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Forecasting the characteristics of crude oil from the Druzhelyubivske oil and gas condensate field

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Abstract

Purpose. The study aims to determine the technological properties and fractional composition of oil from various wells in the Druzhelyubivske oil and gas condensate field (Ukraine). Special attention is paid to predicting the structural and group composition to justify the choice of the most appropriate processing technologies.

Methods. Standard analytical methods were employed to evaluate the physicochemical properties of the crude oil samples, including density, viscosity, water content, mechanical impurities, asphaltenes, resins, paraffins, and sulfur. Fractional distillation enabled the separation of oil into its light and heavy components. Experimental and statistical modeling were used to predict the structural composition based on key technical parameters. The average approximation errors, the coefficient of determination, and the Fisher criterion were used to assess the accuracy of the models.

Findings. It was found that the crude oil samples possess the properties of light oil, including low viscosity, low water and impurity content, and a favorable fractionation profile for further processing. The developed statistical models demonstrated high accuracy in predicting the content of the main chemical components. The results obtained indicate the potential for utilizing combined technologies, specifically catalytic cracking and hydrotreating, to enhance the yield of valuable petroleum products.

Originality. The work presents a comprehensive assessment of oil from the Druzhelyubivske field, which allows filling the gap in modern data on its composition and processing capabilities. For the first time, an approach to determining structural-group indicators (the content of paraffins, resins, and asphaltenes) based on physicochemical characteristics is pro-posed. The use of experimental and statistical modeling to predict these parameters is a new direction in optimizing technological solutions in oil refining.

Practical implications. The results obtained enable us to develop an effective refining strategy tailored to the characteristics of the Druzhelyubivske oil field. The correct choice of refining technologies will contribute to increasing product yield, reducing costs, and increasing economic efficiency. The proposed approach also simplifies the methodology for assessing oil composition and accelerates decision-making on the further development of individual wells.

Keywords: *crude oil, fractional composition, experimental and statistical modeling, oil refining, refining technology*

1. Introduction

The future of oil as a fuel depends on the complex interaction of economic, environmental, technological, and political factors [1], [2]. In particular, global climate change mitigation initiatives, such as the Paris Agreement and national carbon emission reduction programs [3], are putting significant pressure on the oil sector, stimulating the development of carbon-reducing technologies and a transition to cleaner energy sources. In this regard, there is increasing attention to renewable energy resources (solar, wind, bioenergy, hydropower) [4]-[7] and energy storage systems (batteries) [8], [9], which offer an alternative to traditional oil. Additionally, biofuels and synthetic fuels [10], [11] have the potential to reduce dependence on fossil fuels and mitigate carbon emissions.

Despite this, oil remains a critical raw material for many countries, including Ukraine [12]-[14], particularly in sectors where alternative energy sources have not yet been widely adopted. In particular, aviation, as one of the primary consumers of jet fuel, is almost entirely dependent on oil and petroleum products. Similarly, several industrial processes require specific petroleum products with specific physicochemical properties, which complicates the rapid replacement of traditional energy sources. Thus, oil, as a strategic raw material, ensures the stability of key economic and defense sectors, emphasizing the need to develop and maintain domestic oil production potential.

Ukraine's oil industry has traditionally been a vital source of energy and raw materials, supporting the functioning of the industrial sector and transportation system. The largest oil reserves are concentrated in the Poltava, Ivano-Frankivsk, and

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Sumy regions, with volumes of approximately 14-15 million tons per region [15]-[17]. Despite significant potential, the country's oil production remains relatively low and is showing a downward trend due to the depletion of reserves and insufficient development of new fields. This increases import dependence and highlights the need to intensify geological exploration and technological activities to increase self-sufficiency [18]-[20]. In this context, the development of small-tonnage fields, previously considered unpromising, is acquiring strategic importance, contributing to a reduction in import dependence and the expansion of domestic oil resources.

In Ukraine, exploration and development of oil and gas fields, as well as hydrocarbon production, are carried out in three regions: Eastern, Western, and Southern [12], [21]-[23]. The main ones include: Radchenkovske, Zachepilovske, Novogrigoryevske, Kachanovske, Anastasyevske, Rybalske, Prylukske, Trostyanetske, Starosambirske, Boryslavske, Dolinske, and Naddvornyanske. Studies of oil from key Ukrainian fields show a significant diversity of its physical and chemical properties. For example, oil from the Radchenkovske and Zachepilovske fields, located in the Dnipro-Donetsk Basin, is characterized by a low-sulfur composition, a density of about 850-860 kg/m^3, and relative lightness compared to other massifs. The Kachanivske and Rybalske fields exhibit similar characteristics, with oil classified as methane-naphthenic with a sulfur content of less than 0.5% [16], [24]. In the western region, for example, at the Starosamborske and Boryslavske fields in the Carpathian region, oil is characterized by higher viscosity and increased paraffin content, which determines specific processing technologies [25], [26]. These regional differences reflect the geological specifics of the reserves' occurrence and have a significant impact on the choice of oil production and refining methods in Ukraine [27], [28].

A comparative analysis of oil from Ukrainian fields with the benchmark international grades of Brent and Urals reveals several distinctive features. Oil from Ukrainian basins, such as the Dnipro-Donetsk (Radchenkovske, Zachepilovske) and Prykarpatske (Starosambirske, Boryslavske), is characterized by a lower sulfur content (usually less than 0.5%) and a density of 33-39°API, making it similar to light, sweet crude oils, such as Brent. While Brent has a density of 38-40°API and a sulfur content of less than 0.4%, Urals is a blend of heavier, higher-sulfur crude oils with a density of approximately 31-32°API and a sulfur content of 1.2-1.4% [29]-[32]. This difference determines the higher technological attractiveness of Ukrainian oil in terms of refining and obtaining light petroleum products, in contrast to Urals, which requires more complex and costly refining processes. Thus, Ukrainian oil is closer in many respects to the quality of Brent crude, which is an advantage in terms of refining flexibility and market competition.

