

The importance of protecting the quality of crude oil and petroleum products

Znaczenie ochrony jakości ropy naftowej i produktów ropopochodnych

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ABSTRACT: The establishment of a common market for crude oil and petroleum products within the Eurasian Economic Union (EAEU) provides substantial opportunities for stabilizing the energy situation across member states and strengthening the energy security of each participating country. Market integration fosters sustainable economic development, enhances social welfare, and improves the global competitiveness of products manufactured within the EAEU. As a result, the formation of a unified crude oil and petroleum products market may significantly reinforce the institutional foundations of the Union and act as a major catalyst for the economic development of the wider Eurasian region. A crucial component of this integration process is the creation of a robust legal and regulatory framework for metrological support, including draft regulatory acts developed in accordance with international best practices. Accurate, consistent, and harmonized measurement procedures across the Union’s interconnected oil markets are fundamental prerequisites for ensuring transparent trade, fair pricing, and effective quality management. Against this background, the present article addresses the problem of maintaining crude oil quality – commonly conceptualized as the “quality bank” – during transportation operations. The study evaluates this issue in accordance with international standards, using Azerbaijani crude oil as a representative case study.

Keywords: crude oil, asphalthenes, quality bank, special API, Siyazan and Bulla oil fields, acid number.

STRESZCZENIE: Utworzenie wspólnego rynku ropy naftowej i produktów ropopochodnych w ramach Euroazjatyckiej Unii Gospodarczej (EUG) stwarza znaczne możliwości stabilizacji sytuacji energetycznej w państwach członkowskich oraz wzmocnienia bezpieczeństwa energetycznego każdego z krajów członkowskich. Integracja rynków sprzyja zrównoważonemu rozwojowi gospodarstwu, poprawia dobrobyt społeczny i zwiększa globalną konkurencyjność produktów wytwarzanych w ramach EUG. W rezultacie utworzenie jednolitego rynku ropy naftowej i produktów ropopochodnych może znacznie wzmocnić instytucjonalne podstawy Unii i stanowić ważny katalizator rozwoju gospodarczego całego regionu euroazjatyckiego. Istotnym elementem tego procesu integracyjnego jest stworzenie solidnych ram prawnych i regulacyjnych w zakresie wsparcia metrologicznego, w tym opracowanie projektów aktów normatywnych zgodnych z najlepszymi praktykami międzynarodowymi. Dokładne, spójne i zharmonizowane procedury pomiarowe stosowane na połączonych rynkach ropy naftowej Unii są podstawowymi warunkami zapewnienia przejrzystości handlu, uczciwego kształtowania cen oraz skutecznego zarządzania jakością. W tym kontekście niniejszy artykuł porusza problem utrzymania jakości ropy naftowej podczas operacji transportowych, powszechnie określanej mianem „banku jakości”. Analiza została przeprowadzona zgodnie z normami międzynarodowymi, wykorzystując azerską ropę naftową jako reprezentatywny przykład.

Słowa kluczowe: ropa naftowa, asfalteny, bank jakości, wskaźnik API, złoża ropy Siyazan i Bulla, liczba kwasowa.

Introduction

In the regional energy landscape, Azerbaijan occupies a strategically important position as a major producer and exporter of crude oil. Although Azerbaijan is not a member of the Eurasian Economic Union (EAEU), the transportation infrastructure and transit capabilities of EAEU countries are closely integrated with the wider regional energy network.

Several EAEU member states function as key transit corridors or adjacent markets, making the EAEU framework highly relevant to discussions on cross-border crude oil logistics (Ali and Alqam, 2000; Adams, 2014; Bakhtizin et al., 2016; Gurbanov and Sardarova, 2022).

One of the principal challenges in the transportation and storage of crude oil and petroleum products is ensuring the preservation of product quality throughout all stages of the

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Article contributed to the Editor: 09.01.2025. Approved for publication: 08.01.2026.

supply chain. The operational characteristics of main and technological pipeline systems are influenced by numerous factors, including the transport of large volumes of crude oil, long-distance routing, intermediate reception and storage at multiple tank farms, sequential batching of crude and refined products, and the unavoidability of product commingling. Changes in crude oil quality during transport may arise from intrinsic physicochemical transformations as well as from the operational and technological practices of transport enterprises (Ismayilov et al., 2016; Gurbanov and Gasimzade, 2022; Gurbanov et al., 2024).

Refinery technological regimes are regulated by predetermined crude oil quality specifications defined within the quality bank system. Any deviation from the expected crude oil composition during blending can diminish product quality – and consequently market value – and, in extreme cases, may even result in refinery shutdown. In many national pipeline systems, crude oil streams move along separate routes, and the complex mixtures formed at terminal facilities are standardized by refineries that select suppliers based on their processing requirements. In routine operations, oil-transport enterprises generally interact not with oil companies directly but with production units responsible for injecting crude oil into the main pipeline network. In most countries, refineries are consolidated under integrated oil companies that act as primary consumer counterparts (Kelova et al., 2011; Nurullayev, 2014a; Matiyev et al., 2016; Guzmán et al., 2017; Knapik, 2020; Iskandarov et al., 2025).

