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EFFECT OF VALVE TRAYS AND SPIRAL-PRISMATIC PACKING 20×30 ON DISTILLATE FRACTION CHARACTERISTICS DURING RECTIFICATION

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Abstract: This paper analyzes the physicochemical properties of distillate fractions obtained during the rectification of an oil-gas condensate mixture (30% oil, 70% gas condensate). The study aimed to optimize hydrocarbon processing under temperature ranges 20–200°C and pressures of 1–5 atm. Experimental results showed that packed-valve and valve columns achieved up to 75% gasoline fractions and 15% heavy distillates. Infrared spectral analysis revealed: The first sample had peaks at 1606.7 cm⁻¹ and 1507.6 cm⁻¹, indicating high aromatic content, enhancing octane rating for gasoline and kerosene. The second sample showed fewer aromatics and a predominance of alkanes, making it more suitable for diesel production with a high cetane number and better combustibility. The findings are significant for the petrochemical industry, offering opportunities to improve processing efficiency and ensure greater environmental sustainability.

Keywords: oil-gas condensate mixture, rectification, gasoline, kerosene, diesel fuel, density, kinematic viscosity, fractional composition.

Introduction. The innovation strategy of the Republic of Uzbekistan prioritizes the creation of high-paying jobs through the adoption of modern technologies. Achieving this goal requires the development of strategic and practical programs tailored to the country's specific development priorities. The core approach is based on the principle of "innovation for high-tech jobs," which emphasizes the use of advanced technologies and scientific advancements to establish modern production facilities and generate well-paying employment opportunities. These initiatives are part of the 2022–2026 program, which aims to integrate innovative solutions and cutting-edge technologies into production processes. This approach is expected to foster sustainable economic growth and enhance the quality of life for the population [1].

Amid the globalization of the world economy, Uzbekistan faces several significant challenges, with a resource-oriented approach being particularly crucial. In this context, the production of high-value products from domestic oil fields has become an urgent priority.

It is well-known that thermal preparation of raw materials for distillation, along with their rectification, are energy-intensive processes at oil refineries. Given the continuous rise in oil and energy tariffs, many large refineries struggle to meet modern standards for the efficient use of electrical and thermal energy. This highlights the pressing need for improvements in various technological processes, including the thermal preparation (heating) of raw materials for distillation and the optimization of heat exchange equipment operations at refineries [2].

The study of the physical, physicochemical, and thermophysical properties of liquid hydrocarbon feedstocks and their distillation products is crucial for the accurate calculation and efficient organization of processes in oil distillation units [3]. Key quality indicators, such as density and viscosity of distillate fuel fractions, are significantly influenced by the feedstock composition, the type of heat carrier, and the technological distillation regime, including temperature and pressure within the atmospheric distillation column and its heat and mass transfer equipment [4–7]. This st udy focuses on local oils and gas condensates supplied to the Bukhara refinery, which were analyzed as the primary feedstocks [2].

Crude oil and its fractions are complex mixtures primarily composed of hydrocarbons, with minor amounts of impurities such as sulfur, nitrogen, oxygen, and metals. In Uzbekistan, oil refineries currently process oil-gas condensate mixtures, where the gas condensate content ranges from 30% to 70% [8]. Hydrocarbons vary in molecular weight, chemical composition, and structure, which adds complexity to the analysis of oil fractions, particularly those boiling above 215°C. Among the various fractions:

Gasoline (boiling range 30–215°C, hydrocarbons C5–C12) can be individually analyzed for its hydrocarbon composition. Kerosene (180–240°C, hydrocarbons C11–C15), Diesel fuel (240–360°C, hydrocarbons C15–C25), Vacuum gas oil (360–540°C, hydrocarbons C25–C45), and Vacuum residue (>540°C, hydrocarbons >C45) are too complex for precise hydrocarbon analysis due to their structural diversity and high molecular weight.

However, information about the composition of individual components of the feedstock and oil fractions is essential for evaluating existing refinery equipment (distillation columns, separators, etc.) or designing new equipment. Typically, undefined components are identified using a True Boiling Point (TBP) analysis and characterized by their average normal boiling point and specific gravity [9]. TBP analysis of oil and its fractions is generally performed using a laboratory column with theoretical plates operating at a reflux ratio of 5:1 [10].

