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INVESTIGATING CRUDE OIL BLEND INCOMPATIBILITY AND ASSOCIATED BALLAST PRECIPITATION

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Recent research has highlighted specific challenges associated with blending different types of crude oil. Chief among these is the incompatibility of certain crude oil mixtures, which can result in the clogging – and in some cases, shutdown – of field gathering pipeline systems. A key factor contributing to this incompatibility is the presence of solid organic compounds, particularly resins and asphaltenes, which tend to precipitate from solution when incompatible crude oils are mixed. These substances, collectively referred to as ballasts, pose significant operational risks. To investigate the impact of crude oil blending on quality parameters, various crude oil samples and their mixtures were analyzed under laboratory conditions. The results revealed nonlinear deviations in the physical and chemical properties of the mixtures, with pronounced anomalies in quality indicators. Notably, the concentration of ballasts such as resins and asphaltenes did not conform to the expected additive behavior. The study also examined the kinetics of precipitation of ballast materials, including resins, asphaltenes, paraffins, water, salts, and mechanical impurities, in incompatible crude oil blends. It was observed that the majority of ballast deposition occurs within 8 to 10 hours of mixing. These findings underscore that the formation of incompatible mixtures, driven by the chemical composition of the constituent oils, can lead to rapid and intensive precipitation of various ballast materials.

Keywords: crude oil mixing, physical and chemical properties, mechanical mixtures, ballast deposition, asphaltenes.

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Introduction

In the oil and gas industry, the mixing of different types of crude oil and petroleum products is a common occurrence during extraction, transportation, and storage. This blending often happens in collector-discharge systems, pipelines, and storage tanks. Typically, mixing occurs at the interface zones or within designated mixing tanks when different products are transported consecutively through the same pipeline.

In oil fields, mixing can also result from a shortage of storage tanks, leading to the combination of oils with varying properties in a single tank. This practice can significantly affect the quality characteristics of the final product and complicate accurate measurement and inventory control. Such situations frequently lead to discrepancies in accounting during the transfer and receipt of oil.

Recent observations indicate that certain oil mixtures can exhibit unexpected and sharp changes

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in physical properties such as density, viscosity, and volume. These changes are often associated with the kinetics of chemical sedimentation, including the deposition of ballast substances, which is of considerable practical importance in oil processing and quality management [1–3].

It is well established that the configuration of oil transportation networks and the geographical distribution of production sites often prevent crude oil from reaching refineries or consumption points with its original quality characteristics preserved. The infrastructure of both in-field gathering systems and main trunk pipelines is typically designed to handle crude oil in blended form, rather than maintaining the integrity of individual oil streams. As a result, mixing of different crude types during transport is not only common but often unavoidable.

However, this blending process introduces a range of technical and operational challenges. One of the most critical issues is the formation of «undesirable» mixtures –combinations of crude oils that are chemically incompatible or unstable. These mixtures can lead to serious consequences, including the fouling and contamination of vital equipment such as pipelines, storage tanks, heat exchangers, furnaces, and distillation columns. In extreme cases, the accumulation of deposits and chemical residues can result in complete system shutdowns, causing significant operational disruptions and financial losses.

Research has identified the presence of organic solids, particularly precipitated asphaltenes, as a major contributor to the instability of certain crude oil mixtures. Asphaltenes are complex, high-molecular-weight components that are soluble in aromatic solvents like toluene but insoluble in paraffinic solvents such as n-pentane. When crude oils with differing chemical compositions are mixed, the solubility balance of asphaltenes can be disrupted, leading to their precipitation as solid sediments. These sediments not only degrade the quality of the oil but also pose serious risks to equipment integrity and process efficiency.

Despite ongoing efforts to develop practical and cost-effective methods for blending various crude oils, the challenges associated with asphaltene behavior remain unresolved. The unpredictability of their precipitation and the difficulty in controlling their concentration make them a persistent problem in oil handling and processing.