Accordingly, oil-transport enterprises must comply with the specific quality requirements – directly linked to pricing – of the refineries receiving their crude oil, including those in foreign markets. Crude oil remains one of the world's most significant energy resources as a major fossil hydrocarbon source, while refined petroleum products continue to serve as essential energy carriers. This study examines the regulatory requirements established by EAEU member states for systems used to measure the quantity and quality parameters of energy resources transported across the Union via pipeline, rail, road, and maritime modes (Nurullayev, 2014b; Nurullayev et al., 2015; Stratiev et al., 2016; Usubaliyev et al., 2020).

Literature review

Crude oils extracted from different geological formations exhibit substantial variability in type, hydrocarbon composition, fractional distribution (based on boiling-point ranges), viscosity, sulfur content, and the level of mechanical impurities. Before reaching end users, crude oil typically undergoes several stages of controlled mixing at reception points and blending terminals.

These operations invariably modify its consumer properties and commercial valuation. In recent years, mixtures of low-, medium-, and high-sulfur crude oils have increasingly been exported to Central and Western Europe.

In this study, the terms “low-,” “medium-,” and “high-sulfur crude oils” refer to grades classified according to the concentration and composition of sulfur-containing compounds, including mercaptans, sulfides, thiophenes, disulfides, hydrogen sulfide, and elemental sulfur. In international industrial practice, classification is determined by numerical sulfur content thresholds: crude oils containing less than 0.50% by weight of sulfur are classified as low-sulfur (“sweet”), oils containing between 0.50% and 1.50% by weight of sulfur are considered medium-sulfur, and crude oils with sulfur content above 1.50% by weight are categorized as high-sulfur (“sour”). These ranges are consistent with criteria applied by ASTM, API, and the U.S. Energy Information Administration (EIA) (Kuan et al., 2020; Fasih et al., 2023; Ganji et al., 2025).

Because physical and commercial flows are separated within the supply chain, contractual obligations between crude suppliers and buyers – regarding the delivery of defined volumes within a specified timeframe – are fulfilled through a standardized operational mechanism (Wen et al., 2016; Azimi et al., 2018; Zhao et al., 2021). Companies responsible for crude oil acceptance, metering, and custody transfer receive oil of specified quality from producers into the pipeline system. They subsequently deliver an equivalent volume of the resulting blended mixture – comprising crude oils with differing quality characteristics – to consumers at their respective offtake points. Consequently, crude oil from a single supplier may ultimately reach multiple consumers in a mixed form, which is an inherent feature of the monopolistic structure of trunk pipeline systems.

Due to technological, operational, and infrastructural constraints, the pipeline transport network is characterized by a highly complex, large-scale, and heterogeneous operational environment. Crude oil transported through such systems undergoes multistage and multi-variant mixing. The commingling of oils originating from different hydrocarbon deposits – each with distinct compositional and physicochemical properties – inevitably alters key quality parameters. These changes affect the commercial attributes of the crude oil and, therefore, the economic interests of producers. Suppliers of high-quality (light, low-sulfur) crude oils are entitled under bilateral agreements to claim additional compensation if the quality or market value of their product deteriorates during transportation. Conversely, producers of lower-quality crude oils must typically accept discounted pricing (Mingalev et al., 2022; Iskandarov et al., 2025; Sotirov et al., 2025).

To prevent undefined or inequitable redistribution of value among producers during transportation, international oil-trade

practice employs economic compensation mechanisms that reflect the quality-related performance of crude oils. Pipeline operators – and in some systems, producers themselves – develop and apply specialized economic algorithms that determine the necessary financial adjustments. Designated personnel carry out these calculations, and the resulting settlements are submitted to consumers for verification and approval. Through these mechanisms, oil-transport enterprises compensate producers for quality deviations arising from crude blending. This ensures that the final price received by each shipper – after accounting for quality changes – corresponds to the hypothetical value the producer would have obtained if their crude oil had been transported independently. Such mechanisms are collectively known as “quality banks”.

A quality bank fulfills technical, administrative, and legal functions, including the collection, analysis, and calculation of quality-related adjustments, as well as the organization of mutual settlements (discounts or surcharges) for each participating shipper in accordance with an established methodology. To offset quality-related losses during transportation, international pipeline companies employ these financial tools, commonly referred to as Oil Quality Banks (OQB). Existing OQB systems recalculate crude oil prices by incorporating quality changes that occur during transit. Since crude oil quality also fluctuates during transportation through domestic trunk pipeline networks, the implementation of an OQB mechanism may also be justified for internal settlements among shippers. In this context, it is essential to uphold the core principles of national pipeline-transport policy, including: state involvement in the creation and development of trunk pipeline infrastructure; the establishment of pricing principles for pipeline-transport services; the formation and implementation of tax regulations; and the enforcement of nondiscriminatory access rules. Ensuring nondiscriminatory access requires prohibiting contractual terms that are unrelated to the substantive purpose of the agreement, preventing discriminatory conditions that disadvantage one consumer relative to another, and avoiding unjustified refusal to conclude contracts when transportation capacity is available (Moura et al., 2010; Nurullayev, 2014a, 2014b; Gurbanov et al., 2021).

