepnięcia, lepkości oraz ilości osadów z ropy naftowej dla próbek pochodzących ze złóż Muradkhanli i Surakhany, oraz modelowej ropy przygotowanej w warunkach laboratoryjnych w postaci surowej i emulsji, w odniesieniu do ilości związków asfaltenowo-żywiczno-parafinowych, które są ich głównymi składnikami. Eksperymenty laboratoryjne przeprowadzono w temperaturach 10, 20, 40 i 60°C, używając próbek ropy naftowej o stopniach rozcieńczenia od 5% do 40% jako zemulgowanej ropy naftowej. Temperaturę krzepnięcia oraz lepkość pobranych próbek ropy naftowej określono za pomocą odpowiednich metod standardowych, natomiast ilość osadów parafinowych oznaczono metodą "Cold finger test". Analiza wyników licznych eksperymentów wykazała, że temperatura krzepnięcia, lepkość emulsji wodno-ropnych oraz ilość osadów parafinowych na zimnych powierzchniach zależą głównie od temperatury tworzenia emulsji oraz procentowej zawartości wody. Badania wykazały również, że zawartość wody wpływa na wartość właściwości reologicznych emulsji formowanych w temperaturze 10 i 20°C, podczas gdy temperatura krzepnięcia ulega minimalnym zmianom. Wzrost zawartości wody w emulsji prowadzi do wzrostu lepkości. Natomiast emulsje wodno-ropne formowane w temperaturze 40 i 60°C wykazują odmienne tendencje w parametrach reologicznych. Emulsje utworzone w temperaturze 40°C charakteryzują się maksymalnymi temperaturami krzepnięcia, zwiększoną ilością osadów asfaltenowo-żywiczno-parafinowych oraz lepkością w całym zakresie temperatur. Natomiast emulsje wodno-ropne formowane w temperaturze 60°C wykazują minimalne temperatury krzepnięcia oraz minimalną ilość osadów i wartość lepkości. Zatem zgodnie z wynikami analizy składu grupowego emulsji wodno-ropnych ustalono, że badane emulsje są ustabilizowane i stają się trwałe głównie dzięki obecności składników asfaltenowo-żywicznych.

Słowa kluczowe: złoża ropy naftowej Muradkhanli i Surakhany, ropa modelowa, asfalten, żywica, parafina, emulsja, temperatura krzepnięcia.

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Introduction

During oil extraction and transportation, water-oil emulsions form under fluctuating temperatures of the oil flow, resulting in increased viscosity and the formation of asphaltene, resin, and paraffin deposits (ARPD). Research findings present conflicting evidence regarding the intensity of ARPD formation in response to variations in oil dilution levels. This discrepancy highlights the complex, multi-component nature of ARPD, necessitating thorough investigation into its composition and quantity during oil production and transportation processes. Surprisingly, no prior studies have explored the influence of temperature on emulsion formation relative to ARPD content and quantity. The temperature of oil flow can impact the rheological properties of high-paraffin oils differently, depending on the structural conditions that lead to the formation of a paraffin layer around the resin asphaltenes. As temperature decreases in paraffin oils, an increase in the number of crystallization centers prompts the growth of small crystalloids and the formation of polycrystalline aggregates, affecting fluidity. The onset of crystallization and paraffin hydrocarbon deposition is contingent upon the chemical properties and concentration of asphaltenes. In aliphatic-type asphaltenes, numerous aliphatic chains interact with alkanes, hindering crystal growth. These paraffins, primarily composed of straight chains and possessing few radicals, exhibit limited ability to serve as crystallization centers (Glushchenko, 2007; Khidr, 2011).

Conversely, as the content of asphaltenes and resins in the oil increases, the temperature at which paraffin hydrocarbon crystals form rises, and the surface of the crystals undergoes deformation, leading to the creation of new crystallization centers. Aromatic-type asphaltenes weaken the interaction between paraffin and asphaltene, thereby impeding the nucleation process and the growth of the crystal network (Jennings and Weispfennig, 2005).