Recent scientific investigations suggest that the non-linear deviations observed in the physical and chemical properties of crude oil mixtures, when compared to idealized models, are likely due to structural transformations occurring at the nanoscale. Specifically, the behavior of oil nanophases, which are microscopic domains within the fluid matrix, appears to play a crucial role in determining mixture stability. Asphaltenes tend to exhibit problematic behavior at concentrations that correspond to the boundaries of these nanophases, where phase separation and aggregation are most likely to occur [4–8].

Understanding the mechanisms behind these transformations is essential for improving the predictability and control of crude oil blending operations. Further research into the molecular dynamics of oil nanostructures and the thermodynamic conditions that trigger asphaltene precipitation could pave the way for more reliable and efficient blending strategies in the oil and gas industry.

Current models used to simulate and analyze the behavior of crude oil mixtures during transportation and processing remain limited in their predictive capabilities. Specifically, they lack the precision required for reliable engineering calculations when it comes to forecasting changes in the quality parameters of blended oils. This shortfall underscores the need for refining existing models and introducing enhanced criteria to evaluate both «undesirable» and «optimal» concentrations of asphaltenes and other high-molecular-weight compounds.

Such improvements must account for the complex interactions between individual chemical components within transported oil mixtures. These interactions can significantly influence the stability, flow behavior, and overall performance of the blend, especially under varying temperature and pressure conditions encountered during pipeline transport and storage.

To better understand how the mixing of different crude oils affects their rheological and physicochemical properties, a series of laboratory experiments were conducted using oil samples sourced from various fields [9–12]. In particular, crude oils from the Bulla (BO) and Garachukhur (GO) fields in Azerbaijan were selected for detailed analysis, along with mixtures derived from these sources.

The study aimed to observe how blending influences key parameters such as viscosity, density, phase stability, and sedimentation tendencies. By comparing the properties of individual crude oils with those of their mixtures, researchers sought to identify patterns of behavior that could inform future modeling efforts and operational strategies.

Experimental

The physicochemical characteristics of the BO and GO crude oils, along with the methodologies employed in the experimental analysis, are summarized in Table 1. The data collected serves as a foundation for evaluating the compatibility of different crude types and for developing more accurate predictive tools to

guide blending operations in the field.

As shown in Table 1, the crude oil samples from the Bulla (BO) and Garachukhur (GO) fields exhibit notable differences in their rheological and physicochemical properties. These distinctions reflect the unique geological and compositional characteristics of each field, which in turn influence the behavior of the oils during blending and transport.

Results and discussion

Experimental analysis of mixtures derived from BO and GO oils revealed that the quality of the resulting blend does not follow a linear trend, regardless of the sequence in which the oils are combined. Whether the BO oil is added to GO or vice versa, the resulting mixtures, denoted as (GO+BO) and (BO+GO), display nonlinear deviations in key quality indicators. These anomalies suggest complex interactions between the constituent components, which cannot be accurately predicted using simple additive models [13,14].

To further investigate these effects, a series of tests were conducted to determine how the physicochemical properties of the oil mixture vary with changes in the mass fraction of BO oil. The results of these measurements are presented in Table 2.

Using the data from Table 2, a set of functional relationships was established to describe how each property changes as the proportion of BO oil in the mixture increases. These relationships were graphically represented in Figs. 1–5, providing a visual interpretation of the trends and deviations observed. The graphs highlight the nonlinear nature of the changes, reinforcing the need for more sophisticated modeling approaches that account for molecular interactions and phase behavior in mixed crude systems.

These findings are essential for optimizing blending strategies, improving pipeline transport efficiency, and minimizing operational risks associated with incompatible oil mixtures. They also contribute to the broader understanding of how compositional variability affects the performance and quality of crude oil blends in real-world scenarios.