Given these characteristics and comparative advantages of Ukrainian oil, the development of new or small-scale oil fields, previously considered unpromising, is significant for increasing production and improving the quality of crude. Studying the physical and chemical properties of oil from promising regions will optimize production and refining processes, ultimately improving the country's energy independence and competitiveness in the global market.

One such field is the Druzhelyubivske oil and gas condensate field. It is situated on the northern edge of Ukraine's eastern oil and gas region and is a significant hydrocarbon production facility [33]. Exploration work has identified seven hydrocarbon accumulations, including five gas condensate deposits, one gas condensate field with an oil rim, and one oil field.

A layered, vaulted structure, tectonic shielding, and lithological limitations characterize the deposits. All gas condensate deposits were brought into production, and oil deposit production began in 1983. Separate healthy patterns were designed for them, with a maximum of 22 operating wells in 1986; however, the most recent data on field development in the literature date back to 1994. Therefore, the objective of this study was to investigate the physicochemical properties of oil from the Druzhelyubivske field and determine optimal processing routes.

2. Materials and methods

2.1. Research area and raw materials

The research used oil extracted from the Druzhelyubivske oil and gas condensate field. This deposit is located in the Borovsky District of the Kharkiv Region, 4 km from the city-type village of Borova (Fig. 1).

Figure 1. Druzhelyubivske oil and gas condensate field within the national oil and gas regions

From the tectonic perspective [33] (Fig. 2), it is situated in the southeastern part of the northern slope of the Dnipro-Donetsk Basin. The uplift was detected by seismic exploration using the reflected wave method in the Middle and Lower Carboniferous formations. It was prepared as an object for oil and gas exploration in 1972. Drilling began in 1974, and an hour later, when testing well one from deposits of the Bashkir layer (productive 2, B-3, interval 2168-2284 m), a fountain of a gas-condensate mixture with a flow rate of 602 thousand cubic meters per day was obtained.

The geological structure of this region includes carbonate-terrigenous sediments of the lower (Tourney, Visey, Serpukhov layers), middle (Bashkir, Moscow layers), and upper Carboniferous, as well as Triassic, Jurassic, Cretaceous, Paleogene, Neogene, and Quaternary deposits [33]. In the Paleozoic deposits, on the roof of the B-3 horizon, the structure is a brachyanticline with a NW strike. The southwestern wing is disturbed by a landslide with an amplitude of about 180 m. The dimensions of the fold along the isogypsus are 2180 m, 3.4 by 1.6 km.

The mode of development for gas-condensate deposits is gas, with the manifestation of water pressure during subsequent well exploitation.

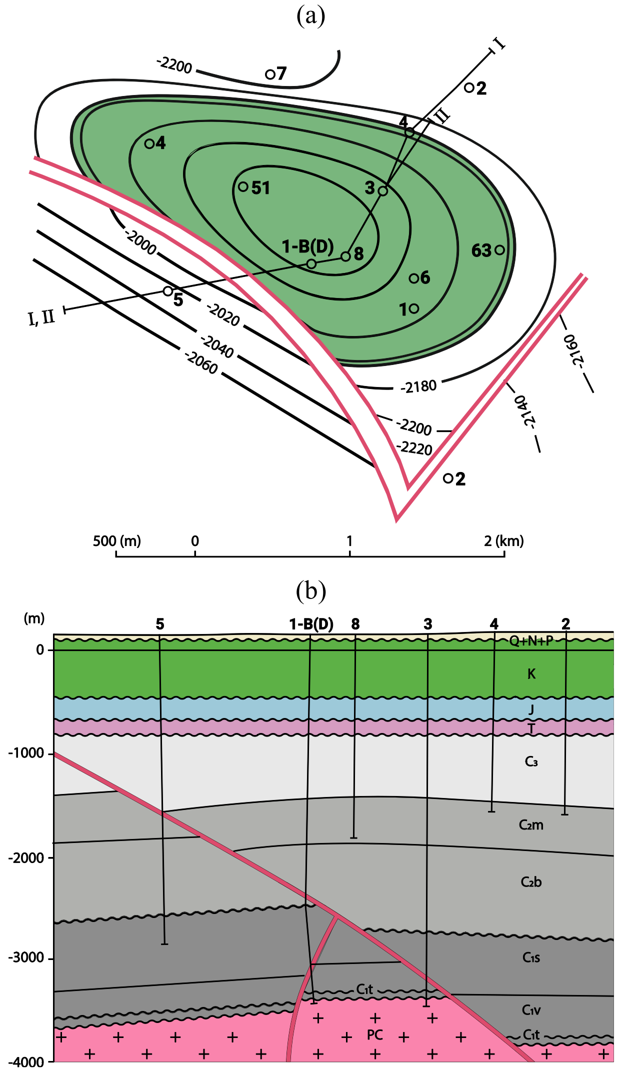

Figure 2. Geological characteristics of the area [33]: (a) structural map of the roof of the productive horizon B-3; (b) geological section along the I-I line

For oil deposits, the regime is water pressure (horizon M-5) and gas caps with water pressure (horizon M-4) (Fig. 3). 40% of gas and 49% of condensate from initial reserves were extracted from gas condensate deposits.