A clearer understanding of OQB principles can be achieved by examining established international examples. One of the most widely cited cases is the OQB implemented in the Cameron Highway Oil Pipeline System (CHOPS), which includes 24- and 30-inch pipelines extending across the outer continental shelf of the Gulf of Mexico and transports crude oil from major deepwater fields to markets in Texas and the U.S. Gulf Coast. The primary objective of this OQB is to minimize either deterioration or enrichment of crude quality for producers delivering into the system. Price-correction factors account

for variations in sulfur content and density, as well as price differentials between the Louisiana Light Sweet (LLS) and South Green Canyon (SGC) benchmark crude oils. The system applies a weighted composite index (WCI) model, in which density and sulfur are assigned weighting factors of 31.5% and 44.3%, respectively, reflecting their relative influence on crude oil valuation within the pricing mechanism.

Research methodology

An analysis of international Quality Bank systems demonstrates that they operate according to several fundamental principles. All Quality Banks assess both the value of the original crude oil injected into the shared pipeline stream and the value of the resulting blended mixture. The pricing algorithm depends primarily on the specific Quality Bank model adopted, and three models are most commonly used worldwide: the density model, the distillation model, and the simplified fractionation model.

The density-based model determines crude oil value as a function of density while also incorporating sulfur content, with the relationship between price and physical properties derived empirically from market data. In the distillation and simplified fractionation models, crude value is calculated from the combined value of its fractions, which is determined by the market prices of petroleum products and the refinery yield structure. The simplified fractionation model further requires that the sulfur content and viscosity of gasoil and fuel oil fractions comply with international product specifications.

In countries where crude oil quality markets are emerging, simplified models based primarily on key quality indicators – such as density and sulfur content – are generally more practical. When implementing a Quality Bank for crude oils transported through a trunk pipeline system, several technical considerations must be addressed. The system must remain simple, operationally convenient, and not require significant additional capital investment. Since pipeline operators are responsible solely for transportation rather than production or refining, the compensation methodology must remain independent of crude oil market prices.

At the initial stages of settlement procedures, density [kg/m^3] and sulfur concentration [$\text{wt}\%$] should serve as the primary quality indicators for evaluating producer contributions. Compensation should be calculated according to the difference between the quality of the blended crude oil received by consumers and the quality of the original crude oil injected by each shipper. To ensure fairness, compensation values should be assumed to vary uniformly across the full range of the relevant quality indicator, implying a linear relationship

Table 1. Comparison of ASTM and GOST standards used for key crude oil quality parameters

Tabela 1. Porównanie norm ASTM i GOST stosowanych do kluczowych parametrów jakości ropy naftowej

Parameter	ASTM standard/method	GOST standard/method	Main differences/notes
Density [at 15°C]	ASTM D4052 (Digital density meter)	GOST 3900 (Hydrometer method)	ASTM uses oscillating U-tube digital method – higher precision. GOST uses hydrometer – acceptable but less precise.
API Gravity	ASTM D287	GOST 3900 (converted from density)	API in GOST calculated indirectly from density; ASTM measures it directly.
Kinematic Viscosity	ASTM D445	GOST 33	Both use capillary viscometers; ASTM specifies more detailed calibration and temperature control.
Dynamic Viscosity	ASTM D7042 (Stabinger viscometer)	GOST 33614 or GOST 1929	ASTM method is automated with higher accuracy; GOST relies mainly on manual capillary methods.
Water Content	ASTM D4377 / D4007 (Karl Fischer or centrifuge)	GOST 2477 (Titration)	ASTM offers Karl Fischer for high accuracy; GOST mainly uses titration/centrifugation.
Chloride Salts	ASTM D3230	GOST 21534	ASTM uses conductometric titration (more sensitive). GOST method is less sensitive but widely used in Commonwealth of Independent States (CIS).
Mechanical Impurities	ASTM D473	GOST 6370	Both use filtration; ASTM specifies more precise filter preparation and drying procedures.
Pour Point	ASTM D97	GOST 20287	Very similar protocols; ASTM includes additional cooling-rate clarifications.
Flash Point	ASTM D92 (Cleveland Open Cup)	GOST 4333	Procedures are comparable; ASTM uses slightly stricter heating rate control.
Sulfur Content	ASTM D4294 (XRF)	GOST R 51947 (XRF)	Methods are almost identical; instrumentation requirements differ minimally.
Water and Sediment (Basic Sediment (BS) and Water (W))	ASTM D4007	GOST 2517/GOST 6370	ASTM uses demulsifier-assisted centrifugation; GOST uses classical methods.

between compensation and changes in quality parameters. For calculation purposes, the pipeline system is conceptualized as a “black box”, in which inflows represent the crude oil batches supplied by producers and outflows represent the blended crude oil delivered to consumers.