Analysis of Figs. 1–5 reveals distinct qualitative and anomalous shifts in the measured parameters of the oil mixture (GO+BO), particularly at mass fractions of 0.58 for BO and 0.42 for GO. These specific blend ratios appear to correspond with critical thresholds where the behavior of the mixture diverges significantly from expected trends, indicating complex interactions between the constituent oils. Notably, Figures 3 to 5 demonstrate that while the paraffin content exhibits relatively predictable changes with varying blend ratios, the concentrations of resins and asphaltenes do not follow a linear or additive pattern. Instead, these components display irregular fluctuations, suggesting that their behavior in mixed systems is governed by non-additive mechanisms. This deviation from the additivity rule, where the properties of a mixture are assumed the weighted average of its components, highlights the intricate molecular dynamics at play.

Such findings reinforce the conclusion that the additivity principle does not hold for crude oil mixtures, especially when dealing with high-molecular-weight fractions like resins and asphaltenes. These components are known to engage in complex intermolecular interactions, including aggregation and phase separation, which can significantly alter the physical and chemical properties of the blend. The observed anomalies underscore the importance of developing advanced predictive models that account for nonlinear behavior and molecular compatibility in oil blending operations [14].

To further investigate the behavior of ballast

Table 1

Physicochemical parameters of crude oils of Bulla (BO) and Garachukhur (GO) fields

Parameter	Value		Research method
	BO	GO	
Density at 20^0 C, kg/m^3	973.4	914.7	AUSS 3900
Kinematic viscosity at 20^0C, sSt	15.76	6.41	AUSS 33
Resin, wt.%	10.27	13.28	Chromatograph
Asphaltenes, wt.%	0.23	0.64	AUSS 11858
Paraffins, wt.%	13.34	2.53	AUSS 11851
Saturated vapour pressure, kPa	16.2	9.7	AUSS 1756
Set point, ^{0}C	+9	+3	AUSS 20287
Mechanical mixtures, wt.%	5.72	6.42	AUSS 6370
Salts, mg/l	480.6	530.3	AUSS 21534
The amount of water, wt.%	43.2	56.4	AUSS 2477

Table 2

Physicochemical parameters of the BO+GO oil mixture

Parameter	Value											
	mass fraction of BO oil in the mixture											
	0.01	0.05	0.10	0.15	0.20	0.30	0.35	0.40	0.42	0.44	0.46	0.48
Density at 20^0 C, kg/m^3	908.5	917.6	920.3	923.8	926.7	932.1	936.4	939.1	942.5	943.4	945.7	946.6
Kinematic viscosity at 20^0C, sSt	7.36	8.75	9.48	11.59	13.83	15.95	19.46	24.84	28.35	34.42	42.35	49.27
Resin, % of total mass	13.19	13.11	13.07	13.02	12.89	13.26	13.35	13.39	13.42	13.46	13.51	13.65
Asphaltenes, % of total mass	0.65	0.62	0.59	0.56	0.54	0.57	0.60	0.62	0.63	0.64	0.65	0.67
Paraffins, % of total mass	2.59	3.29	4.12	4.86	5.34	7.35	8.16	8.67	8.73	8.86	8.89	9.05
Vapor pressure, kPa	9.8	10.1	10.2	11.8	12.3	11.9	11.8	11.5	11.3	11.2	11.1	10.9
Pour point temperature, ^{0}C	+3	+3	+3	+3	+6	+6	+6	+6	+6	+6	+6	+6
Mechanical impurities, % of total mass	6.39	6.38	6.37	6.36	6.35	6.21	6.19	6.17	6.16	6.15	6.14	6.13
Salts, mg/l	528.6	526.4	523.1	520.9	518.7	512.3	511.9	510.7	509.8	509.1	508.3	507.2
Water content, % of total mass	55.3	54.8	53.6	52.9	52.1	51.3	50.8	50.2	49.9	49.6	49.2	48.7