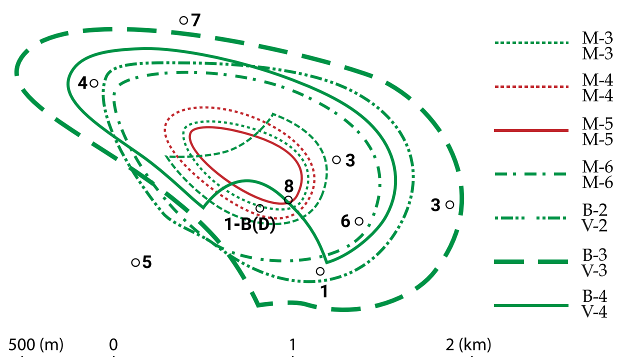

Figure 3. Scheme of drawing up the proposed contours [33]

Thus, to study the properties of oil from the Druzhelyubivske oil and gas condensate field, samples were taken from 7 wells (No. 54, 57, 58, 61, 67, 69, 70). The investigated samples are shown in Figure 4.

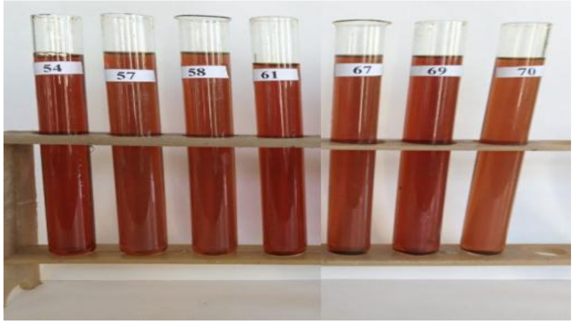

Figure 4. General view of the studied oil samples of the Druzhelyubivske oil and gas condensate field (the healthy number is indicated on the test tubes)

2.2. Methods

The indicators of the high-quality oil component, as well as its physicochemical and operational characteristics, which affect the quality of the produced products, are the most important for evaluating the oil. Therefore, the main physical and chemical properties parameters were determined using standard analysis methods for oil and oil products.

To determine the methods of further processing the studied oil and evaluate its quality and properties, we used the technical conditions "Oil for oil refining enterprises" [34]. To determine the methods of further processing of the studied oil, as well as to assess its quality and properties, the Technical Conditions "Oil for Oil Refineries" were used [34].

According to [35], the density of oil was determined at a constant temperature using a THG-1298 manual installation and an ANT-1 hydrometer. The kinematic viscosity was determined according to [36] in a thermostat by measuring the flow time of a specific volume of the tested oil at a given temperature under the influence of gravity using VZH-4 type viscometers. The water content in the studied samples was determined using the Dean-Stark method [37]. Straight-run gasoline was used as a solvent. Mechanical impurities were determined by the mass retained by membrane filters during the filtration of oil samples, as described in [38]. The salt content was measured according to [39] using the electrical conductivity method with an oil solution in an alcohol solvent, as determined by a laboratory salt meter. Using the ElvaX S Lab X-ray fluorescence analyzer, the sulfur content in the studied oil samples was determined according to the method [40]. Asphaltenes and resins were estimated according to [41] by precipitation from oil with excess n-heptane, followed by filtration and purification of the precipitate by washing with heptane and toluene. Their quantitative determination was carried out after the solvent had evaporated.

The pour point of the oil was determined according to [42] by controlled cooling with periodic flow testing, recording the minimum temperature at which mobility was maintained. The melting point of paraffins was determined according to [43] using the incandescence method, with registration of both melting and cooling temperatures. The fractional composition of the oil was determined according to the method [44] using the ARN-LAB-11 automatic apparatus at atmospheric pressure in the temperature range up to 400°C. The measurement accuracy was 0.1°C for the boiling point and 0.2 ml for the condensate volume. Regression experimental-statistical models, indicators of their adequacy, and other relevant calculations were performed using PP Statistaca.

To assess the adequacy of the obtained models, the selected values of the experimental factors (X_1-X_4) were substituted into the regression equation, and the expected values of the response functions Y_{ij}^{reg} were found, and the residuals were calculated:

$$\Delta Y_{ij} = Y_{ij}^{reg} - Y_{ij}, \quad (1)$$

where:

Y_{ij} – observed values of indicators obtained in the experiment and literature data;

Y_{ij}^{reg} – value of recall functions calculated by regression equations;

j – sample number;

i – number of equations for the studied indicator: $i = 1$ – linear model for paraffin content; $i = 2$ – linear model for the resin content; $i = 3$ – linear model for asphaltene content.

The adequacy of the models was assessed by the following parameters: average relative approximation errors (ε_i); determination coefficient (R_i^2), Fisher's criteria (F_i), and statistics $\left(F_{r_i}\right)$ [45], [46].

The Formula calculated the index of average relative error of approximation:

$$\varepsilon_i = \frac{1}{n}\sum_{j=1}^{n}\left|\frac{Y_{ij} - Y_{ij}^{reg}}{Y_{ij}}\right|, \quad (2)$$

where:

n – sample volume;

Y_{ij} – observed values of indicators obtained in the experiment and literature data;

Y_{ij}^{reg} – value of recall functions calculated by regression equations;

j – sample number;

i – equation number for the indicator under study.

The coefficient of determination (R^2), which characterizes the significance of the dependence of recall functions on process factors and takes values from 0 to 1, was determined according to the following methods [45], [46].

The measure of statistical significance of the correlation coefficient R_i^2 is the statistical criterion $\left(F_{r_i}\right)$, the value of which was calculated according to the Formula:

$$F_{r_i} = \frac{n - k_i - 1}{k_i} \cdot \frac{R_i^2}{1 - R_i^2}, \quad (3)$$

where:

k_i – number of coefficients of the regression equation without the free term.

If $F_{r_i} \le F_{rkr_i}$, then the null hypothesis H_0: (the regression equation is not statistically significant) is accepted. Otherwise, the alternative hypothesis H_1: (the regression equation is statistically significant) is accepted. If $F_{r_i} > F_{rkr_i}$, the null hypothesis is rejected, confirming that the regression equation is statistically significant at the chosen significance level α.