To enhance clarity, Table 1 provides a comparative overview of the ASTM and GOST standards referenced in this study. Although both regulatory systems are widely used in crude oil quality assessment, ASTM methods generally offer higher measurement precision and greater automation, whereas GOST standards remain prevalent in laboratories throughout the Commonwealth of Independent States (CIS) region. The comparability and harmonization of analytical results obtained under these two regulatory frameworks are ensured by GOST R ISO 5725-2-2002, which establishes internationally accepted requirements for analytical accuracy, repeatability, and reproducibility (ASTM D 4057-2022; ASTM D 4052; ASTM D 445; ASTM D 4006-2022).

The current state of the transportation system for major petroleum products is characterized by several noteworthy

features. These include the substantial volumes of transported materials – according to international statistics, more than 26% of transported hydrocarbons in recent years have consisted of refined petroleum products – as well as transport routes that frequently extend for more than a thousand kilometers. The system also depends on numerous intermediate tank farms along the route, where petroleum products are received, stored, and subsequently redistributed. Additional operational characteristics include the commingling of petroleum products of the same grade but originating from different producers, as well as the sequential transport of petroleum products of different grades through direct compounding.

A comparative analysis of international approaches to metrological support for measuring the quantity and quality parameters of energy carriers reveals methodological differences among European (EN), American (ASTM), and international (ISO) standards. These distinctions arise from the differing measurement techniques, procedures, and instrumentation specified within each regulatory framework. At the same time, it is evident that EAEU member states predominantly apply

standards derived from European and American methodologies, which remain aligned with global practice while accommodating regional operational specifics. The ongoing harmonization of principles governing the development and implementation of standards across countries supports enhanced cooperation among participating states and contributes to the advancement of unified metrological systems (Jennings and Weispenig, 2005; Centeno et al., 2011; Bambinek et al., 2023; Gasimzade, 2024).

Research results and discussion

Through extensive collaboration with international oil companies and research institutions, a modified operational model for the Oil Quality Bank has been developed, along with the official regulations governing its operation, a methodology for performing mutual settlements among shippers, and standardized relative values for key crude oil quality indicators – specifically density and sulfur content. The model applies unified cost coefficients to specific deviation units of these indicators, enabling the calculation of compensation for crude oil injected into the pipeline system. Compensation is determined by comparing the average input quality parameters of each producer with the average output quality parameters of the blended crude oil received by groups of consumers. Discussions regarding the establishment of an Oil Quality Bank consistently demonstrate the necessity of such a system. Results from our experimental and industrial trials on the Oil and Petroleum Products Quality Bank further confirm that the accuracy and reliability of outcomes depend critically on strict adherence to proper sampling procedures in accordance with international standards (RD 153-39.4-034-98; RD 39-0147098-003-1999b).

The implementation of these standards within relevant institutions requires rigorous compliance with established protocols. Sampling of crude oil and petroleum products must be conducted in accordance with ASTM D4057-2022 and GOST 2517-2012. Samples taken from storage tanks must be collected using stationary or portable devices specifically designed to ensure proper sampling as prescribed by these standards. All portable sampling devices and their accessories must be constructed from materials that do not produce sparks upon impact and do not accumulate static electricity. Before sampling, all devices must be clean and dry. Equipment used for collecting and storing samples of light petroleum products should be washed with detergent or gasoline after use, whereas devices used for heavy crude oils or heavy fractions must be cleaned with an appropriate solvent and thoroughly rinsed with hot water. All cleaned equipment must be dried and stored in a clean, dry environment.

A control sample must be taken from the tank delivering the petroleum product. For groups of identical tanks loaded simultaneously, a combined spot sample should be taken from every fourth tank, provided that the total number of tanks is at least two. Representative samples may also be collected directly from the receiving line of a petroleum depot during unloading operations. Sampling from pipeline systems may be performed manually or automatically, and each sample must be accompanied by documentation confirming the presence of authorized representatives from both the supplying and receiving parties (ASTM D 4057-2022; ASTM D 4006-2022; GOST, 2517-2012). When all sampling operations during transportation are carried out in strict accordance with these standards – and when laboratory analyses follow these same requirements – effective monitoring of the Oil Quality Bank can be ensured.

Heteroatomic compounds – particularly sulfur-, nitrogen-, and oxygen-containing species, as well as heavy metals – present in crude oils have adverse effects on the physicochemical and rheological properties of blended crude. Oils with elevated concentrations of such components are considered high-risk materials and therefore have significantly lower market value, making them undesirable for producers and transport enterprises. The detrimental influence of these components is well documented across numerous international standards and analytical methods (ASTM D 4057-2022; ASTM D 4006-2022; ASTM D 4052; ASTM D 445; ASTM D 1250-2021; ASTM D 473-2021; ASTM D 4294-2020; ASTM D 323-2020; ASTM D 1159-2020; ASTM D 1160-2020; ASTM D189-2019; ASTM D 4929-2019; ASTM D 3230-2019; ASTM D 2502-2019; ASTM D 5708-2015; ASTM D 482-2013; ASTM D 5853-2018; RD 39-0147098-003-1999b; RD 153-39.4-034-98; ASTM D 1298-2017; ASTM D 4629-2017; IP 143-2005; UOP 163-79; UOP 375-06; BP 237/76; GOST R ISO 5725-2-2002; GOST 2517-2012; GOST 2177-2021).