As temperature decreases, paraffins adopt a dispersed gel structure, causing a significant spike in viscosity. Meanwhile, asphaltenes tend to form gel-like structures, even in lower temperature environments, further elevating oil viscosity and inducing non-Newtonian flow. Resins and aromatic hydrocarbons effectively contribute to increased viscosity across a wider temperature range. The rheological properties of emulsions formed by paraffin oils are influenced not only by the quantity and chemical properties of their components but also by the volume content of the water phase and the size of water globules. At temperatures exceeding the initial temperature of paraffin crystallization, emulsions comprising oils with minimal water phase content demonstrate Newtonian fluid characteristics. However, increased interaction with water globules as water content rises leads to the development of anomalous viscosity (Bakhtizin et al., 2016; Matiyev et al., 2016). The structural changes occurring with decreasing temperature in paraffin oil and emulsions result in alterations in rheological properties during both deformation and quiescence. Structural hysteresis is observed during both the increase in velocity gradient and the cessation of deformation. Due to insufficient understanding of the mechanism behind structure formation involving asphaltenes, resins, and high molecular weight paraffins in emulsions, unresolved issues persist in the production, transportation, and treatment of oil. Therefore, investigating the influence of temperature on the structural and mechanical properties of water-oil emulsions during their formation holds significant relevance. Such research can facilitate the prediction and regulation of emulsions during oil extraction and transportation processes (Tolonsky et al., 2003; Mingalev et al., 2022). The annual increase in water content in the exploited fields of Azerbaijan presents significant challenges to the oil industry. Beyond corrosion risks to pipelines and equipment, the formation water present in oil also influences changes in the rheological properties and overall quality of the oil. The concentration and viscosity attributes of the emulsion play a crucial role in determining the most effective transportation method for the product. Elevated viscosity levels result in greater hydraulic resistance within pipelines and increased power consumption of pumping units during transportation, thus adversely affecting the economic efficiency of product transportation and processing (Wilde, 2009; Shardina, 2015).

The calculation of viscosity properties in water-oil emulsions is essential not only for assessing transportation efficiency but also for subsequent hydraulic calculations necessary when examining other pipeline parameters. Precise viscosity characterization is a critical aspect of transportation analysis. Identifying effective formulas for determining the theoretical viscosity of oil-water emulsions with minimal errors is a significant concern within the oil industry. It's important to note that the dynamic viscosity of oil-water emulsions does not conform to the additivity property and cannot be calculated as the sum of the viscosities of oil and water (Mukhamadiev and Notov, 2008; Nebogina et al., 2008).

The rheological properties of an emulsion are influenced by various factors, including dynamic viscosity, temperature, pressure, oil viscosity, velocity vector, water content, dispersion, and droplet diameter. While numerous studies have investigated the impact of these factors, the influence of asphaltene-resin--paraffin compounds on viscosity and dilution in oil emulsions remains largely unexplored (Khairov, 1996; Neobogina et al., 2018). Due to the scarcity of adequate data in scientific research, examining the influence of the conditions under which water-oil emulsions form on their structural and mechanical properties holds significant relevance. Such research endeavors will aid in predicting processes during the extraction and transportation of emulsions. The objective of this study is to investigate the impact of temperature on the formation of deposits in oil-water emulsions at various dilution degrees, as well as their rheological properties (Nurullayev et al., 2022, 2023).

Research methodology

The freezing temperature of the oil was determined under laboratory conditions following the PD 39-3-812-82 methodology (RD 1983). The assessment of paraffin content in the oil employed a method involving adsorption and extraction, wherein a solvent was added to the oil. Concurrently, the content of resin and asphaltenes in silica gel was determined. To determine the quantity of asphaltene-resin-paraffin deposits (ARPD) deposited from high-paraffin oil, experiments were conducted both with and without reagents, utilizing the "Cold finger test" method. This method is instrumental in evaluating reagent efficiency and determining optimal consumption rates. It operates on the principle of precipitating ARPD from moving oil onto a cold metallic surface. The experiments involved measuring the mass of oil deposits accumulated on the surface of a "cold tube" at temperatures of 10°C, 20°C, 30°C, and 40°C using an analytical scale. The asphaltene component's mass fraction in oil deposition was determined by separating asphaltenes via Golden's "Cold finger test" method, while resin substances were analyzed using the chromatography (calon-adsorption) method. The research involved determining the freezing temperature and the mass of asphaltene-resin-paraffin deposits, expressed both in percentage and grams, in samples of both commodity and emulsion oil extracted from the Muradkhanli and Surakhany fields, as well as in model oil. Viscometric analysis was conducted using a "Reotest-2" rotary viscometer.