Continued Table 2

0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.68	0.75	0.80	0.85	0.90	0.92	0.94	0.96	0.98
950.3	952.1	954.5	955.8	956.5	955.8	954.2	954.7	958.6	961.5	964.3	967.6	968.8	969.7	971.1	972.4
56.09	58.41	62.35	67.83	71.62	69.33	65.24	59.16	31.95	26.45	20.89	18.54	17.92	15.30	14.12	13.61
13.92	14.08	14.12	14.25	14.39	14.08	13.56	13.24	12.85	12.62	12.09	11.98	11.76	11.52	11.41	11.25
0.69	0.72	0.74	0.76	0.78	0.69	0.63	0.61	0.58	0.49	0.43	0.39	0.36	0.34	0.32	0.30
9.07	9.21	9.26	9.34	9.42	10.08	10.21	10.76	11.34	11.43	11.71	12.54	12.63	12.72	12.85	13.08
10.8	10.6	10.4	10.2	9.8	10.2	10.6	11.3	11.8	12.5	13.7	14.5	14.8	14.9	15.2	15.6
+6	+6	+9	+9	+9	+9	0	0	0	0	0	+3	+3	+3	+3	+3
6.12	6.11	6.09	6.07	6.05	6.03	6.01	5.98	5.97	5.95	5.93	5.89	5.86	5.84	5.82	5.78
506.4	505.8	505.1	504.3	503.2	501.4	500.8	498.5	497.6	495.3	492.7	490.6	489.5	488.9	487.6	486.9
48.5	48.1	47.6	47.2	46.9	46.8	46.6	46.5	45.1	44.9	44.7	44.5	44.2	43.9	43.7	43.6

components in blended crude oils, the sedimentation kinetics of various impurities was studied under controlled laboratory conditions. The focus was placed on mixtures of Garachukhur (GO) and Bulla (BO) crude oils at mass fractions of 42% GO and 58% BO, which had previously shown anomalous behavior in physicochemical properties.