3. Results and discussion

As part of the study on the oil properties of the Druzhelyubivske oil and gas condensate field, detailed experiments were conducted to investigate its physical and chemical characteristics, which reflect key parameters of the oil, such as viscosity, density, fractional composition, and behavior under various conditions.

Based on the results of determining the density of the studied oil samples, as shown in Figure 5, it was found that the density of the samples at a standard temperature of 15°C ranges from 732.2 to 734.3 kg/m^3. According to [34], this oil can be classified as light oil (density less than 853.6 kg/m^3). As is known [47], light oil contains a high percentage of light fractions and is characterized by low viscosity, which facilitates its processing. Therefore, further studies were conducted to determine the viscosity.

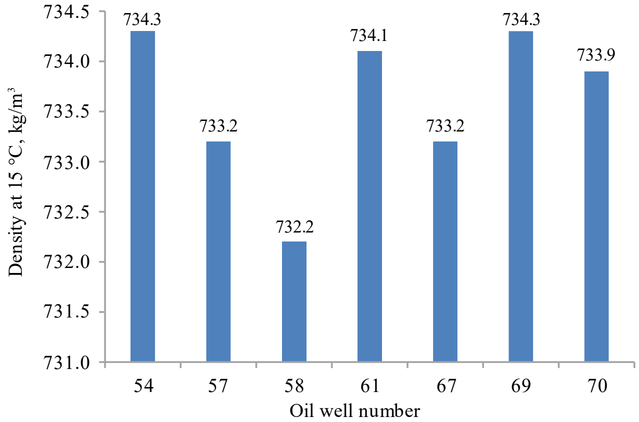

Figure 5. Density of investigated oil samples at 15°C

The low density of the investigated oil samples contributes to higher fluidity under normal conditions. Thus, Figure 6 shows the kinematic viscosity data at 20 and 50°C. The viscosity of the investigated oil samples decreases significantly with increasing temperature. At 20°C, the viscosity values range from 1.84 to 2.19 mm^2/s; at 50°C, the values decrease from 0.77 to 0.97 mm^2/s. This is typical of most hydrocarbon liquids, as intermolecular interaction decreases with increasing temperature, and the liquid becomes less viscous.

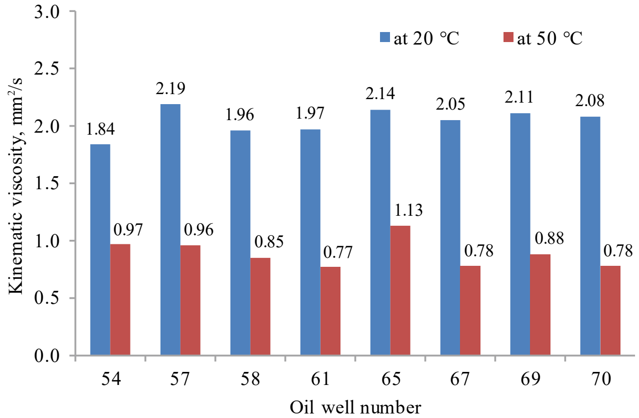

Figure 6. Kinematic viscosity of the investigated oil samples

The density of the crude oil under study at 15°C is approximately 733 kg/m^3, which is significantly lower than that of the benchmark Brent and Urals grades (approximately 835-871 kg/m^3), indicating a lighter crude structure. Kinematic viscosity at 20°C ranges from 1.84-2.19 mm²/s, and at 50°C, from 0.77-1.13 mm²/s, which corresponds to Brent values and is significantly lower than that of Urals. These characteristics indicate increased fluidity, which simplifies transportation and refining processes. Consequently, based on these physicochemical parameters, the crude oil is classified as a light grade, similar to Brent.

Further studies aimed to determine indicators such as water content, mechanical impurities, and the presence of salts.

No water content was detected in the studied oil samples, and the content of mechanical impurities is within the range of 0 to 0.03%. The obtained data indicate high oil purity with minimal contamination. The studied soil samples probably belong to high-quality grades or were extracted from fields with minimal accompanying impurities.

Salts in oil can adversely affect equipment used in the petrochemical industry by corroding pipelines and other equipment. Additionally, salts can contaminate water and other surrounding components during oil refining; therefore, controlling their content at all stages of extraction and refining is essential. Thus, Figure 7a summarizes the data on salt content in the oil samples studied. The salt content analysis indicates that the solution's composition is primarily homogeneous and meets the permissible indicators. This allows the use of the investigated samples without requiring additional purification in most cases. However, the detected minimum value (well No. 67 – 2.1 mg/dm^3) indicates the possibility of local deviations, so it is necessary to monitor and, if required, conduct additional studies to maintain stable quality.