Analysis and discussion of results

The freezing temperature serves as a crucial parameter in oil systems, influenced by the hydrocarbon content of the oil and the presence of mineral salts in the water phase of water and emulsions. Research on the impact of water-oil emulsion formation conditions has revealed that the temperature at which the emulsion forms significantly affects various structural-mechanical properties, including the freezing temperature. For instance, freezing temperatures for emulsions formed at 10°C and 20°C exhibit slight variations depending on the water content. Emulsions formed at 40°C demonstrate higher freezing temperatures compared to those formed at 10°C and 20°C, as well as compared to the initial oil. Conversely, during the formation of emulsions at 60°C, the freezing temperature for the investigated system is notably reduced. In the research process, two oil samples with differing rheo-physical-chemical indicators were utilized. Dependencies on the freezing temperature of emulsions for both oil samples in commodity form and at various percentage ratios with formation waters were investigated, with the results presented in Tables 1 and 2.

Table 1. Freezing temperature of Muradkhanli oil emulsion formed under different conditions

Tabela 1. Temperatura krzepnięcia emulsji ropnej ze złoża Muradkhanli powstałej w zróżnicowanych warunkach

Formation temperature [°C]	Freezing temperature [°C]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	+9.5	+11.5	+11.0	+11.5	+11.0	+11.5
20	+9.0	+9.5	+9.0	+9.5	+9.0	+10.5
40	+8.5	+10.5	+13.5	+16.5	+18.0	+19.5
60	+6.5	+7.5	+8.5	+9.0	+9.5	+9.5

Table 2. Freezing temperature of Surakhany oil emulsion formed under different conditions

Tabela 2. Temperatura krzepnięcia emulsji ropnej ze złoża Surakhany powstałej w zróżnicowanych warunkach

Formation temperature [°C]	Freezing temperature [°C]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	–2.0	+3.5	+3.5	+4.0	+4.0	+4.5
20	–3.5	+1.0	+2.0	+2.5	+2.5	+3.0
40	–4.5	+2.0	+2.5	+3.0	+3.0	+3.5
60	–7.0	–6.5	–6.0	–5.5	–5.0	–3.0

Tables 1 and 2 highlight significant differences in component composition between Surakhany and Muradkhanli oils. The conducted research clearly indicates that both oil samples, with differing concentrations and component compositions, also exhibit diversity in terms of hydrocarbon content. While the formation and development of paraffin crystal centers occurs at very high temperatures in Muradkhanli oil, it occurs at low temperatures in Surakhany oil. The emulsions formed by both oil samples with varying percentages of formation water differ from the research findings conducted with commodity oil. This is evidenced by the research conducted on the effect of the water phase remaining in a dispersed form within the oil and its impact on the freezing temperature at different formation temperatures.

In light of these findings, research was conducted to study the effect of the model oil prepared by mixing both oils in a 50% + 50% ratio on freezing temperature, which is one of its rheological parameters, as depicted in Table 3.

Table 3. The freezing temperature of the Muradkhanli + Surakhany (50% + 50%) model oil emulsion under various conditions

Tabela 3. Temperatura krzepnięcia modelowej emulsji ropnej ze złóż Muradkhanli + Surakhany (50% + 50%) w zróżnicowanych warunkach

Formation temperature [°C]	Freezing temperature [°C]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	+10.5	+11.0	+11.0	+11.5	+12.0	+12.5
20	+9.0	+10.0	+9.0	+10.5	+9.5	+11.5
40	+8.5	+10.5	+14.5	+18.5	+19.0	+20.5
60	+7.5	+8.5	+10.5	+10.0	+10.5	+11.5

While the freezing temperature of Surakhany oil is lower and that of Muradkhanli oil is higher, the freezing temperature of the prepared model oil yields higher results than those shown by both oils individually. This discrepancy can be attributed to the mixing of two oil samples with distinct differences in certain percentages. The presence of similar hydrocarbons in the minority causes significant changes in the rheological parameters of the model oil, leading to more anomalous properties. As the model oil, prepared with high-molecular compounds, loses its solubility property in a new dispersed medium, its colloidal property is strengthened, creating favorable conditions for the formation of paraffin crystal lattices. Consequently, turbidity observed when determining the freezing temperature occurs more rapidly, and the model oil loses its fluidity even at favorable temperatures.