Because such oils have low market value, their export to distant foreign markets leads to considerable loss of foreign exchange revenue. Moreover, the admission of high-sulfur crude – particularly oils containing elevated levels of sulfur-, nitrogen-, and oxygen-bearing compounds, as well as heavy metals – does not comply with established transportation standards. For this reason, producers of these crude oils typically have limited access to the main pipeline network. The reason for this limitation is obvious: once high-sulfur crude enters the blended stream, producers of low-sulfur crude incur financial losses because the price of the blended product is lower. Consequently, low-sulfur suppliers are compelled to indirectly compensate high-sulfur suppliers through a reduction in the value of their export share.

At present, numerous methods exist for predicting incompatibility effects during the blending of different crude oils and

petroleum fuels; however, the vast majority of these methods have been developed by foreign researchers, and comparable studies on Azerbaijani crude oils are still rare. Research on the mixing behavior of Azerbaijani crude oils – including studies involving commercial petroleum products or liquefied oils – has been virtually absent. The present study seeks to address these gaps by examining the above-mentioned issues for Azerbaijani crude oils using established analytical methodologies.

Sulfur and other acidic constituents, such as naphthenic acids, are known to increase the corrosivity of crude oil and are commonly used as indicators of acidity. Heavy petroleum fuels typically contain high concentrations of asphaltenes, metals, and other contaminants, all of which negatively affect the performance of refinery dehydration and desalting units. Like many other crude oils worldwide, Azerbaijani oils exhibit broad variability in physicochemical and rheological properties. Oils from different fields often differ substantially in viscosity, pour point, paraffin and asphaltene content, and degree of hydration. Reliable information on the quality characteristics of blended oils is therefore essential not only for crude oil accounting but also for forecasting the operational regimes of blending facilities, storage tanks, and processing units receiving these oils. Analytical evaluation must thus be conducted in accordance with international standards, as summarized in Table 2.

Nevertheless, consistent with global practice, the results of assessing how mixing influences the physicochemical and rheological properties of Azerbaijani crude oils show that models and calculation schemes developed for idealized systems may diverge significantly from behavior observed in real mixtures. For instance, the commonly applied rule of additivity may produce notably inaccurate predictions for actual crude blends.

In this study, crude oils from the Bulla (BO) and Siyazan (SO) fields were selected as research objects. Preliminary laboratory results reflecting the principal rheological and phys-

Table 2. Physico-chemical indicators determined by international methods that affect the quality bank of oils

Tabela 2. Wskaźniki fizykochemiczne określone metodami międzynarodowymi, wpływające na funkcjonowanie banku jakości ropy naftowej

Names of analyses performed on oil	Test methods performed
Density at 20°C [kg/m ³]	ASTM D1298
Special API	ASTM D1250
Sulfur [% by mass]	ASTM D4294
Amount of water [% by mass]	ASTM D4006
Kinematic viscosity, [cSt] at 20°C	ASTM D445
Saturated vapor pressure [kPa]	ASTM D323
Pour point [°C]	ASTM D5853
Mechanical admixtures [% by mass]	ASTM D473
Coke residue in the fraction boiling above 260°C [% by mass]	ASTM D189
Mercaptan sulfur [ppm]	UOP 163
Hydrogen sulfide [ppm]	UOP 163
Chlorides in oil [ppm]	ASTM D4929
The amount of fractional chlorides boiling at 204°C [ppm]	ASTM D4929
Nitrogen content [ppm]	ASTM D4629
Amount of salts [mg/l]	ASTM D3230
Acid number [mg KOH/g]	GOST 5985
Ash content [% by mass]	ASTM D482
Asphaltenes content [% by mass]	IP 143
Paraffin content [% by mass]	BP 237/76
Bromine number [g/100 g], for fraction boiling up to 360°C	ASTM D1159/1160
Metals [ppm]	ASTM D 5708
Molecular mass [g/mol]	ASTM D2502
Characterizing factor	UOP 375
Distillation (at 101.5 kPa) [°C] Start of boiling, end of boiling	GOST 2177

Table 3. Rheophysical and chemical characteristics of Bulla (BO) and Siyazan (SO) crude oils

Tabela 3. Właściwości reofizyczne i chemiczne rop naftowych Bulla (BO) i Siyazan (SO)

Indicators	BO	SO	Methods of conducting analyses
Density at 20°C [kg/m ³]	973.4	978.9	GOST 3900
Kinematic viscosity [mm ² /s] at 20°C	15.76	8.23	GOST 33
Amount of resins [% by mass]	10.27	11.12	Adsorption liquid chromatography (SARA fractionation)
Asphaltenes content [% by mass]	0.23	0.81	GOST 11858
Amount of paraffins [% by mass]	13.34	1.18	GOST 11851
Vapor pressure [kPa]	16.2	13.9	GOST 1756
Pour point [°C]	+9	-6	GOST 20287
Mechanical admixtures [% by mass]	5.72	4.83	GOST 6370
Amount of salts [mg/l]	480.6	398.4	GOST 21534
Water content [% by mass]	43.2	35.7	GOST 2477

icochemical properties of BO and SO oils – as well as the analytical procedures employed – are presented in Table 2. The non-monotonic behavior observed in several key quality indicators confirms that the resulting mixtures cannot be treated as additive systems. Because the crude oil samples were collected prior to field-level desalting and dehydration operations, the water contents reported in Table 3 represent the original emulsion state rather than pipeline-ready crude.