Due to the high cost and lengthy process of TBP (True Boiling Point) analyses, alternative distillation methods are commonly used to evaluate the distillation characteristics of petroleum fractions [11]. In this study, we measured the density and viscosity of distillate fractions, including gasoline, kerosene, and diesel fuel, obtained from the distillation of oil, gas condensate, and their mixtures using an experimental distillation column (as part of a controlled experiment) [8].

This research focuses on the physicochemical properties of the oil-gas condensate mixture, as well as its resulting products from the Kokdumalak oil and gas condensate field, specifically from wells No. 1-4.

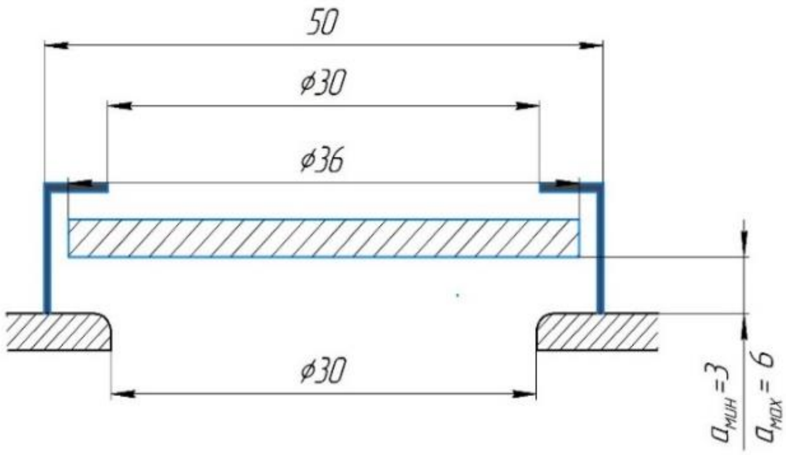


Fig. 1. Valve tray

Materials and Methods. The study examined oil-gas condensate mixtures (70% gas condensate, 30% oil) from the Kokdumalak field. Research was conducted at the Institute of General and Inorganic Chemistry, Academy of Sciences of Uzbekistan. In the "Processes and Apparatus of Chemical Technology" laboratory, an experimental system was developed to optimize the rectification of multicomponent mixtures under atmospheric and excess pressure conditions (Fig. 3).

Two experiments were conducted: one using a valve column (2) and the other using a valve-packed column. The experiment utilized two different types of sections: valve sections (2) and valve-packed sections (6), with a section height of 300 mm.

Each of the three valve sections (3) contains two circular contact trays (7) with a diameter of 36 mm, spaced 50 mm apart, and vapor openings of 30 mm. Valve diameters are 30 mm, with heights ranging from 3 to 6 mm. The oil-gas condensate mixture (30% oil, 70% gas condensate, 13.75 liters or 10 kg) is heated from 20 to 360°C, causing the evaporation of low-boiling components. Vapors pass through six valves, interact with condensing liquid, and flow down to lower trays via overflow tubes (8). The hydrocarbon vapors are then condensed and cooled in the condenser-cooler (3), with distillate collected in a calibrated receiver (4). Temperature and pressure are monitored using a thermometer and manometer.

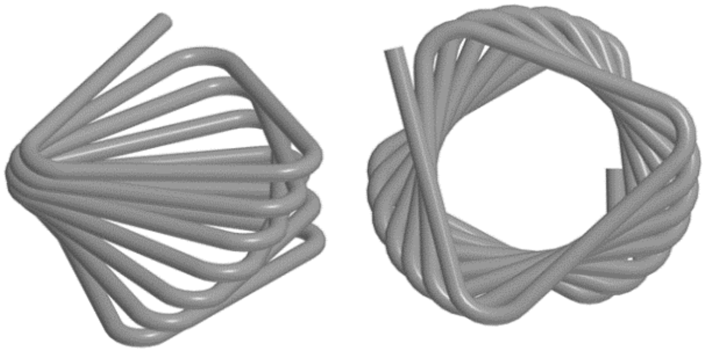
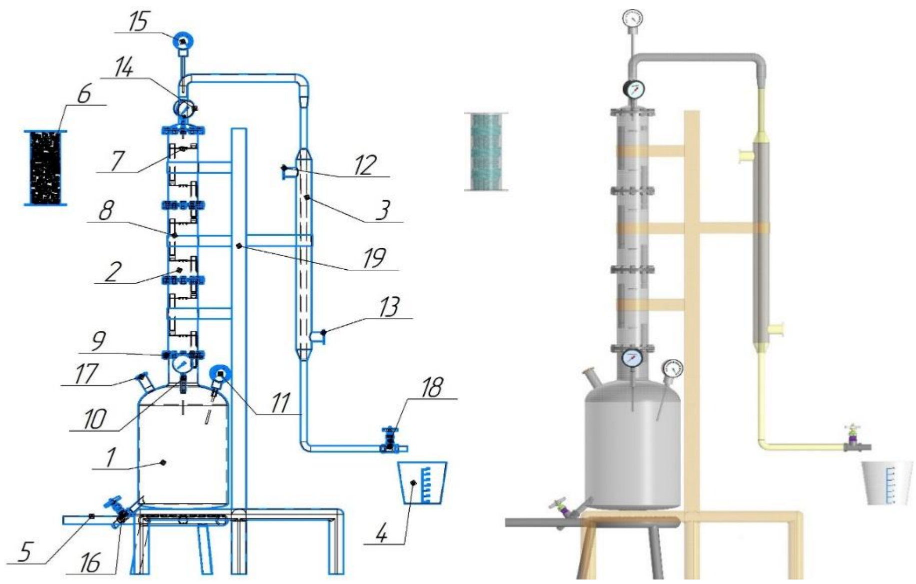