Freezing temperature and viscosity are considered crucial factors in decision-making during transportation in complex technological oil systems. The temperature dependences of viscosity for water-in-oil emulsions with different amounts of water formed at 10, 20, 40, and 60°C are provided in Tables 4 and 5.

As observed in Tables 4 and 5, the viscosity of Muradkhanli and Surakhany oils heated to 60°C is very low. Emulsions formed at 40°C exhibit the highest viscosity value, while those formed at 60°C demonstrate the minimum value. Additionally, the viscosity of emulsions formed at 10°C is similar to that of emulsions formed at 20°C. Further research was conducted to

Table 4. Viscosity of Muradkhanli oil emulsion formed under different conditions

Tabela 4. Lepkość emulsji ropnej ze złoża Muradkhanli utworzonej zróżnicowanych warunkach

Formation temperature [°C]	Viscosity [mPa·s]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	314.6	537.2	797.5	1212.1	1598.4	1786.2
20	281.3	492.6	721.8	1103.6	1487.9	1609.4
40	119.8	512.9	854.1	1573.5	1863.1	2157.3
60	76.4	127.4	294.6	438.3	672.4	894.7

Table 5. Viscosity of Surakhany oil emulsion formed under different conditions

Tabela 5. Lepkość emulsji ropnej ze złoża Surakhany utworzonej w zróżnicowanych warunkach

Formation temperature [°C]	Viscosity [mPa·s]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	61.5	70.1	70.8	71.4	71.9	74.5
20	58.8	64.9	68.8	69.2	69.7	70.4
40	49.4	65.2	73.3	74.7	75.2	82.1
60	38.8	41.1	47.8	48.2	49.3	57.3

determine the viscosity of model oil, and the results obtained are presented in table 6.

During the analysis of the results obtained from our research on determining the viscosity of the model oil, we observed a sharp anomaly in viscosity values, similar to the freezing temperature. This anomaly is attributed to the combination of two different oil colloidal systems, where an increase in the solute-to-solvent ratio induces specific changes in viscosity. The increase in the water phase in emulsions correlates with an increase in viscosity, a trend observed across different formation temperatures for all investigated water-oil emulsions. As temperature decreases, oil solubility deteriorates, leading to the formation of paraffin hydrocarbon crystals within the system. Temperature gradients in the medium and oil flow, along with the presence of paraffin hydrocarbons and water in the oil system, contribute to the formation of asphaltene-resin-paraffin deposits (ARPD). The composition and intensity of ARPD formation are influenced by various factors, such as the component composition of oil, decrease in temperature of oil flow, degassing of oil, and water content.

Table 6. Viscosity of Muradkhanli + Surakhany (50% + 50%) oil emulsion formed under different conditions

Tabela 6. Lepkość modelowej emulsji ropnej ze złóż Muradkhanli + Surakhany (50% + 50%) utworzonej w zróżnicowanych warunkach

Formation temperature [°C]	Viscosity [mPa·s]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	345.2	588.3	873.2	1284.3	1699.8	1864.4
20	312.5	504.8	791.2	1177.2	1572.9	1657.9
40	139.2	389.5	916.7	1607.7	1901.6	2231.5
60	96.7	157.1	312.6	555.8	689.1	914.2

Tables 7 and 8 illustrate the effect of water content on the amount of water-oil emulsions at different temperatures. The quantification of ARPD was conducted using a device based on the "Cold finger test" method.

Table 7. Amount of asphaltene-resin-paraffin (ARP) precipitate in Muradkhanli oil emulsion formed under different conditions

Tabela 7. Ilość osadu AŻP w emulsji ropnej ze złoża Muradkhanli utworzonej w zróżnicowanych warunkach

Formation temperature [°C]	Amount of precipitation [g/100 g]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	20.3	30.6	29.1	28.7	24.3	24.1
20	19.7	29.4	27.2	23.4	22.7	22.3
40	31.2	36.3	36.7	36.9	37.2	37.0
60	3.1	6.2	7.3	8.8	10.2	14.8

Table 8. Amount of asphaltene-resin-paraffin (ARP) precipitate in Surakhany oil emulsion formed under different conditions

Tabela 8. Ilość osadu AŻP w emulsji ropnej ze złoża Surakhany utworzonej w zróżnicowanych warunkach

Formation temperature [°C]	Amount of precipitation [g/100 g]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	7.40	7.9	9.1	9.9	10.3	11.1
20	5.90	6.2	7.8	8.3	8.9	9.0
40	2.20	3.5	4.7	5.4	5.6	5.9
60	1.07	1.2	1.8	2.1	2.4	2.8

As observed in the table, the addition of water to the system leads to a 1–5-fold increase in the deposition amount at high temperatures compared to the initial oil. Muradkhanli and Surakhany oils exhibit differences in composition and high molecular weight compounds, despite the notable variations in amounts. Research was conducted to determine the amount of asphaltene-resin-paraffin deposits (ARPD) in the model oil prepared based on the visually observed diversity of oils. The results obtained are reflected in Table 9.

