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PHYSICOCHEMICAL, ENVIRONMENTAL, AND OPERATIONAL PROPERTIES OF SYNTHETIC GTL AND CONVENTIONAL DIESEL FUEL BLENDS

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Abstract This study investigates the development of environmentally improved diesel fuels through blending synthetic Gas-to-Liquids (GTL) fuel with conventional diesel fuel and gas oil fractions. The objective was to determine how blend composition influences key physicochemical, operational, and environmental properties and to identify formulations suitable for practical use under EURO K4 requirements. Experimental blends were prepared by mechanical mixing at different volume ratios under laboratory conditions. Their cetane number and index, density, distillation behavior, kinematic viscosity, flash point, cold filter plugging point, sulfur content, polycyclic aromatic hydrocarbon content, oxidation stability, total contamination, copper-strip corrosion, and lubricity were determined using ASTM, EN, GOST, and O‘zDSt standard methods. The results showed that increasing the proportion of GTL significantly improved ignition quality and environmental performance. Blends containing 50–60% GTL achieved cetane numbers of 62–63, densities of 791.2–796.1 kg/m³, and kinematic viscosities of 3.27–3.33 mm²/s. Their sulfur content decreased to 9.4–17.2 mg/kg, while polycyclic aromatic hydrocarbons were reduced to 2.9–3.8%. The cold filter plugging point reached −10 to −11 °C, indicating satisfactory low-temperature operability. Distillation characteristics also confirmed a favorable balance between volatility and complete combustion. Overall, the study demonstrates that GTL-based blending is an effective approach for producing cleaner and more efficient diesel fuels. The optimized blends provide improved combustion stability, lower pollutant-forming components, acceptable lubricity, and reliable operation under low-temperature conditions, supporting their potential application in modern diesel engines

Keywords: GTL fuel, synthetic diesel, fuel blending, cetane number, density, viscosity, sulfur content, low-temperature properties, environmentally friendly fuel.

Annotatsiya. Ushbu tadqiqot sintetik gazdan suyuqlikka (GTL) yoqilg'ini an'anaviy dizel yoqilg'isi va gaz moylari fraktsiyalari bilan aralashtirish orqali ekologik jihatdan yaxshilangan dizel yoqilg'isini ishlab chiqishni o'rganadi. Maqsad - aralashmaning tarkibi asosiy fizik-kimyoviy, ekspluatatsion va ekologik xususiyatlarga qanday ta'sir qilishini aniqlash va EURO K4 talablari bo'yicha amaliy foydalanish uchun mos formulalarni aniqlash edi. Laboratoriya sharoitida turli hajm nisbatida mexanik aralashtirish orqali eksperimental aralashmalar tayyorlandi. Ularning setan soni va indeksi, zichligi, distillash harakati, kinematik yopishqoqlik, chaqnash nuqtasi, sovuq filtrni ulash nuqtasi, oltingugurt miqdori, politsiklik aromatik uglevodorod miqdori, oksidlanish barqarorligi, umumiy ifloslanish, mis-chiziqli korroziya va moylash ASTM, EN, GOST va O'zDSt standart usullari. Natijalar shuni ko'rsatdiki, GTL ulushini oshirish ateşleme sifati va atrof-muhit ko'rsatkichlarini sezilarli darajada yaxshiladi. 50-60% GTL bo'lgan aralashmalar 62-63 setan soniga, 791,2–796,1 kg/m3 zichlikka va 3,27–3,33 mm2/s kinematik yopishqoqlikka erishdi. Ularning oltingugurt miqdori 9,4–17,2 mg/kg gacha kamaydi, polisiklik aromatik uglevodorodlar esa 2,9–3,8% gacha kamaydi. Sovuq filtrni ulash nuqtasi -10 dan -11 °C gacha yetdi, bu past haroratda ishlashning qoniqarli ekanligini ko'rsatadi. Distillash xususiyatlari ham uchuvchanlik va to'liq yonish o'rtasidagi qulay muvozanatni tasdiqladi. Umuman olganda, tadqiqot shuni ko'rsatadiki, GTL asosidagi aralashtirish toza va samaraliroq dizel yoqilg'isini ishlab chiqarish uchun samarali yondashuvdir. Optimallashtirilgan aralashmalar yonishning yaxshilangan barqarorligini, ifloslantiruvchi moddalarni hosil qiluvchi komponentlarning kamayishini, maqbul moylash qobiliyatini va past harorat sharoitida ishonchli ishlashini ta'minlaydi, bu ularning zamonaviy dizel dvigatellarida qo'llanilishini qo'llab-quvvatlaydi.