A similar pattern of variation in quality indicators is observed when Bulla (BO) and Siyazan (SO) crude oils are blended at different mass fractions. At a 50:50 SO-BO ratio, pronounced anomalous behavior appears across nearly all measured parameters. In this compositional interval, the concentration of heteroatomic compounds – including sulfur-, nitrogen-, and oxygen-containing species, as well as trace heavy metals – becomes more prominent, and the mixture exhibits a distinct increase in resin, asphaltene, and paraffin contents, as illustrated in Figure 1.

Moreover, the observed nonlinear behavior is not limited to saturates, aromatics, resins, and asphaltenes (SARA) components. As shown in Figure 2, the density of BO-SO blends deviates slightly from the ideal additive line, with the greatest deviations occurring in the intermediate composition range. Even more significant anomalies arise in the rheological properties. Figure 3 reveals a marked nonlinear increase in kinematic viscosity, forming a pronounced peak at a BO mass fraction of approximately 0.6. This behavior suggests structural rear-

rangements within the colloidal system and further confirms that the mixture exhibits non-ideal, interaction-controlled behavior rather than simple linear compositional averaging.

In this study, the purpose of plotting the dashed theoretical lines in Figures 1–3 was not to estimate measurement uncertainty or determine error coefficients using conventional error bars. Rather, the main objective was to assess the consistency between theoretical additive predictions and the experimentally observed behavior of the BO-SO crude oil blends,

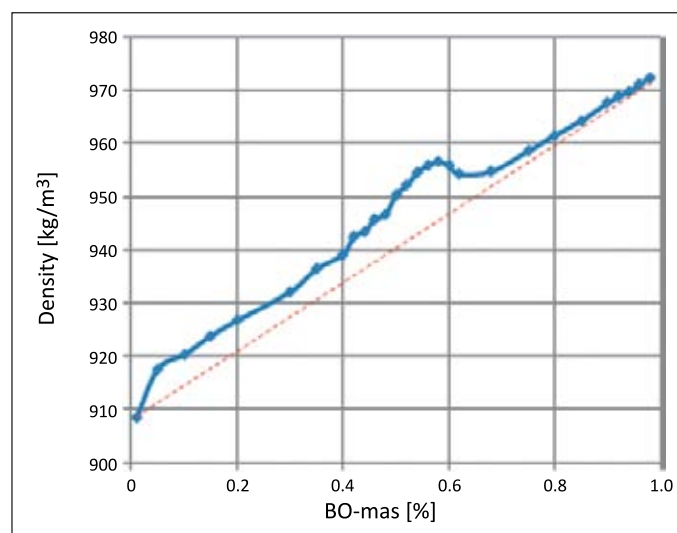


Figure 2. Experimental density of BO-SO blends as a function of BO mass fraction, with theoretical additive line (dashed)

Rysunek 2. Gęstość eksperymentalna mieszanin BO-SO w zależności od udziału masowego BO, z teoretyczną linią addytywności (przerywana)

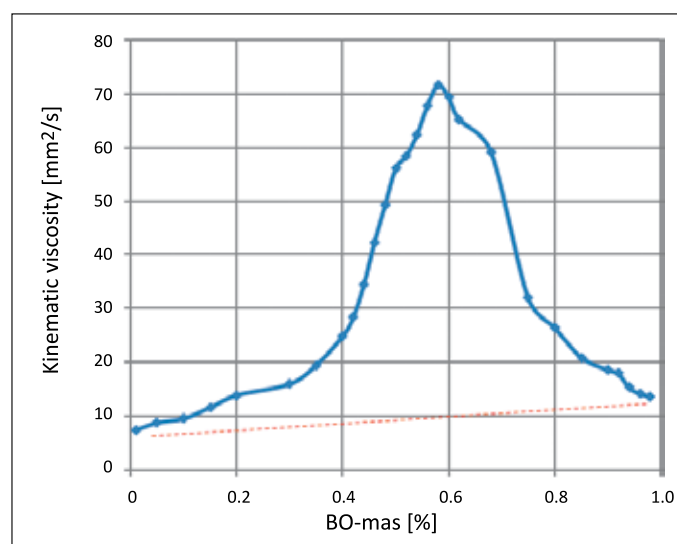


Figure 3. Kinematic viscosity of BO-SO blends versus BO mass fraction, including theoretical additive line (dashed)

Rysunek 3. Lepkość kinematyczna mieszanin BO-SO w zależności od udziału masowego BO, z teoretyczną linią addytywności (przerywana)