Table 9. The amount of asphaltene-resin-paraffin (ARP) precipitate in the emulsion of Muradkhanli + Surakhany (50% + 50%) oil formed under different conditions

Tabela 9. Ilość osadu AŻP modelowej emulsji ropnej ze złóż Muradkhanli + Surakhany (50% + 50%) utworzonej w zróżnicowanych warunkach

Formation temperature [°C]	Amount of precipitation [g/100 g]					
	refined oil	emulsion (5%)	emulsion (10%)	emulsion (20%)	emulsion (30%)	emulsion (40%)
10	21.6	32.5	32.1	31.6	30.8	29.6
20	20.4	30.8	31.0	28.5	29.7	27.8
40	37.7	38.7	39.5	40.7	42.3	44.2
60	6.1	8.1	8.3	9.3	17.6	24.9

In our research, similar to findings from other studies, we observed higher deposit amounts compared to individual oils. This phenomenon is attributed to changes in composition-structure properties, particularly the lower presence of aromatic hydrocarbons compared to isoprenoid hydrocarbons. Oils with a predominance of aromatic hydrocarbons over paraffin hydrocarbons with a radical structure tend to exhibit relatively low asphaltene-resin-paraffin deposits (ARPD) and dissolve in the oil dispersion medium. However, with an increase in the percentage of saturated hydrocarbons in the oil during intensive mixing, the deposits lose solubility and remain suspended in the oil. Consequently, a higher percentage of deposits was observed in our research.

Tables 10–12 present the results of experiments on the percentage of asphaltenes, resins, and paraffins in Muradkhanli, Surakhany, and model oils, respectively.

The tables demonstrate a noticeable trend: as the water percentage in oils increases, the proportion of paraffins decreases, while the amount of resin and asphaltenes in the deposit increases. This phenomenon occurs because water phases in the oil dispersion medium enhance the stable bonds formed by asphaltenes and resins, thereby creating a stable barrier function around the phases. Consequently, with a higher water percentage, the proportion of asphaltene-resin compounds also increases. Additionally, structures formed by asphaltene-resin high-molecular compounds exhibit thermal stability and characteristic hard decomposition. Consequently, the solubility of these compounds in the emulsion medium is more challenging compared to commodity oils.

Table 10. Group composition of asphaltene-resin-paraffin (ARP) precipitate separated from oil and water-oil emulsions formed by Muradkhanli oil at different temperatures

Tabela 10. Skład grupowy osadu AŻP wydzielonego z emulsji ropnych i wodno-ropnych złoża Muradkhanli powstałych w różnych temperaturach

Refined oil / emulsified oil	Formation temperature [°C]	Amount of mass ratio [%]		
		asphaltenes	paraffin + wax	resins
Refined oil	10	2.6	79.1	18.3
	20	4.2	78.3	17.5
	40	4.9	77.9	17.2
	60	7.1	76.1	16.8
Emulsion (5%)	10	4.1	76.8	19.1
	20	5.3	75.8	18.9
	40	5.7	76.0	18.3
	60	8.1	74.0	17.9
Emulsion (10%)	10	4.3	76.2	19.5
	20	5.6	75.5	18.9
	40	5.9	75.7	18.4
	60	8.4	72.5	19.1
Emulsion (20%)	10	4.3	75.6	20.1
	20	5.8	74.9	19.3
	40	6.2	74.2	19.6
	60	8.4	71.8	19.8
Emulsion (30%)	10	4.5	76.8	18.7
	20	6.1	76.5	17.4
	40	6.4	76.0	17.6
	60	8.6	72.9	18.5
Emulsion (40%)	10	4.7	77.2	18.1
	20	6.2	76.0	17.8
	40	6.7	76.4	16.9
	60	14.9	64.4	20.7