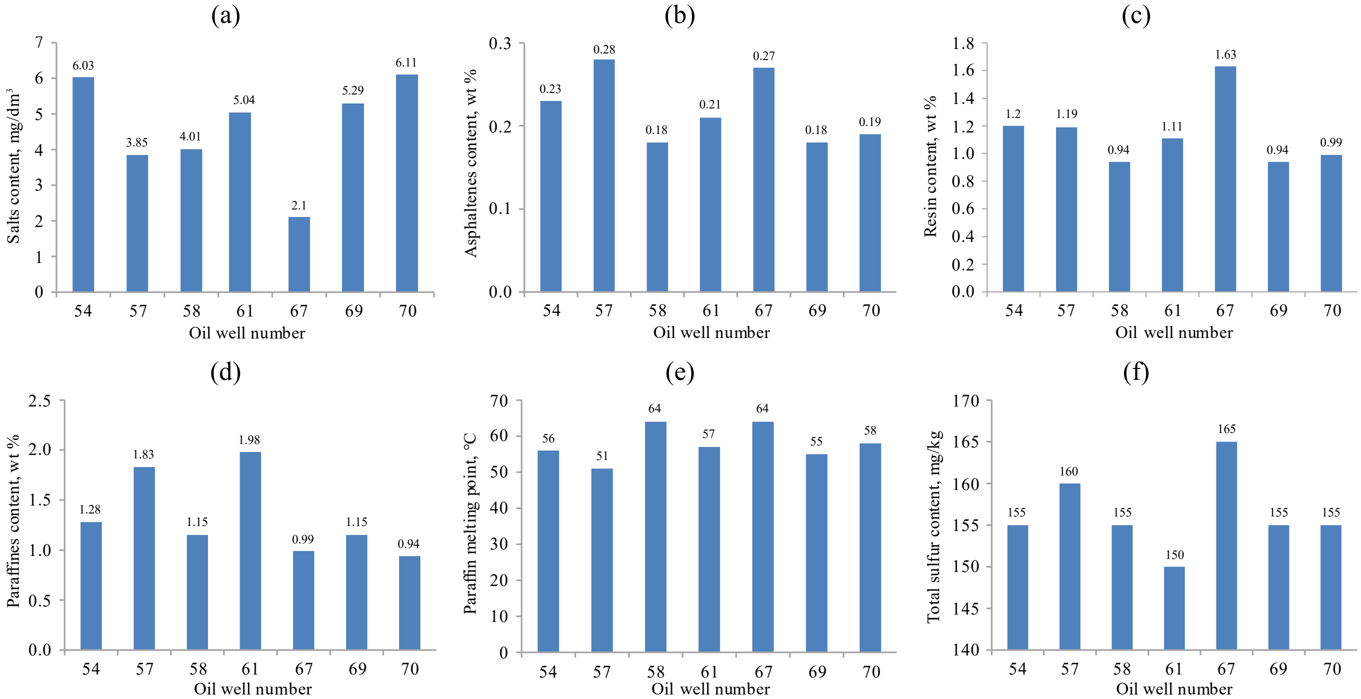

Figure 7. Composition characteristics of the investigated oil samples: (a) salt content; (b) asphaltene content; (c) resin content; (d) paraffin content; (e) paraffin melting point; (f) total sulfur content

Asphaltenes, paraffines, and resins are essential characteristics of oil. Determining the content of asphaltenes, paraffin, and resins in oil is a crucial task because these components significantly impact the properties, transportation, processing, and end-use of the oil. Therefore, Figures 7b-f show the data obtained to determine their content.

Thus, asphaltenes in the studied oil samples vary, with the minimum value ranging from 0.18 to 0.28%. The obtained data indicate that the studied samples belong to oil with a low content of asphaltenes, which is characteristic of light or medium-density oils. The investigated oil samples have good operational and refining characteristics in this connection. They are stable, easy to transport and refine, and yield predominantly light oil products. This makes it in demand for economically viable processing; however, for an objective assessment of the economic feasibility of processing, a comprehensive technical and financial analysis is necessary.

Tar in oil can affect the performance of processes such as cracking and distillation, resulting in lower yields of light fractions and higher levels of heavy fractions.

Resins in crude oil and asphaltenes are usually present in the composition and are part of the heavy fractions that can affect their physical and chemical properties. Resins generally give the oil a more viscous and dense consistency. Like asphaltenes, resins can cause problems in oil transportation and refining, as they can settle in pipelines or block catalytic processes in the petrochemical industry.

The obtained data on tar content in the studied samples are shown in Figure 7c. The data show that the tar content varies from 0.94 to 1.63%, indicating the diversity of oil composition. High values (1.63% for well No. 67) may indicate the presence of heavy hydrocarbon fractions, which can suggest high viscosity or density of the oil. In contrast, low tar content values (0.94 and 0.99% for wells No. 58 and 69) may indicate that the oil is lighter and has better refining characteristics. Thus, the oil under study has balanced properties. It is stable and relatively easy to transport and refine, but may yield slightly heavy fractions when refined. This oil is suitable for universal use, including the production of both light and heavy oil products.

Research data on paraffin content are shown in Figure 7d. Analysis of the obtained data reveals that the paraffin content ranges from 0.94 to 1.98%, indicating variations in oil composition. High values may indicate that more paraffin hydrocarbons are present in the oil, making it more viscous and prone to deposit formation at low temperatures. Low values (0.94 and 0.99% for wells No. 58 and 69) indicate fewer paraffins in these oil samples and may be more easily processed.

The melting points of paraffins shown in Figure 7e are in the range of 51-64°C. According to industrial and operational standards, the melting points of paraffins in the range of about 50-70°C are considered critical. At temperatures below this range, there is a risk of crystallization and precipitation of paraffins in the equipment, which can lead to blockages, reduced throughput, and increased wear of the equipment. Therefore, Ukrainian refineries processing oils with such a paraffin composition pay significant attention to temperature control and the use of antioxidant and dewaxing technologies to prevent difficulties associated with paraffin deposits. At melting points close to the lower thresholds (approximately 50-55°C), maintaining temperatures during transportation and primary processing above the melting point is crucial to keep the fluidity of the feedstock.

To produce high-quality fuels that meet modern environmental standards, sulfur content is a crucial indicator. This is particularly important for products such as diesel and jet fuel, where the presence of sulfur can lead to harmful emissions during combustion. Therefore, Figure 7f shows the data on sulfur content in the studied oil samples. The sulfur content varies from 150 to 165 mg/kg.

According to [34], the investigated oil is classified as low-sulfur oil. However, with a sulfur content of 150-165 mg/kg, the oil will require hydrotreating to meet environmental standards and ensure the production of high-quality end products. Hydrotreating will help reduce the sulfur content of petroleum products such as gasoline and diesel.