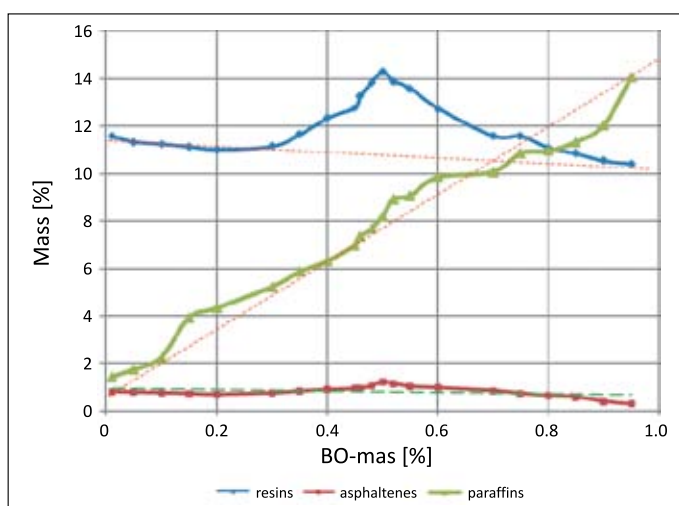


Figure 1. Changes in paraffin, resin and asphaltene contents in BO-SO crude oil blends: X-axis – mass fraction of Bulla oil (BO) [wt %]; Y-axis – measured content of the corresponding component [wt%]; Error bars represent the standard deviation of triplicate measurements

Rysunek 1. Zmiany zawartości parafiny, żywicy i asfaltenów w mieszanekach ropy naftowej BO-SO: Oś X: udział masowy ropy Bulla (BO) [% mas.]; Oś Y: zmierzona zawartość odpowiedniego składnika [% mas.]; słupki błędów reprezentują odchylenie standardowe potrójnych pomiarów

based on 20–30 individual mixing experiments performed at various blend ratios. As shown in Figure 1, the dashed lines represent the theoretical additive values predicted by the linear mixing rule. If the components behaved ideally, these trends would be strictly linear. However, the experimental data deviate markedly from the theoretical lines and exhibit pronounced nonlinear behavior. These deviations confirm the fundamentally non-additive behavior of SARA components during crude oil blending.

Analysis of 20 blend samples indicates that the largest deviations from the theoretical line occur in the resin and paraffin fractions, whereas the asphaltene fraction displays comparatively smaller departures. This behavior is consistent with the colloidal nature of crude oils: resins and paraffins are more sensitive to changes in composition, frequently initiating aggregation-disaggregation processes and redistribution among dispersed phases.

Figures 2 and 3 illustrate the density and kinematic viscosity of the BO-SO blends. For these parameters, 30 experimental measurements were compared with theoretical additive predictions. The density curve (Figure 2) closely follows the theoretical additive line, with only minor deviations, indicating that density behaves largely as an additive property in these mixtures. In contrast, kinematic viscosity (Figure 3) demonstrates strongly nonlinear behavior, with a pronounced peak at a BO mass fraction of approximately 0.6. This behavior suggests structural rearrangements within the colloidal system, including partial aggregation of resins and asphaltenes or changes in dispersion stability. These results show that viscosity is governed primarily by intermolecular interactions and cannot be reliably predicted by simple compositional averaging.

The observed discrepancies between theoretical and experimental values can be attributed to the presence of high-molecular weight heteroatomic compounds within the resin–asphaltene–paraffin matrix. Resin–asphaltene substances contain complex structures incorporating nitrogen, sulfur, oxygen, and various metal atoms. Between 70% and 90% of resins consist of heteroatomic compounds that are thermally and chemically unstable and can gradually oxidize into heavier asphaltenes. Asphaltenes themselves possess higher molecular weight and undergo further condensation through oxidation, sulfonation, nitration, halogenation, and other reactions. Under oxidative conditions (presence of atmospheric oxygen), asphaltenes undergo further reactions, resulting in the formation of insoluble carbenes and carboids.

These transformations significantly affect the rheological and physical properties of crude oils during transportation. Even small changes in the relative proportions of resins, asphaltenes, and paraffins may noticeably alter viscosity, pour point, and

dispersion stability – parameters that are critical for pipeline operation and for maintaining the accuracy of Oil Quality Bank (OQB) assessments.

The purpose of the present research is not to develop or calculate an OQB compensation mechanism. Instead, the study provides experimentally validated quality indicators for BO-SO blends – including density, viscosity, SARA fractions, salt content, and water content – that may serve as input data for future OQB valuation models. Precise determination of these parameters is essential because deviations in in-transit crude oil quality from expected ranges may impact both the OQB balance and the operating regimes of pipeline transportation systems.

Based on the experimental results, optimized BO-SO blending ratios can improve transport-related properties by reducing viscosity and stabilizing density, thereby decreasing pumping energy requirements and contributing to more efficient pipeline operation. Although these findings are promising from both practical and economic perspectives, large-scale validation under real transportation conditions is necessary before broader implementation.

Operating principles of Oil Quality Bank (OQB) systems in the American and European markets

Oil Quality Bank (OQB) systems have been widely adopted in large, integrated pipeline networks across North America and Europe to ensure fair compensation for quality changes occurring during transportation. Although their overarching goal – maintaining economic neutrality for shippers – is shared, the operational principles vary considerably between regions.