Table 11. Group composition of asphaltene-resin-paraffin (ARP) precipitate separated from oil and water-oil emulsions formed by Surakhany oil at different temperatures

Tabela 11. Skład grupowy osadu AŻP wydzielonego z emulsji ropnych i wodno-ropnych złoża Surakhany powstałych w różnych temperaturach

Refined oil / emulsified oil	Formation temperature [°C]	Amount of mass ratio [%]		
		asphaltenes	paraffin + wax	resins
Refined oil	10	0.5	95.7	3.8
	20	1.1	94.3	4.6
	40	11.0	50.8	38.2
	60	29.4	30.1	40.5
Emulsion (5%)	10	1.7	93.5	4.8
	20	2.3	90.9	6.8
	40	12.7	62.1	25.2
	60	30.6	34.4	35.0

cont. Table 11/cd. Tabela 11

Refined oil / emulsified oil	Formation temperature [°C]	Amount of mass ratio [%]		
		asphaltenes	paraffin + wax	resins
Emulsion (10%)	10	2.4	92.5	5.1
	20	4.9	88.7	6.4
	40	14.1	52.8	33.1
	60	31.4	35.9	32.7
Emulsion (20%)	10	2.7	92.1	5.2
	20	5.2	86.9	7.9
	40	14.8	54.2	31.0
	60	32.0	37.8	30.2
Emulsion (30%)	10	3.1	91.4	5.5
	20	5.5	87.2	7.3
	40	15.3	55.0	29.7
	60	33.1	38.9	28.0
Emulsion (40%)	10	3.6	91.2	5.2
	20	5.9	88.2	5.9
	40	15.7	56.2	28.1
	60	34.5	40.3	25.2

Table 12. Group composition of asphaltene-resin-paraffin (ARP) sediment separated from oil and water-oil emulsions formed by Muradkhanli + Surakhany (50% + 50%) oil at different temperatures

Tabela 12. Skład grupowy osadu AŻP wydzielonego z modelowych emulsji ropnych i wodno-ropnych ze złóż Muradkhanli + Surakhany (50% + 50%) w różnych temperaturach

Refined oil / emulsified oil	Formation temperature [°C]	Amount of mass ratio [%]		
		asphaltenes	paraffin + wax	resins
Refined oil	10	14.9	64.7	20.4
	20	17.2	62.9	19.9
	40	18.4	61.8	19.8
	60	21.1	60.1	18.8
Emulsion (5%)	10	15.6	62.3	22.1
	20	16.0	61.1	20.9
	40	17.5	62.0	20.5
	60	18.1	56.6	25.3
Emulsion (10%)	10	15.9	61.8	20.1
	20	16.6	61.2	22.2
	40	17.2	61.7	21.1
	60	18.4	56.2	25.4
Emulsion (20%)	10	16.0	61.6	22.4
	20	16.4	60.9	22.7
	40	17.1	61.3	21.6
	60	18.6	55.8	25.6
Emulsion (30%)	10	16.3	65.9	17.8
	20	16.9	65.2	17.9
	40	17.5	64.4	18.1
	60	19.2	60.8	20.0
Emulsion (40%)	10	15.7	66.5	17.8
	20	16.1	66.1	17.8
	40	16.7	65.4	17.9
	60	19.5	63.2	17.3

Tables 13, 14, and 15 present detailed information on the quantities of asphaltene, resin, and paraffin components in the oil, measured in grams.

In Surakhany commodity oil at 60°C, the total amount of asphaltene and resin components is 0.43 times greater than the total amount of paraffin hydrocarbons. In the 5% emulsion

Table 13. Group composition of ARP precipitate separated from oil and water-oil emulsions formed by Muradkhanli oil at different temperatures

Tabela 13. Skład grupowy osadu AŻP wydzielonego z emulsji ropnych i wodno-ropnych utworzonych przez ropę ze złoża Muradkhanli w różnych temperaturach