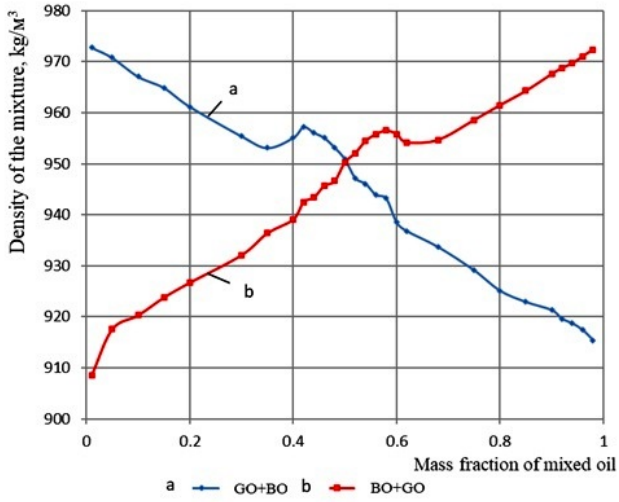


Fig. 1. Variation of the density of the mixture

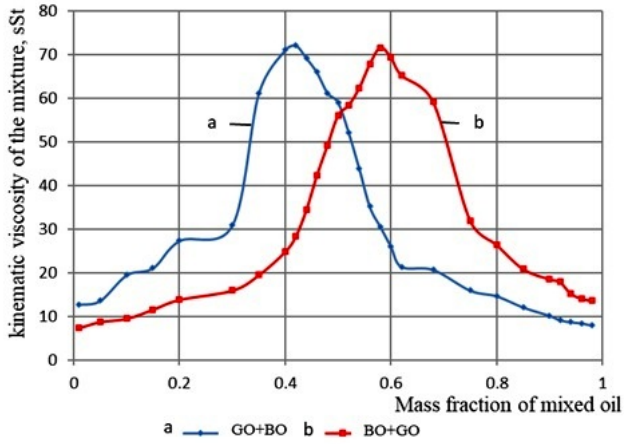


Fig. 2. Variation of the kinematic viscosity of the mixture

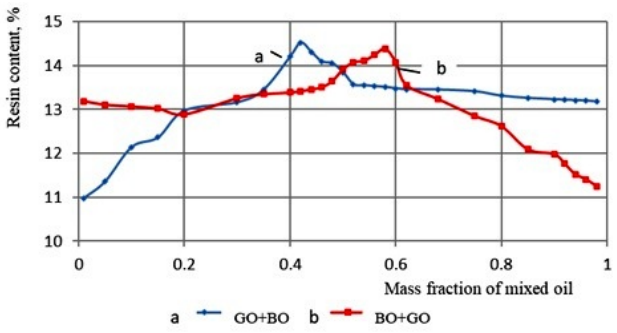


Fig. 3. Change in the resin content in the mixture

Immediately following the preparation of each mixture, samples were allowed to settle at a constant temperature of 20^{0}C. Hourly measurements were conducted to quantify the deposition of ballast materials, including resin-asphaltene-paraffin (RAP) complexes, mechanical impurities, water, and salts. These measurements were performed in accordance with established industry standards to ensure consistency and reliability.

The results of these hourly assessments, along with the total amount of ballast deposits accumulated over a 24-hour period, are presented in Table 3. The data provides a comprehensive view of how different types of impurities separate from the oil mixture over time.

Using the information from Table 3, time-dependent profiles were constructed to illustrate the sedimentation kinetics of the combined ballast components (RAP+mechanical mixtures, water, and salts). These profiles are graphically represented in Fig. 6, offering valuable insight into the dynamics of impurity separation in mixed crude systems.

As shown in Fig. 6, the majority of ballast deposition occurs within the first 8 to 10 hours of settling. During the initial 8-hour period, the rate of

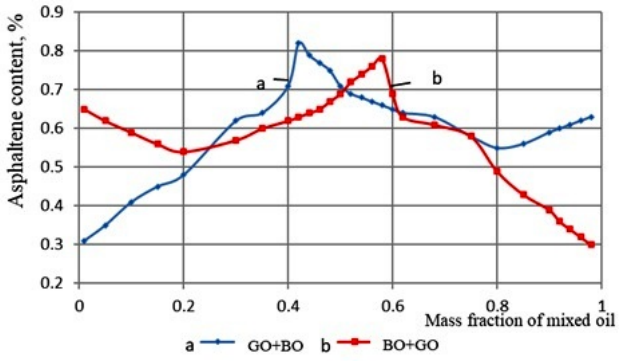


Fig. 4. Change in the asphaltene content in the mixture

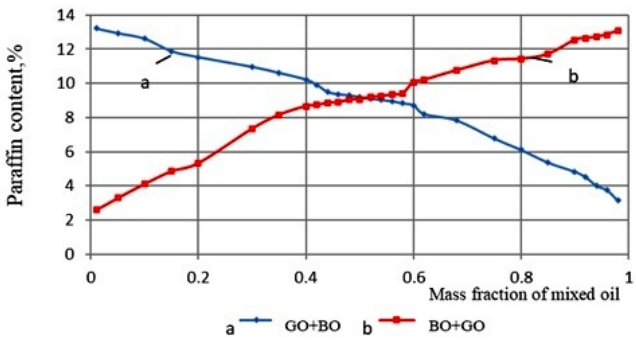


Fig. 5. Change in the paraffin content in the mixture

Table 3

Sedimentation kinetics of ballasts in GO:BO (42:58%) mixtures at 20^{0}C

Ballasts	Value											
	time, hour											
	1	2	3	4	5	6	7	8	9	10	11	12
RAP+Mechanical mixtures, wt.%	0.03	0.04	0.05	0.06	0.08	0.11	0.19	0.28	0.18	0.09	0.05	0.04
Total amount of RAP+mechanical mixtures, wt.%	0.03	0.07	0.12	0.18	0.26	0.37	0.56	0.84	1.02	1.11	1.16	1.20
Water, wt.%	0.9	1.1	1.2	1.3	1.8	2.1	3.8	5.9	2.7	1.6	0.9	0.8
Total amount of water, wt.%	0.9	2.0	3.2	4.5	6.3	8.4	12.2	18.1	20.8	22.4	23.3	24.1
Salts, wt.%	10.1	11.3	11.6	12.1	12.5	13.2	14.3	20.5	16.3	12.1	11.2	10.1
Total amount of salts, wt.%	10.1	21.4	33.0	45.1	57.6	70.8	85.1	105.6	121.9	134.0	145.2	155.3