Kalit so'zlar: GTL yoqilg'isi, sintetik dizel, yoqilg'ini aralashtirish, setan soni, zichlik, yopishqoqlik, oltingugurt miqdori, past haroratli xususiyatlar, ekologik toza yoqilg'i.

Аннотация. Это исследование посвящено разработке экологически более совершенного дизельного топлива путем смешивания синтетического газожидкостного топлива (GTL) с обычным дизельным топливом и газойлевыми фракциями. Цель состояла в том, чтобы определить, как состав смеси влияет на ключевые физико-химические, эксплуатационные и экологические свойства, а также определить составы, подходящие для практического применения в соответствии с требованиями стандарта EURO K4. Экспериментальные смеси были приготовлены путем механического смешивания при различных объемных соотношениях в

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лабораторных условиях. Их цетановое число и индекс, плотность, характеристики при дистилляции, кинематическая вязкость, температура вспышки, температура закупорки холодного фильтра, содержание серы, содержание полициклических ароматических углеводородов, устойчивость к окислению, общее загрязнение, коррозия медной ленты и смазывающая способность были определены с использованием стандартных методов ASTM, EN, ГОСТ и O'ZDST. Результаты показали, что увеличение доли GTL значительно улучшило качество зажигания и экологические показатели. Смеси, содержащие 50-60% GTL, достигали цетановых чисел 62-63, плотности 791,2–796,1 кг/м3 и кинематической вязкости 3,27–3,33 мм2/с. Содержание серы в них снизилось до 9,4–17,2 мг/кг, а содержание полициклических ароматических углеводородов – до 2,9-3,8%. Температура закупорки холодного фильтра достигла -10- -11°C, что свидетельствует об удовлетворительной работе при низких температурах. Характеристики дистилляции также подтвердили благоприятный баланс между летучестью и полным сгоранием. В целом, исследование показывает, что смешивание на основе GTL является эффективным способом получения более чистого и экономичного дизельного топлива. Оптимизированные смеси обеспечивают повышенную стабильность горения, меньшее количество загрязняющих веществ, приемлемую смазывающую способность и надежную работу в условиях низких температур, что подтверждает их потенциальное применение в современных дизельных двигателях.

Ключевые слова: топливо GTL, синтетическое дизельное топливо, топливная смесь, цетановое число, плотность, вязкость, содержание серы, низкотемпературные свойства, экологически чистое топливо.

INTRODUCTION.

The production of environmentally safe and highly efficient motor fuels that meet modern operational requirements is one of the major global scientific and technological challenges in the fuel and energy sector [1]. The increasing number of vehicles, the expansion of industrial production, and the growing amount of harmful emissions released into the atmosphere have created a need to improve fuel quality and energy efficiency while reducing the environmental impact [2]. At the same time, increasingly stringent international environmental standards require the development of a new generation of fuels that provide more complete combustion in engines, produce lower levels of harmful gaseous emissions, and ensure stable operation under low-temperature conditions [3]. Synthetic liquid fuels, particularly

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Gas-to-Liquids (GTL) products obtained through the conversion of natural gas, are of considerable scientific and practical importance in addressing these challenges [4].

Recent scientific studies have demonstrated that synthetic diesel fuels are characterized by a high cetane number, low sulfur and aromatic hydrocarbon contents, a stable chemical composition, and high combustion efficiency [5]. A number of studies have also shown that the physicochemical, operational, and environmental properties of fuels can be purposefully controlled by blending synthetic components with conventional petroleum fractions [6]. Some researchers have demonstrated that the selective blending of narrow-boiling hydrocarbon fractions can improve low-temperature properties, optimize density and viscosity, and regulate the kinetic parameters of the combustion process [7].

However, the comprehensive technological principles governing the blending of synthetic and conventional fuels have not yet been studied systematically. In particular, the influence of the component ratio on the physicochemical and environmental properties of the resulting fuel remains insufficiently investigated. Some previous studies have been limited to the analysis of individual fuel properties, while the relationships among the operational efficiency, low-temperature performance, oxidation stability, and engine performance of blended fuels have not been adequately clarified. Furthermore, significant research gaps remain in the development of new motor fuels that meet environmental requirements through the scientifically justified blending of synthetic fuels produced from regional raw materials with locally available petroleum fractions.