Refined oil / emulsified oil	Formation temperature [°C]	Mass ratio quantity [g/100 g]		
		asphaltenes	paraffin + wax	resins
Refined oil	10	0.52	16.10	3.70
	20	0.80	15.43	3.45
	40	1.50	24.30	5.40
	60	0.20	2.40	0.50
Emulsion (5%)	10	1.30	23.70	5.90
	20	1.60	22.30	5.56
	40	2.10	27.59	6.64
	60	0.50	4.59	1.11
Emulsion (10%)	10	1.25	22.17	5.67
	20	1.50	20.54	5.14
	40	2.17	27.78	6.75
	60	0.61	5.29	1.39
Emulsion (20%)	10	1.23	21.70	5.77
	20	1.36	17.53	4.52
	40	2.29	27.38	7.23
	60	0.74	6.32	1.74
Emulsion (30%)	10	1.10	18.66	4.50
	20	1.38	17.37	3.95
	40	2.38	28.27	6.55
	60	0.88	7.44	1.88
Emulsion (40%)	10	1.13	18.61	4.36
	20	1.38	16.95	3.97
	40	2.48	28.27	6.25
	60	2.21	9.53	3.07

Table 14. Group composition of asphaltene-resin-paraffin (ARP) precipitate separated from Surakhany oil and water-oil emulsions at different temperatures

Tabela 14. Skład grupowy osadu AŻP wydzielonego z emulsji ropnych i wodno-ropnych utworzonych przez ropę ze złoża Surakhany w różnych temperaturach

Refined oil / emulsified oil	Formation temperature [°C]	Mass ratio quantity [g/100 g]		
		asphaltenes	paraffin + wax	resins
Refined oil	10	0.037	7.08	0.28
	20	0.060	5.56	0.27
	40	0.240	1.18	0.84
	60	0.310	0.32	0.43
Emulsion (5%)	10	0.130	7.39	0.38
	20	0.140	5.64	0.42
	40	0.440	2.17	0.88
	60	0.370	0.41	0.42

cont. Table 14/cd. Tabela 14

Refined oil / emulsified oil	Formation temperature [°C]	Amount of mass ratio [%]		
		asphaltenes	paraffin + wax	resins
Emulsion (10%)	10	0.22	8.42	0.46
	20	0.38	6.92	0.50
	40	0.66	2.48	1.55
	60	0.57	0.65	0.59
Emulsion (20%)	10	0.27	9.12	0.51
	20	0.43	7.20	0.66
	40	0.80	2.93	1.67
	60	0.67	0.79	0.63
Emulsion (30%)	10	0.32	9.41	0.57
	20	0.49	7.76	0.65
	40	0.86	3.08	1.66
	60	0.79	0.94	0.67
Emulsion (40%)	10	0.40	10.10	0.58
	20	0.53	7.94	0.53
	40	0.93	3.32	1.57
	60	0.97	1.13	0.71

Table 15. Group composition of asphaltene-resin-paraffin (ARP) precipitate separated from oil and water-oil emulsions formed by Muradkhanli + Surakhany (50% + 50%) oil at different temperatures

Tabela 15. Skład grupowy osadu AŻP wydzielonego z emulsji ropnych i wodno-ropnych utworzonych przez modelową ropę ze złóż Muradkhanli + Surakhany (50% + 50%) w różnych temperaturach

Refined oil / emulsified oil	Formation temperature [°C]	Mass ratio quantity [g/100 g]		
		asphaltenes	paraffin + wax	resins
Refined oil	10	3.22	13.97	4.41
	20	3.51	12.83	4.06
	40	6.94	23.30	7.46
	60	1.29	3.67	1.15
Emulsion (5%)	10	5.07	20.25	7.18
	20	4.93	18.82	6.44
	40	6.77	23.99	7.94
	60	1.47	4.58	2.05
Emulsion (10%)	10	5.10	19.84	6.45
	20	5.15	18.97	6.88
	40	6.94	24.37	8.34
	60	1.53	4.67	2.11
Emulsion (20%)	10	5.06	19.47	7.08
	20	4.67	17.36	6.47
	40	17.10	61.30	6.96
	60	1.73	5.19	2.38
Emulsion (30%)	10	5.03	20.30	5.48
	20	5.02	19.36	5.32
	40	7.40	27.24	7.66
	60	3.38	10.70	3.52
Emulsion (40%)	10	4.65	18.49	5.27
	20	4.48	18.38	4.95
	40	3.27	28.91	7.92
	60	4.86	15.74	4.31