Continued Table 3

13	14	15	16	17	18	19	20	21	22	23	24
0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
1.23	1.26	1.29	1.32	1.34	1.36	1.38	1.40	1.42	1.43	1.44	1.45
0.6	0.5	0.7	0.6	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.1
24.7	25.2	25.9	26.5	26.9	27.2	27.4	27.6	27.8	28.0	28.2	28.3
9.1	6.2	9.3	8.3	5.2	4.8	4.5	4.1	3.9	3.5	3.7	3.6
164.4	170.6	179.9	188.2	193.4	198.2	202.7	206.8	210.7	214.2	217.9	221.5

sediment accumulation is particularly rapid, indicating a high level of instability and active separation. However, after reaching a peak, the rate of deposition begins to decline sharply. By the 10th hour, the sedimentation process slows significantly and approaches completion, with minimal additional accumulation observed beyond this point.

These findings suggest that the separation of ballast materials in crude oil mixtures is governed by time-sensitive kinetic processes, which are influenced by the chemical composition and compatibility of the blended crude oils. Understanding this kinetics is essential for optimizing storage protocols, minimizing equipment fouling, and improving the overall efficiency of oil handling operations.

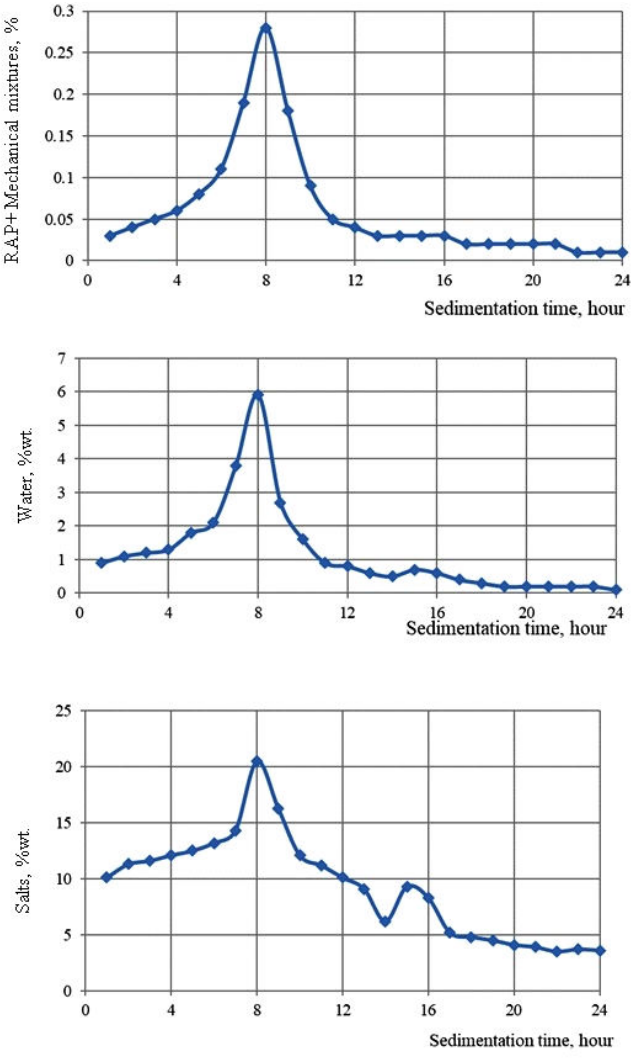


Fig. 6. Sedimentation kinetics of ballasts in GO:BO (42:58%) mixtures at 20^{0}C

Conclusions

The study of crude oil mixtures from the Garachukhur (GO) and Bulla (BO) fields has revealed significant nonlinear deviations in rheological and physicochemical properties, particularly at mass fractions of 42% GO and 58% BO. These anomalies, observed in parameters such as density, viscosity, and resin-asphaltene-paraffin (RAP) content, underscore the limitations of additive models in predicting the behavior of blended crude oils.