Fig. 2. The spiral-prismatic packing (20x30 mm)

In the second experiment, the upper column section is replaced with a packed section to increase vapor-liquid contact area. This enhances heat and mass transfer efficiency, resulting in improved separation of the mixture's components and greater distillation effectiveness.

The spiral-prismatic packing 20x30 mm (Fig.2) that we would like to recommend has not yet been used in the oil refining process. This packing has 20 turns in the form of triangles, each arranged at a rotational angle of 18 degrees relative to each other.

The efficiency of primary oil processing units (AT units) is one of the key factors in increasing the profitability of a refinery. This is due to the fact that, because of the energy-intensive nature of the rectification process and the high productivity of the raw materials, AT units are the largest energy consumers at refineries.



1 - column pot; 2 - valve section of the column; 3 - condenser-cooler; 4 - distillate collector; 5 - gas burner; 6 - packed section of the column; 7 - valve tray; 8 - overflow tube; 9 - flange connection; 10, 14 - manometer; 11, 15 - thermometer; 12 - inlet nozzle for cold water; 13 - outlet nozzle for water; 16, 18 - valve.

Fig. 3 – Experimental setup for studying the rectification process

The experiments were conducted at temperatures ranging from 20 to 350°C. The yield of light fractions from the oil-gas condensate mixture and the temperature of component separation were recorded. Standard methods for measuring boiling points and fraction yields were used. The equipment ensured precise temperature control and analysis of the composition of the resulting fractions.

During the experiment, the oil-gas condensate mixture was distilled using two types of columns: packed and valve. The process parameters, such as temperature and the mass fraction of the outgoing fractions, were recorded. The results obtained were plotted on a graph (Fig. 4) to compare the efficiency of the two column types. Special attention was given to the clarity of fraction separation and the conformity of the resulting products with quality standards.

In addition to distillation experiments, FT-IR spectroscopy was used to analyze light fractions from a mixture of 30% oil and 70% gas condensate. Distillation was performed using packed-valve and valve columns at 60–120°C to evaluate separation efficiency. Analysis on a PerkinElmer UATR Two/FT-IR Spectrum Two spectrometer (4000–450 cm^{-1}, 4 cm^{-1} resolution) focused on absorption bands of CH_2, CH_3 groups, and aromatic C=C bonds. This approach revealed structural details of hydrocarbons and variations in light fraction yields with temperature, enabling quality assessment of the products for different column types.

The distillation of the oil-gas condensate mixture (30% oil and 70% gas condensate), as well as gasoline, kerosene, and diesel fuel, was carried out on an experimental setup with valve and valve-packed sections. To determine the composition of the oil-gas condensate fractions, a method meeting the requirements of GOST 2177-99 and ISO 3405 [8, 10-11] was used.

In the experiments to determine the density of the feedstock and distillate samples at temperatures ranging from 20 to 360 °C, the Oscillating U-Tube Method was employed in accordance with ISO 12185 [3, 4] within the range of 600 kg/m^3 to 1100 kg/m^3, using an oscillating U-tube density meter. For this purpose, hydrometers of types ANT and AN for oil (Ukraine, TU3 14307481.008-95) [8] were applied.