Additionally, we conducted a study to determine the fractional composition of the studied oil samples and predict their behavior during refining. The obtained data are shown in Table 1. The presented data show that oil is predominantly composed of light fractions. The distillation fraction ranges from 85 to 91%, indicating that the oil samples studied are predominantly composed of light hydrocarbons that boil at relatively low temperatures (up to 200°C).

This means the oil contains various fractions, including gasoline, kerosene, and diesel fuel. The distillation fraction (fractions that boil up to 200°C) is 76.92-82.35%, confirming the oil's high content of light fractions.

Table 1. Fractionation indicators of the studied oil samples

Indicators	Well number						
	54	57	58	61	67	69	70
Boiling point at °C	31	30	32	29	34	32	34
End of boiling at °C	310	360	305	307	360	313	322
Reflux fraction, %	87	91	87	85	89	87	88
Percentage of balance, %	13	9	13	15	11	13	12
Share of losses, %	0	0	0	0	0	0	0
Reflux fraction boiling point -200°C, %	80.45	76.92	79.31	82.35	78.65	81.6	79.54
Reflux fraction 200-300°C, %	18.39	9.89	19.54	16.47	19.10	17.24	19.31
Reflux fraction >300°C, %	1.16	13.19	1.15	1.18	2.25	1.16	1.15

The distillation fraction (fractions boiling at temperatures above 300°C) ranges from 1.12 to 13.19%. These fractions represent heavy hydrocarbons such as fuel oils, asphalts, and other products that require additional processing steps to obtain more valuable products.

The percentage of residue varies from 9 to 15%, which also confirms the presence of heavy components in the oil.

The boiling point of oil at different concentrations (10, 20, 30, 40, 50 and so on) shows that oil is mainly composed of light and medium fractions that boil between 59 and 265°C. Temperatures for the heavier fractions (above 300°C) indicate the presence of more viscous hydrocarbons that can be used to produce heavy products. At the same time, the distillation end temperature varies from 305 to 360°C, indicating that the oil may contain a significant proportion of heavy fractions, especially in its residual portion.

Crude oil with this composition (a high proportion of light fractions and a moderate proportion of heavy fractions) is suitable for refining into various petroleum products, including gasoline, diesel fuel, kerosene, and other chemical products [48], [49].

Comparing the physicochemical characteristics of the studied oil with reference grades such as Brent and Urals, it can be observed that the feedstock is more similar to light, low-sulfur Brent oil in several key parameters. The share of light fractions in the studied oil is primarily within the range of 77-82%, which corresponds to a good yield of gasoline and kerosene fractions, comparable to that of Brent. At the same time, the presence of fractions above 300°C and a residue of up to 15% indicates the need for more intensive hydrotreating and catalytic cracking processes, which are typical for refining oil with characteristics similar to those of Urals crude oil. Physicochemical properties, including density, kinematic viscosity at 20 and 50°C, mass fraction of water and mechanical impurities, as well as low sulfur and salt content, further confirm the lightness and relative purity of the studied oil. These characteristics indicate reduced technological difficulties during processing associated with the removal of harmful impurities and improved product quality.

Considering the complexity of the structure-group analysis definition, it is proposed to create the possibility of predicting the content of individual structures based on some technical analysis and fractional composition indicators.

The following recall function designations and key process control factors were used to determine the content of paraffin, resins, and asphaltenes:

– X_1 – density at 20°C, kg/m^3;
– X_2 – viscosity index, VI;
– X_3 – initial boiling point, °C;
– X_4 – reflux fraction > 300°C, %;
– Y_1 – paraffin content, %;
– Y_2 – resin content, %;
– Y_3 – asphaltenes content, %.

We obtained the following Equations:

$$Y_1 = -62.9407 - 0.0943X_1 + 0.0126X_2 - \\ -0.1806X_3 + 0.0527X_4; \quad (4)$$

$$Y_2 = -78.1477 + 0.1048X_1 + 0.0130X_2 + \\ +0.0501X_3 + 0.0514X_4; \quad (5)$$

$$Y_3 = -12.4690 + 0.0170X_1 + 0.0017X_2 + \\ +0.0045X_3 + 0.0117X_4. \quad (6)$$

Since the modulus of the correlation coefficients between all pairs of variables did not exceed 0.8, and the Variance Inflation Factor (VIF) in the obtained equations for each independent variable was less than 10, it is believed that the effect of multicollinearity is not observed; therefore, the regression models are acceptable for further analysis.

Substituting X_1-X_4 values for each sample into the above equations, we found the predicted values of the indicator obtained from the regression equation $\left(Y_{ij}^{reg}\right)$ and relative errors (ε_i) for Y_i, which are also given in Table 2.

Table 2. Experimental data, calculated values of recall functions, and relative errors for the parameters Y1, Y2, and Y3

Oil well number	X_1, kg/m^3	X_2, VI	X_3, °C	X_4, °C	Y_1, %	Y_1^{reg}, %	$Y_1\varepsilon_i$	Y_2, %	Y_2^{reg}, %	$Y_2\varepsilon_i$	Y_3, %	Y_3^{reg}, %	$Y_3\varepsilon_i$
54	730.2	78.516	31	1.16	1.28	1.38	0.0753	1.20	1.03	0.1410	0.23	0.20	0.1309
57	729.1	58.114	30	13.19	1.83	1.84	0.0006	1.19	1.22	0.0239	0.28	0.28	0.0121
58	728.1	91.253	32	1.15	1.15	1.16	0.0062	0.94	1.03	0.0918	0.18	0.19	0.0552
61	730.0	96.507	29	1.18	1.98	1.95	0.0174	1.11	1.15	0.0315	0.21	0.22	0.0363
67	729.1	93.606	34	2.25	0.99	0.98	0.0122	1.63	1.32	0.1911	0.27	0.23	0.1378
69	730.2	69.456	32	1.16	1.15	1.08	0.0591	0.94	0.96	0.0244	0.18	0.19	0.0520
70	729.8	90.731	34	1.15	0.94	0.95	0.0104	0.99	1.30	0.3110	0.19	0.23	0.1947

The following parameters assessed the adequacy of the models: mean relative approximation errors (ε_i); coefficient of determination (R_i^2), Fisher's criteria (F_i) and statistics $\left(F_{r_i}\right)$.