Experimental results further demonstrated that the sedimentation kinetics of ballast materials, including RAP complexes, mechanical impurities, water, and salts, are highly time-dependent. The majority of ballast deposition occurred within the first 8 to 10 hours of settling at 20^{0}C, with a rapid accumulation phase followed by a sharp decline in sedimentation rate. This behavior confirms the presence of dynamic molecular interactions and phase instabilities in incompatible oil mixtures.

The findings highlight the critical need for improved predictive models that account for molecular compatibility, nanophase boundaries, and nonlinear behavior in crude oil blending. Such models would enhance the accuracy of engineering calculations and support more effective operational decision-making in oil transport and processing.

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ДОСЛІДЖЕННЯ НЕСУМІСНОСТІ СУМІШЕЙ СИРОЇ НАФТИ ТА ПОВ'ЯЗАНОГО З ЦИМ ВИПАДІННЯ БАЛАСТНИХ РЕЧОВИН

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Останні дослідження виявили суттєві проблеми, пов'язані зі змішуванням різних типів сирої нафти. Головною з них є несумісність деяких сумішей сирої нафти, яка може спричинити закупорювання, а в окремих випадках і зупинку роботи промислових систем збору нафти трубопроводами. Ключовим чинником, що зумовлює цю несумісність, є наявність твердих органічних сполук, зокрема смол і асфальтенів, які мають тенденцію випадати з розчину під час змішування несумісних видів сирої нафти. Ці речовини, які в сукупності називають баластними, створюють значні експлуатаційні ризики. Для дослідження впливу змішування сирої нафти на показники її якості в лабораторних умовах було проаналізовано різні зразки сирої нафти та їхні суміші. Результати виявили нелінійні відхилення фізичних і хімічних властивостей сумішей, а також виражені аномалії показників якості. Зокрема, концентрації таких баластних речовин, як смоли та асфальтени, не відповідали очікуваній адитивній поведінці. Також було досліджено кінетику випадіння баластних речовин, зокрема смол, асфальтенів, парафінів, води, солей і механічних домішок, у сумішах несумісних видів сирої нафти. Встановлено, що більша частина баластних відкладень утворюється протягом 8–10 годин після змішування. Отримані результати свідчать про те, що утворення несумісних сумішей, зумовлене хімічним складом компонентів нафти, може призводити до швидкого та інтенсивного випадіння різних баластних речовин.

Ключові слова: змішування сирої нафти; фізичні та хімічні властивості; механічні суміші; відкладення баластних речовин; асфальтени.

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INVESTIGATING CRUDE OIL BLEND INCOMPATIBILITY AND ASSOCIATED BALLAST PRECIPITATION

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Recent research has highlighted specific challenges associated with blending different types of crude oil. Chief among these is the incompatibility of certain crude oil mixtures, which can result in the clogging – and in some cases, shutdown – of field gathering pipeline systems. A key factor contributing to this incompatibility is the presence of solid organic compounds, particularly resins and asphaltenes, which tend to precipitate from solution when incompatible crude oils are mixed. These substances, collectively referred to as ballasts, pose significant operational risks. To investigate the impact of crude oil blending on quality parameters, various crude oil samples and their mixtures were analyzed under laboratory conditions. The results revealed nonlinear deviations in the physical and chemical properties of the mixtures, with pronounced anomalies in quality indicators. Notably, the concentration of ballasts such as resins and asphaltenes did not conform to the expected additive behavior. The study also examined the kinetics of precipitation of ballast materials, including resins, asphaltenes, paraffins, water, salts, and mechanical impurities, in incompatible crude oil blends. It was observed that the majority of ballast deposition occurs within 8 to 10 hours of mixing. These findings underscore that the formation of incompatible mixtures, driven by the chemical composition of the constituent oils, can lead to rapid and intensive precipitation of various ballast materials.

Keywords: crude oil mixing; physical and chemical properties; mechanical mixtures; ballast deposition; asphaltenes.

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