The water content in the oil-gas condensate mixture and distillates was determined by the Dean and Stark method in accordance with GOST 2477-65. Mechanical impurities were identified using a Soxhlet extraction apparatus following GOST 6370-2018.

The cetane index of the diesel fuel was recalculated following the standards outlined in GOST 27768-88, utilizing the liquid's density and the boiling point of the 50% fraction determined through GOST 2177-82.

The sulfur content was determined using Spectroscan S in accordance with GOST R 51947-2002 and ASTM D 4294-98 protocols. To ensure accuracy, methods for determining deviations were applied as per GOST regulations, and two parallel measurements were averaged, maintaining a 95% confidence level, as required by the standard.

Results and Discussion. In this research, the key physicochemical characteristics and the composition of hydrocarbons in the oil-gas condensate blend (comprising 30%

oil and 70% gas condensate) were identified, along with the gasoline fraction obtained from the Kokdumalak oil-gas condensate field.

The fractional makeup of the oil-gas condensate blend was analyzed using an experimental apparatus, following ASTM 2892 and ASTM 5236 guidelines, and a True Boiling Point (TBP) curve was generated. The atmospheric distillation process of the oil up to 350°C is illustrated in Figure 4.

Valve Column (Curve 1): In this column, the initial temperature of fraction distillation is higher, and a more gradual increase in temperature is observed up to 350 °C. This profile indicates a more gradual evaporation of light fractions, which can lead to a more stable separation of heavy and light fractions. Packed-Valve Column (Curve 2): The temperature at the beginning of fraction distillation is lower compared to the valve column.

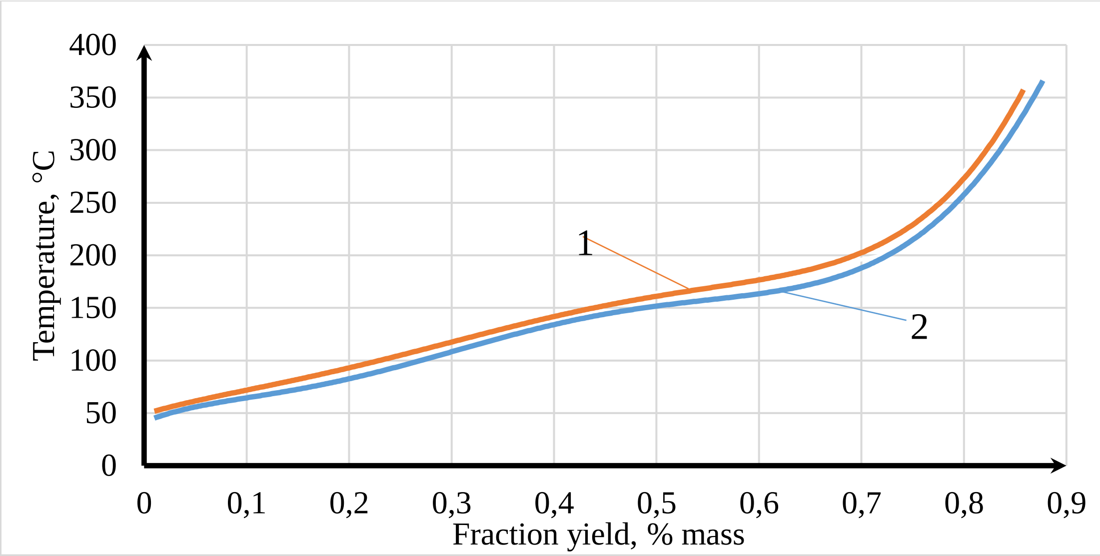


Fig. 4. Fractional Composition of an Oil-Gas Condensate Mixture (30% Oil, 70% Gas Condensate) in Packed-Valve (2) and Valve Columns (1).

The curve shows a sharper increase in temperature after 60% of the fraction yield. This indicates that light fractions are more actively released when using the packed-valve column. The packed-valve column (curve 2) provides more efficient extraction of light fractions at lower temperatures, indicating its high efficiency in fraction separation.

Analysis: The valve column (curve 1) demonstrates a more uniform fraction separation, which may be preferable when more precise control over the product composition is required. Based on the analysis of the graph, it can be concluded that the packed-valve column is more effective for the rapid and energy-efficient extraction of light fractions.

The experimental IR spectrum data showed the presence of characteristic absorption peaks for alkanes and aromatic compounds in light fractions of the oil-gas condensate mixture (30% oil + 70% gas condensate). Peaks corresponding to C-H stretching vibrations were observed, confirming the presence of aliphatic hydrocarbons.