When checking the adequacy of the equations (Equations (4)-(6)), the following regularities were established.

A specific part of the residual $\left(\Delta Y_i = Y_{ij}^{reg} - Y_i\right)$, depicted in the histograms and probit plots (Fig. 8), is not centered around zero, indicating asymmetry and some violations of the assumptions of normality and autocorrelation.

The values of the coefficients of determination are: $R_1^2 = 0.9847$, $R_2^2 = 0.3408$, $R_3^2 = 0.6235$. That is, 98.47% of the change in recall functions (Y_1), 62.35% of the change in recall functions (Y_2) and only 34.08% of the change in recall functions (Y_3) are determined by the selected process control factors (X_1-X_4). The calculated values of the criterion statistic are: $F_{r_1} = 32.2430$, $F_{r_2} = 0.2585$, $F_{r_3} = 0.8279$. According to the table of values of Fisher's criterion at significance level $\alpha = 0{,}05$, the critical value is $F_{rkr_1} = F(0.05;4;2) = 19.2468$. This indicates the statistical significance of the correlation coefficient R_1 $\left(F_{rkr_1} < F_{r_1}\right)$.

The value of the correlation coefficient $R_1 = 0.9923$ indicates a very high linear correlation between factors Y_1 and X_1, X_2, X_3, X_4, as well as the average linear correlation between parameters Y_1 and parameters X_1, X_2, X_3, X_4, and the appropriateness of the assumption about the linear nature of the relationship. Note that the coefficients α_2 ($p < 0.1$), α_3 ($p < 0.05$), and α_4 ($p < 0.1$) are statistically significant for the parameters X_2, X_3, and X_4, respectively, in the linear regression equation for Y_1.

The values of the correlation coefficients ($R_2 = 0.5838$ and $R^3 = 0.7896$) and Fisher's criterion do not indicate the statistical significance of the correlation coefficients R^2 and R^3 $\left(F_{r_i} \le F_{rkr_i}\right)$. But their values indicate a significant impact of these indicators on Y_2 and Y_3.

Average relative errors of approximation are equal to $\varepsilon_1 = 0.0259$ (2.59%), $\varepsilon_2 = 0.1164$ (11.64%), $\varepsilon_3 = 0.0884$ (8.84%). According to recommendations, the prediction accuracy is high at ε = 0-10%; it is good at ε = 10-20%; and it is satisfactory at ε = 20-50%.

Although the values of the correlation coefficients do not indicate the statistical significance of the coefficients for Y_2 and Y_3, the other presented analysis indicators, along with the absence of multicollinearity, allow us to state that the regression models are acceptable for further work.

In general, the results obtained are in agreement with our works in this direction [50]-[54].

4. Conclusions

During comprehensive studies of the Druzhelyubivske oil and gas condensate field, the oil's primary physical and chemical properties were thoroughly studied and characterized using standard analysis methods for oil and petroleum products. Reproducible results were obtained, confirmed by calculations of the experimental statistical model adequacy indicators, which indicate high measurement accuracy and reliability.

Analysis of the oil's fractional composition revealed a balanced content of light and heavy hydrocarbon components, which is a crucial factor in selecting the optimal refining method. This ratio of fractions makes this oil a highly valuable raw material capable of producing a wide range of products – from light petroleum products (such as gasoline and kerosene) to heavy fractions (including oils and diesel fuel) with high added value.

Based on the data obtained, it is recommended to use process flowcharts focused on processing low-sulfur raw materials. In this case, the optimal solution is to utilize basic processes of primary distillation with hydrotreating, which will ensure a high yield of light petroleum products at minimal cost. At the same time, given the presence of a moderate amount of heavy fractions, it is necessary to provide for the introduction of catalytic cracking to increase the yield of light and medium fractions and reduce the proportion of heavy residues.

The proposed new approach to analyzing the structural and group composition of oil, based on standard quality indicators of the studied field, will simplify and accelerate decision-making on developing an effective oil processing strategy tailored to the specific characteristics of crude oil from this field or even a separate well. Currently, the research is limited to the Druzhelyubivske oil and gas condensate field. Still, it will be expanded and adapted by the authors to other low-yield and/or new fields in Ukraine.