American OQB Systems. In the United States, OQB mechanisms are primarily associated with extensive offshore and on-shore crude oil transportation networks. One of the most prominent examples is the Cameron Highway Oil Pipeline System (CHOPS), which transports crude oil from deepwater fields in the Gulf of Mexico to refining hubs along the Texas Gulf Coast. The American OQB model applies correction factors based on two principal quality parameters: sulfur content and API gravity (density). Weighting factors of approximately 44% for sulfur and 31% for density are used to calculate economic adjustments. The system seeks to minimize either deterioration or enrichment of crude oil quality for individual producers by aligning the final blended crude delivered to refineries with the original quality of crude supplied to the network. Price differentials between benchmark crudes – most notably Louisiana Light Sweet (LLS) and South Green Canyon (SGC) – serve as the reference framework for financial settlements.

European OQB Systems. In Europe, OQB-type mechanisms are applied within regulated crude streams such as the North Sea, the Norwegian Continental Shelf, and interconnected offshore pipeline systems (e.g., the Forties Pipeline System and the Oseberg Blend). European OQB systems place strong emphasis on harmonized monitoring of density, sulfur content, acidity, and SARA composition. Financial settlements are linked to pricing differentials among regional benchmark crude oils such as Brent Blend and Oseberg. These systems operate under strict regulatory oversight, ensuring transparency, non-discriminatory access, and full traceability of quality-related adjustments. Compared with North American models, European systems rely more heavily on standardized reporting rules (EN/ISO standards) and formalized quality-neutral pipeline policies.

Comparison. Although both regions aim to provide equitable compensation for quality variations arising from blending and transportation, American OQB systems emphasize market-driven benchmark differentials, whereas European systems prioritize regulatory harmonization, standardized monitoring, and multi-parameter quality control. Together, these international practices offer valuable methodological insights for the development of a national OQB framework in Azerbaijan.

Conclusion

The proposed methodology and organizational framework for implementing an Oil Quality Bank are both practically feasible and economically justified, offering substantial long-term benefits. An OQB system enables the calculation of compensation payments to crude oil producers for quality changes occurring during pipeline transportation. When properly controlled and monitored, such a system allows for more effective management of the market value of Azerbaijani crude oil – both domestically and internationally – by aligning its quality characteristics with established industry standards.

In operational practice, the management of transportation and blending processes across Azerbaijan's oil-producing regions pursues two primary objectives within State Oil Company of the Azerbaijan Republic's (SOCAR) pipeline infrastructure. The first objective is to ensure a stable supply of high-quality commercial crude oil that meets the specifications required by domestic refineries. The second objective is to maximize foreign exchange revenues through the selection of optimal quality parameters for export blends, thereby enhancing the competitiveness and economic value of exported crude oil.

If the program for establishing an Oil Quality Bank is fully implemented, new opportunities will arise for revising

the economic terms of transportation contracts for crude oil and petroleum products. Through more efficient management of transport enterprises and improved coordination among stakeholders, the OQB framework can enhance transparency, strengthen equitable compensation mechanisms, and overall, reinforce the economic foundations of crude oil logistics.

Acknowledgements

The authors gratefully acknowledge the research council of State Oil Company of the Azerbaijan Republic (SOCAR) and Azerbaijan State University of Oil and Industry.

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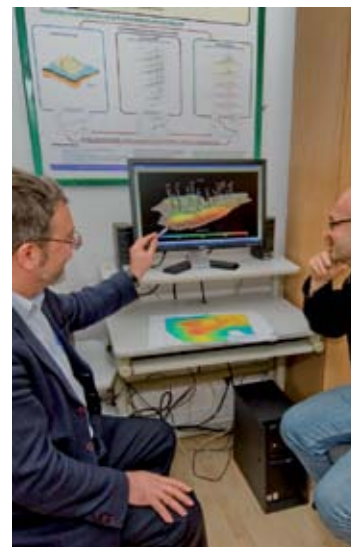
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OFERTA BADAWCZA ZAKŁADU SYMULACJI ZŁOŻ WĘGLOWODORÓW I PMG

- sporządzanie ilościowych charakterystyk złóż naftowych (konstruowanie statycznych modeli złożowych);
- analizy geostatystyczne dla potrzeb projektowania modeli złóż naftowych, w tym PMG i wielofazowych obliczeń wolumetrycznych;
- konstruowanie dynamicznych symulacyjnych modeli złóż i ich kalibracja;
- wszechstronne badania symulacyjne dla potrzeb:
 - weryfikacji zasobów płynów złożowych,
 - wtórnych metod zwiększania wydobywania (zatlaczanie gazu lub wody, procesy WAG, procesy wypierania mieszającego, oddziaływanie chemiczne),
 - optymalizacji rozwiercania i udostępniania złóż,
 - prognozowania złożowych i hydraulicznych (w tym termalnych) charakterystyk odwiertów (w szczególności poziomych) dla celów optymalnego ich projektowania,
 - sekwestracji CO₂;
- projektowanie, realizacja i wdrażanie systemów baz danych dla potrzeb górnictwa naftowego.



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