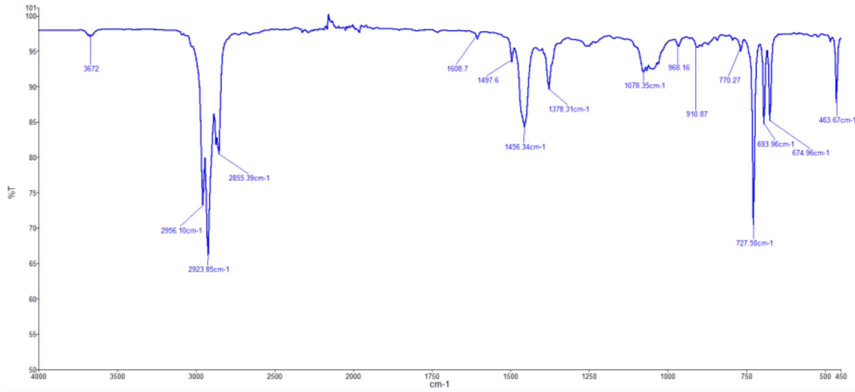


Fig. 5. Spectral analysis of the light fraction obtained from the packed-valve column

During the distillation of the oil-gas condensate mixture (30% oil, 70% gas condensate) at 60–120°C in a packed-valve column, the sample showed the following spectral results (Figure 5):

• 2923.85 cm⁻¹ and 2956.10 cm⁻¹: C–H stretching vibrations, indicating alkanes.

• 1456.34 cm⁻¹: C–H bending vibrations, confirming alkanes.

• 1606.7 cm⁻¹: C=C stretching, indicating aromatic hydrocarbons.

• 1507.6 cm⁻¹ and 1378.31 cm⁻¹: Aromatic C=C vibrations.

The results show a high content of alkanes and aromatics, making the fraction suitable for gasoline production due to improved volatility and octane rating.

During the distillation in the valve column under the same temperature conditions (60°C - 120°C), the second sample showed the following results (Figure 6):

• Peaks at 2925.07 cm⁻¹ and 2956.66 cm⁻¹: Similar to the first sample, these peaks indicate the presence of aliphatic compounds, characteristic of alkanes.

• Peak at 1455.84 cm⁻¹: Indicates C-H deformation vibrations, confirming the presence of alkanes.

• Absence of a distinct peak at 1606.7 cm⁻¹: Fewer peaks associated with aromatic hydrocarbons compared to the first sample, suggesting a lower content of aromatic compounds.

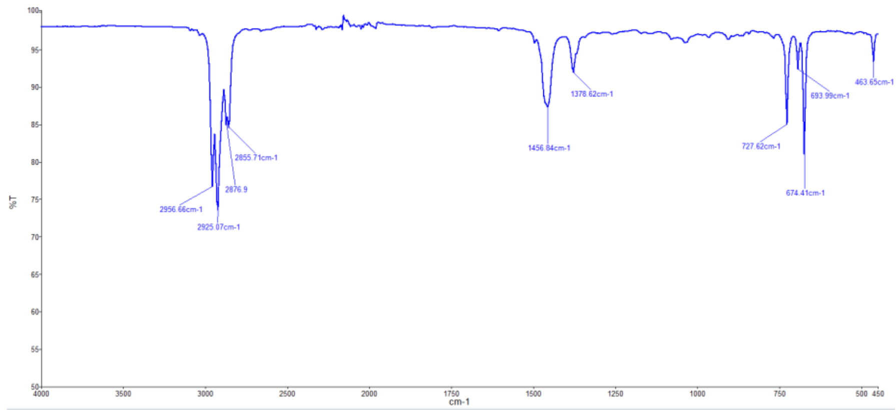


Fig.6. Spectral analysis of the light fraction obtained in the valve column

Thus, the second sample contains fewer aromatics, making it less suitable for gasoline production but better for diesel fuel, where low aromatic content enhances cetane number.