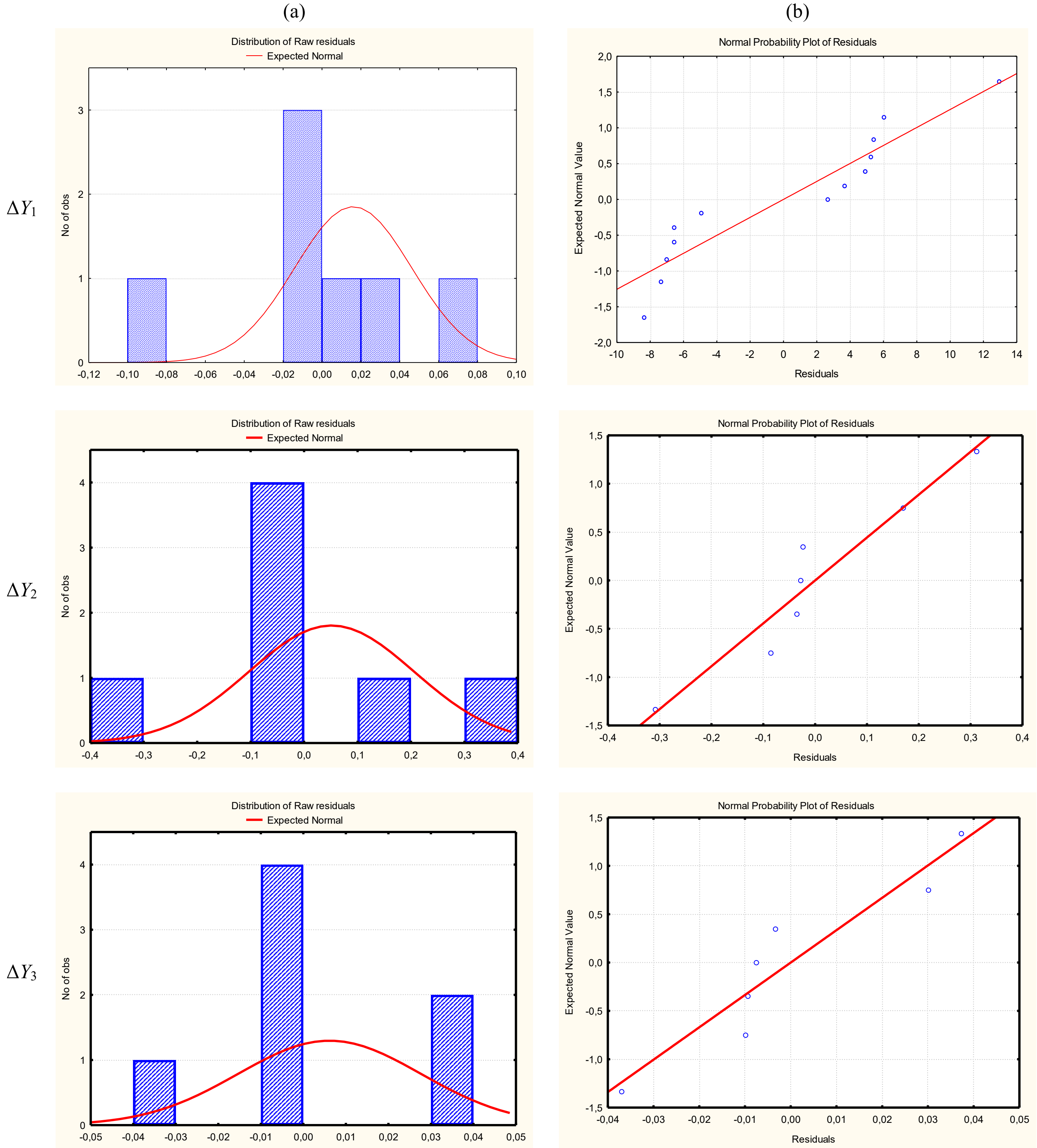

Figure 8. Distribution diagnostics of model residuals: (a) histogram of residuals; (b) probit plot of balances

Author contributions

Conceptualization: MC; Data curation: MC, HB, SP; Formal analysis: SP; Investigation: DM, YR, OB; Methodology: MC, HB, SP, YR, OB; Project administration: DM; Resources: DM; Software: HB; Supervision: DM; Visualization: MC, SP; Writing – original draft: DM, MC, HB, SP, YR, OB; Writing – review & editing: MC, SP, YR, OB. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Прогнозування характеристик нафти Дружелюбівського нафтогазоконденсатного родовища

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Мета. Дослідження спрямоване на визначення технологічних властивостей і фракційного складу нафти з різних свердловин Дружелюбівського нафтогазоконденсатного родовища (Україна). Окрему увагу приділено прогнозуванню структурно-групового складу для обґрунтування вибору найбільш доцільних технологій переробки.

Методика. Для оцінки фізико-хімічних властивостей зразків сирої нафти були використані стандартні аналітичні методи: визначення щільності, в’язкості, вмісту води, механічних домішок, асфальтенів, смол, парафінів та сірки. Фракційна перегонка дала змогу розподілити нафту на легкі та важкі компоненти. Для прогнозування структурного складу на основі ключових технічних параметрів застосовано експериментально-статистичне моделювання. Точність моделей оцінювали за середніми похибками апроксимації, коефіцієнтом детермінації та критерієм Фішера.

Результати. Виявлено, що зразки сирої нафти мають властивості легкої нафти – низьку в’язкість, незначний вміст води й домішок та сприятливий профіль фракціонування для подальшої переробки. Розроблені статистичні моделі продемонстрували високу точність прогнозування вмісту основних хімічних компонентів. Отримані результати свідчать про перспективність застосування комбінованих технологій, зокрема каталітичного крекінгу та гідроочищення, для підвищення виходу цінних нафтопродуктів.

Наукова новизна. У роботі подано комплексну оцінку нафти Дружелюбівського родовища, що дозволяє заповнити прогалину в сучасних даних щодо її складу та можливостей переробки. Уперше запропоновано підхід до визначення структурно-групових показників (вміст парафінів, смол і асфальтенів) на основі фізико-хімічних характеристик. Використання експериментально-статистичного моделювання для прогнозування цих параметрів є новим напрямом оптимізації технологічних рішень у нафтопереробці.

Практична значимість. Отримані результати дають змогу сформувати ефективну стратегію переробки, адаптовану до особливостей нафти Дружелюбівського родовища. Коректний вибір технологій переробки сприятиме підвищенню виходу продукції, зниженню витрат і підвищенню економічної ефективності. Запропонований підхід також спрощує методологію оцінки складу нафти та прискорює прийняття рішень щодо подальшої розробки окремих свердловин.

Ключові слова: *сира нафта, фракційний склад, експериментально-статистичне моделювання, переробка нафти, технологія переробки*

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