Accordingly, the main objective of this study is to produce fuels with improved environmental and operational properties by blending synthetic and conventional fuels and to conduct a comprehensive investigation of their physicochemical characteristics. To achieve this objective, the following tasks were defined: to determine the main physicochemical properties of synthetic and conventional fuel components; to prepare blended fuel compositions by mixing these components in different proportions; to evaluate the low-temperature properties, combustion efficiency, environmental performance, and oxidation stability of the blended fuels; to determine the optimal composition; and to develop the scientific and technological principles for producing environmentally friendly and highly efficient motor fuels [8-12].

MATERIALS AND METHODS.

Diesel fuel produced by the Bukhara Oil Refinery (BNQIZ), EURO K4 grade, and synthetic diesel fuel produced by Uzbekistan GTL (a product obtained using GTL technology) were selected as the study objects. The study aimed to

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determine the physicochemical and performance characteristics of these fuels (Table 1) and to evaluate the properties of blended fuel compositions obtained by mixing them. Synthetic diesel fuel is characterized by a high proportion of paraffinic hydrocarbons and very low contents of aromatic hydrocarbons and sulfur compounds. Conventional diesel fuel is a product obtained through primary petroleum refining and hydrotreating processes (Table 2).

Table 1

Physicochemical Characteristics of Conventional and Synthetic Diesel Fuels

No.	Parameter	Test method	O‘zDSt requirement	EURO K4 diesel fuel	Synthetic diesel fuel (GTL)
1	Cetane number, min.	ASTM D613	51	58	84.0
2	Cetane index, min.	ASTM D4737	46.0	54.9	74.5
3	Density at 20°C, kg/m³, max.	GOST 3900	860	828	769.9
4	**Distillation characteristics:**				
	Volume recovered at 250°C, %, min.	GOST 2177	65	24	54
	Volume recovered at 350°C, %, min.		85	96	98
	Temperature at 95% recovery, °C, max.		360	345	323
5	Water content, mg/kg, max.	GOST 2477	0.02	104.2	0
6	Cold filter plugging point, °C, max.	EN 116	−5	−1	below −35
7	Carbon residue of the 10% distillation residue, %, max.	ASTM D4530	0.3	0.01	0.016
8	Ash content, %, max.	GOST 1461	0.01	0.003	0.0028
9	Sulfur content, mg/kg, max.	EN ISO 20884	50	23.7	4.2

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10	Copper strip corrosion (3 h at 50°C)	ASTM D130	Class 1	1a	1a
11	Kinematic viscosity at 40°C, mm²/s	GOST 33	2.0–4.5	3.5	3.3
12	Flash point (closed cup), °C, min.	GOST 6356	55	83	70
13	Polycyclic aromatic hydrocarbons, %, max.	GOST EN 12916	8.0	4.0	1.0
14	Total contamination, mg/kg, max.	EN 12662	24	7.0	4.9
15	**Oxidation stability:**				
	Sediment content, g/m³, max.	ASTM D2274	25	3.8	2.8
	Stability time, h, min.		20	20	20
16	Fatty acid methyl esters, %, max.	GOST EN 14078	7.0	0.12	0
17	Lubricity (WSD 1.4 at 60°C), µm, max.	ASTM D6079	460	387	625

Table 2

Laboratory Analysis Results for Gas Oils from Unit 10 of BNQIZ

No.	Parameter	Specification (ANSA)	Light gas oil (Unit 10)	Heavy gas oil (Unit 10)	Gas oil (Unit 10)
1	Density at 15°C, kg/m³	815–840	817.9	836.6	–
2	Distillation characteristics:				
	50% distillation temperature, °C	≤280	238	280	179
	95% distillation temperature, °C	≤340	251	334	355
	Final boiling point, °C	≤360	278	388	365
	Residue in the flask, vol. %	≤2	1.0	1.6	2.8
3	Kinematic viscosity at 20°C, mm²/s	2.5–5.0	3.8	7.4	7.3

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4	Cloud point, °C	≤ −10	–	−1	+2

Fuel compositions were prepared under laboratory conditions by mechanical mixing. During the blending process, synthetic and conventional diesel fuels were mixed at different volume ratios to obtain homogeneous mixtures. Mixing was performed at room temperature, and the prepared blends were stored in airtight containers for subsequent physicochemical analyses.