Table 1

Physicochemical characteristics of the oil-gas condensate mixture (30% oil + 70% gas condensate) from the Kokdumalak field

Parameters	Samples of Oil-Gas Condensate from the Kokdumalak Field			
Wells	Well No. 1	Well No. 2	Well No. 3	Well No. 4
Density at 20°C, kg/m³	760	763	767,5	770,8
Kinematic Viscosity at 20°C, mm²/s	1,415	1,421	1,432	1,448
Pour Point, °C	17	17	18	19
Mass Fraction of Water, % (max)	0,075	0,08	0,09	0,095
Mechanical Impurities Content, % (max)	0.037	0.030	0.032	0.035
Volume, % mass:				
- Sulfur	3,5	3,53	3,53	3,57
- Nitrogen	0,11	-	-	-
- Silicate Resins	3,5	4,9	4,6	2,7
- Asphaltenes	0,5	0,59	0,51	0,35
- Paraffins	1,95	2,6	3,87	2,1
Paraffin Pour Point, °C	45	46	47	48
Coking Ability, %	1.12	1.3	1.4	1.2
Ash Content, %	0.22	0.21	0.23	0.30
Acid Number, mg KOH/g	0.13	0.11	0.12	0.15
Fraction Yield, % mass:				
- Up to 200°C	74,2	72,5	71,4	69,2
- Up to 350°C	87,7	84.9	84.3	88.1

Further Study: Subsequently, we studied the physicochemical properties of the fractions obtained from the oil-gas condensate mixture (30% oil + 70% gas condensate)

during distillation in the packed-valve column.

Table 1 highlights the superior processing qualities of the oil-gas condensate mixture due to its low density (760 kg/m³) and kinematic viscosity (1.415 mm²/s at 20°C), indicating its lightness and excellent fluidity. The low water content (0.075%) and minimal mechanical impurities (0.037%) confirm its high purity, making Sample 1 the most suitable for processing compared to other samples.

The oil-gas condensate mixtures from the Kokdumalak field are classified as naphthenic-paraffinic type. According to the national standard O'zDSt 3031:2015, the mixture is designated as 2.0.1.0, reflecting its specific hydrocarbon profile. The studies reveal a significant presence of gasoline and kerosene fractions, classifying the mixture as light oil with densities ranging from 760 to 770.8 kg/m³ and kinematic viscosities between 1.415 and 1.448 mm²/s at 20°C.

Key characteristics include: Pour point: 17–19°C.Paraffin pour point: 45–48°C. Fractional composition: Up to 87.7% yield for fractions boiling within the 70–350°C range. Resin content: 2.7–4.9%. Asphaltene content: 0.35–0.59%.

For detailed distillate analysis, the physicochemical properties of gasoline, kerosene, diesel fuel, and oil distillates obtained from well No. 1 were studied. The gasoline properties are summarized in Table 2 and illustrated in Figure 7.

Figure 4 demonstrates the relationship between the density of the gasoline fraction at 20°C and the fraction yield as a function of distillation temperature. The data pertains to an oil-gas condensate mixture (30% oil + 70% gas condensate) obtained using a packed-valve column from the Kokdumalak field.

Blue Line (Left Y-Axis, Fraction Yield, %):

The **blue line** demonstrates the change in the yield of fractions as the distillation temperature increases. Initially, at a temperature of 52°C, the yield is about 4%. As the temperature rises to 180°C, the yield of light hydrocarbons also increases, reaching 72.25%. This trend indicates an effective separation of light hydrocarbons in the packed valve column, resulting in a higher yield of gasoline fractions.