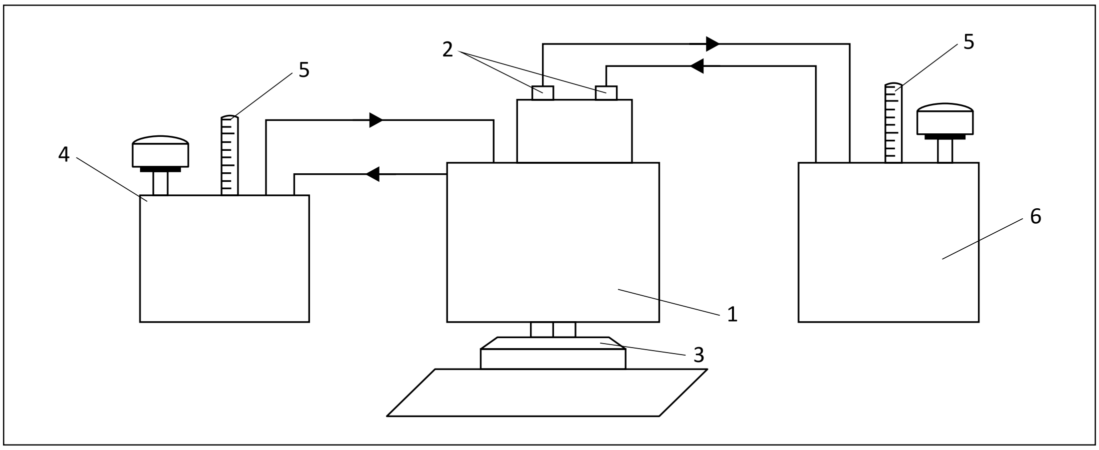

Figure 1. The principle diagram of the special device for the determination of paraffin deposition by "Cold finger test" method: 1 – dual vessel, 2 – cold finger, 3 – mixer, 4 – heater, 5 – thermometer, 6 – refrigerator

Rysunek 1. Schemat zasady działania specjalnego urządzenia do badania wytrącania osadów pafarinowych metodą „*Cold finger test*": 1 – naczynie dwuwarstwowe, 2 – „*cold finger*", 3 – mieszalnik, 4 – grzałka, 5 – termometr, 6 – chłodziarka

Surakhany oil, this quantity is 0.51 times greater, while in the 10% emulsion, it is 0.57 times greater. Similarly, in the 20% emulsion, the asphaltene and resin components are 0.61 times greater than the total amount of paraffin hydrocarbons. For the 30% emulsion, this quantity is 0.64 times greater, and in the 40% emulsion, it is 0.68 times greater.

The quantity of asphaltene and resin components in the model commodity oil is 1.51 times less than the total amount of paraffin components. In the 5% emulsion model oil, the combined amount of asphaltene and resin components is 1.3 times less than the total amount of paraffin hydrocarbons. Similarly, in the 10% emulsion model oil, this quantity is 1.29 times less, while in the 20% emulsion model oil, it is 1.27 times less. For the 30% emulsion model oil, the asphaltene and resin components are 1.56 times less than the total paraffin hydrocarbons, and in the 40% emulsion model oil, this amount is 1.72 times less.

The Figure 1 illustrates the schematic diagram of the device utilized for determining asphaltene-resin-paraffin deposits (ARPD) based on the "Cold finger test" method.

Conclusion

1. The study investigated the dependence of freezing temperature, viscosity, and the amount of oil deposits in samples from the Muradkhanli and Surakhany fields as well as model oils in both commodity and emulsion forms, on the asphaltene-resin-paraffin compounds, their primary components. Laboratory experiments were conducted at temperatures of 10°C, 20°C, 40°C, and 60°C using crude oil samples with water contents ranging from 5% to 40% for emulsified oil.
2. The freezing temperature of water-oil emulsions, viscosity, and the quantity of paraffin deposits formed on cold surfaces were found to predominantly depend on the temperature of emulsion formation and the percentage of water content.
3. It was observed during the research that the amount of water has a more significant impact on the rheological properties of emulsions formed at 10°C and 20°C compared to the temperature itself, while the freezing temperature shows minimal variation.
4. Emulsions formed at 40°C exhibited the highest freezing temperatures, accompanied by increased asphaltene-resin--paraffin deposits and viscosity across the temperature range. Conversely, water-oil emulsions formed at 60°C displayed minimal freezing temperatures, deposits content, and viscosity values.
5. Based on the analysis of the component composition of water-oil emulsions, it was concluded that the stability of the investigated emulsions is primarily attributed to the presence of asphaltene-resin components.

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