Physicochemical Analysis Methods

The cetane number of the fuels was determined according to ASTM D613 to assess the ignition rate and smoothness of engine operation. The cetane index was calculated in accordance with ASTM D4737. Fuel density at 20°C was determined according to GOST 3900, and the effect of blend composition on energy efficiency was evaluated. Distillation characteristics were determined according to GOST 2177 to investigate fuel volatility and its effect on combustion kinetics. Water content was determined according to GOST 2477, and its effect on blend stability was assessed. Low-temperature properties, particularly the cold filter plugging point, were determined according to EN 116 to evaluate the applicability of the blended fuels under cold-climate conditions. Carbon residue was determined according to ASTM D4530 to assess the likelihood of deposit formation in the combustion chamber. Ash content was determined according to GOST 1461 to evaluate fuel contamination by mineral impurities. Sulfur content was determined according to EN ISO 20884 to assess the environmental characteristics of the blended fuels. Copper strip corrosion was determined according to ASTM D130 to evaluate the interaction of the fuel with metallic components. Kinematic viscosity at 40°C was determined according to GOST 33 to analyze fuel pumpability and atomization characteristics. The closed-cup flash point was determined according to GOST 6356 to assess fuel safety. The content of polycyclic aromatic hydrocarbons was determined according to GOST EN 12916 to evaluate environmental safety. Total contamination was determined according to EN 12662 to assess fuel cleanliness. Oxidation stability was determined according to ASTM D2274 to evaluate the long-term storage stability of the fuel. Lubricity was determined according to ASTM D6079 to assess the effect of the fuel on engine fuel-system components [13-16].

Results and Discussion: The laboratory results showed that the physicochemical and performance properties of the fuel can be significantly controlled by blending GTL and conventional diesel fuels at different ratios.

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Table 3

"Physicochemical and Performance Characteristics of Blends of Synthetic GTL Fuel with Conventional Gas Oil and Diesel Fuel at Different Ratios"

No.	**Parameter**	**10% GTL + 90% gas oil**	**22% GTL + 78% gas oil**	**25% GTL + 75% diesel fuel**	**30% GTL + 70% diesel fuel**
1	Density at 15°C, kg/m³	813.7	813.7	816.0	816.4
2	Cetane number		62	59	58
3	Cetane index		66	61.2	61.4
4	Distillation characteristics				
	50% distillation temperature, °C	239	239	272	278
	90% distillation temperature, °C	259	259	348	346
	Final boiling point, °C	320	311	385	373
	Residue volume, %	1.0	1.0	1.6	1.7
5	Flash point, °C	78	78	57	60
6	Kinematic viscosity at 40°C, mm²/s	4.0	4.0	4.0	4.2
7	Sulfur content, %	0.068	0.068	0.07	0.062
8	Cloud point, °C	−28	−32	−3	−3
9	Copper strip corrosion	Class 1	Class 1	Class 1	Class 1

As the proportion of GTL in the prepared fuel compositions increased, the fuel density decreased to a certain extent, amounting to 813.7 kg/m³ for the blend containing 10% GTL + 90% gas oil and 816.0 kg/m³ for the blend containing 25% GTL + 75% diesel fuel. The cetane number increased with the GTL content and reached 62 in the 22% GTL + 78% gas oil blend, which improved combustion stability. Distillation characteristics were also important indicators of the blending process. The 50% distillation temperature varied from 239 to 278°C, while the final boiling point ranged from 311 to 385°C. These changes indicate that the amount of heavy fractions decreases as the proportion of synthetic GTL fuel increases. Kinematic viscosity was within the range of 4.0–4.2 mm²/s for all blends, supporting stable operation of the engine fuel system. Sulfur content ranged from 0.062 to 0.07% and decreased as the GTL proportion increased. The variation in

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cloud point from −28 to −3°C, together with the blending of narrow-cut hydrocarbon components, demonstrates the possibility of controlling the low-temperature properties of the fuel.