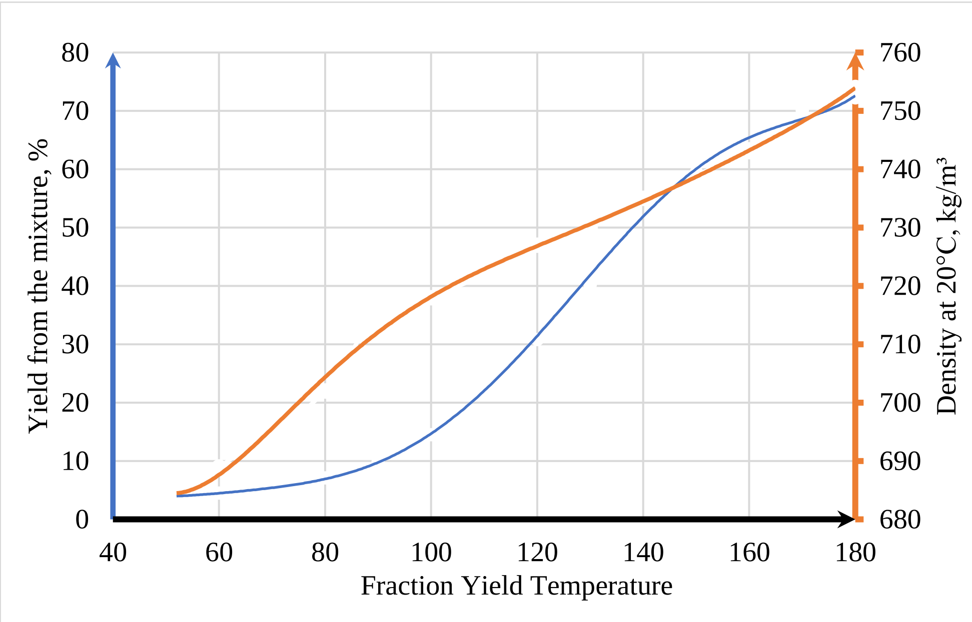


Fig. 7. Dependence of Yield and Density of Gasoline Fraction on Temperature

Orange Line (Right Y-Axis, Density at 20°C, kg/m³):

The **orange line** shows the variation in density with increasing temperature. The initial density at 52°C is 684 kg/m³, which reflects the predominance of light hydrocarbons. As the temperature increases, the density rises, reaching 754 kg/m³ at 180°C. This indicates a gradual transition to heavier hydrocarbons, which is characteristic of gasoline fractions.

Table 2

Physicochemical Properties of the Gasoline Fraction (200–180°C) of the Oil and Gas Condensate Mixture (30% Oil + 70% Gas Condensate) from the Kukdumlok Field

Temperature of Fraction Collection, °C (Initial Boiling Point)	Fractional Composition, °C Initial Boiling Point	10%	50%	90%	Sulfur Content, wt.%
До 52	-	-	-	-	
60	-	-	-	-	
70	-	-	-	-	
80	43	67	72	76	
90	48	72	84	88	
100	52	75	89	95	
110	57	78	92	105	
120	60	81	107	113	1.55
130	63	84	112	121	
140	67	87	117	129	
150	70	90	121	138	
160	72	92	126	148	
170	73	94	131	162	
180	78	96	136	171	

The physicochemical characteristics of the gasoline fraction from the oil-gas condensate mixture of the Kukdumalak field are summarized in Table 2. The data include fractional composition temperature points and sulfur content, reflecting the material's properties and its suitability for further processing.

The sulfur content in the gasoline fraction is 1.55% by mass, remaining constant across the temperature range of 52°C to 180°C. This highlights the need for further desulfurization, as elevated sulfur levels can degrade fuel performance and increase corrosive activity. The fractional composition illustrates the evaporation behavior of the mixture’s components at various temperatures. For example: At a distillation temperature of 80°C: Initial boiling point: 43°C. 10% evaporates at 67°C, 50% at 72°C, and 90% at 76°C.

This data shows a gradual transition from lighter hydrocarbons to heavier components, which begin evaporating at higher temperatures. As the temperature rises to 120°C–180°C, the complete evaporation of heavier hydrocarbons becomes evident, with boiling points increasing progressively for 10%, 50%, and 90% evaporation, reflecting the complexity of the hydrocarbon structure.

In summary, the gasoline fraction exhibits a wide evaporation range and stable sulfur content, emphasizing the necessity for further processing, such as desulfurization, to improve fuel quality and operational performance.

Conclusion. The study of physicochemical properties and infrared spectra of oil-gas condensate mixtures from the Kokdumalak field confirms their high potential for processing into valuable petroleum products.

Packed-valve column sample: Exhibited higher concentrations of aromatic hydrocarbons, as indicated by pronounced peaks at 1600 cm^{-1} and 1500 cm^{-1}. These compounds enhance the octane rating, making the sample suitable for gasoline production.

Valve column sample: Contained fewer aromatics, which is better suited for diesel fuel production due to its higher cetane number and improved combustion stability.
The analysis of the gasoline fraction (70–180°C) revealed low density (684–754 kg/m^3) and kinematic viscosity (0.4581–0.7517 mm^2/s), making it ideal for high-octane gasoline production, though sulfur desulfurization is required (content up to 1.55%).

Thus, oil-gas condensate mixtures from the Kokdumalak field show strong potential for producing high-quality gasoline and diesel fuels. Further optimization, particularly sulfur removal, is necessary to meet environmental standards and improve product quality. The studied fractions exhibit excellent combustion efficiency and energy characteristics, making them suitable for various applications across different climates.

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