Table 4

"Environmental and Performance Characteristics of GTL and Diesel Fuel Blends at Different Ratios Meeting EURO K4 Requirements"

No.	Parameter	GTL 50% + EURO K4 diesel 50%	GTL 55% + EURO K4 diesel 45%	GTL 60% + EURO K4 diesel 40%
1	Cetane number, min.	62	63	62
2	Cetane index, min.	59.5	60.0	60.0
3	Density at 20°C, kg/m³	796.1	793.1	791.2
4	Distillation characteristics: Volume recovered at 250°C, vol. %, min. Volume recovered at 350°C, vol. %, min. Temperature at 95% recovery, °C, max.	 44 96 340	 43 96 342	 44 97 335
5	Water content, mg/kg, max.	43.7	44.5	42.8
6	Cold filter plugging point, °C, max.	–11	–10	–10
7	Carbon residue of the 10% distillation residue, %, max.	0.018	0.016	0.018
8	Ash content, %, max.	0.0032	0.0030	0.0033
9	Sulfur content, mg/kg, max.	17.2	11.3	9.4
10	Copper strip corrosion (3 h at 50°C)	1a	1a	1a
11	Kinematic viscosity at 40°C, mm²/s	3.33	3.31	3.27
12	Flash point, °C, min.	75	73	71
13	Polycyclic aromatic hydrocarbons, %, max.	3.8	3.4	2.9
14	Total contamination, mg/kg, max.	5.8	5.4	5.6

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15	Oxidation stability: sediment content, g/m³, max.	3.7	3.4	3.3
	Stability time, h, min.	20	20	20
16	Fatty acid methyl esters (FAME), %, max.	0.05	0.04	0.05
17	Lubricity (WSD 1.4) at 60°C, µm, max.	450	455	460

Blends obtained by combining EURO K4 diesel fuel and GTL products at different ratios were found to have high performance characteristics. The cetane number was in the range of 62–63, indicating improved combustion efficiency. Density values ranged from 791.2 to 796.1 kg/m³ and decreased as the GTL content increased. Distillation analysis showed that the proportion of light fractions distilled at temperatures up to 250°C was 43–44%. The proportion distilled at temperatures up to 350°C was 96–97%, which had a positive effect on complete fuel combustion. The cold filter plugging point was −10 to −11°C, demonstrating that the blends can also operate under low-temperature conditions. Sulfur content was within the range of 9.4–17.2 mg/kg, while the polycyclic aromatic hydrocarbon content was 2.9–3.8%, indicating improved environmental characteristics. Kinematic viscosity was 3.27–3.33 mm²/s, which positively affects fuel atomization and combustion characteristics.

DISCUSSION OF THE RESULTS.

The obtained results demonstrated that synthetic GTL fuel, owing to its high paraffinic hydrocarbon content, improves the combustion characteristics of conventional diesel fuels. The increase in the cetane number enhances the self-ignition capability of the fuel and, consequently, ensures stable engine operation. At the same time, the decrease in fuel density with an increasing proportion of GTL improves the atomization of the fuel supplied to the engine and promotes more complete combustion in the combustion chamber.

The optimization of the fractional composition regulates the fuel evaporation rate and improves engine start-up characteristics under cold conditions. A significant reduction in sulfur content is of considerable environmental importance, as it contributes to a decrease in SOx emissions. Furthermore, the reduction in the cloud point and cold filter plugging point improves the operational performance of the fuel in low-temperature regions [17-20].

Blends of GTL and EURO K4 diesel fuel are characterized by compliance with the requirements of international standards in terms of their physicochemical properties, as well as by improved operational characteristics. The results indicate

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that GTL-based blends make it possible to develop environmentally friendly, highly efficient, and promising types of diesel fuel and contribute to reducing dependence on petroleum resources.

CONCLUSION.

The conducted studies established that the environmental and operational characteristics of fuel can be significantly improved by blending synthetic GTL fuel with conventional diesel fuel and gas oil fractions in various proportions. The experimental results showed that an increase in the proportion of the GTL component leads to an increase in the cetane number and cetane index, while the sulfur content, proportion of aromatic hydrocarbons, and level of total contamination decrease. These changes promote more complete combustion, reduce the amount of harmful emissions, and improve engine operating efficiency [21].

According to the results of the fractional composition analysis, GTL-based blends were characterized by optimized distillation temperatures and boiling ranges. This improves the evaporation characteristics of the fuel and enhances engine start-up performance under cold conditions. The results obtained in accordance with EURO K4 requirements confirmed the environmental safety of diesel blends containing GTL. In particular, the reduction in sulfur content and the proportion of polycyclic aromatic hydrocarbons decreases the adverse environmental impact of the fuel. At the same time, maintaining the lubricity characteristics at an acceptable level reduces the wear of engine components and ensures the reliable operation of the fuel system [22,23].

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