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Evaluation of the Impact of Density on Selected Quality Control Tests of Petroleum Products at North Refineries Company (NRC), Baiji

Omar Abed Habeeb [1], Mahmod A. Abdulqader [2,3*], Muneef M. Mohammed [4], Mohammed Ali Ahmed[4], Ahmad Labib Khalaf[4], Yousif Saleh Mahmoud[4], Aisha Nafeh Mohammed[4]

[1] North Refineries Company (NRC) Baiji, Ministry of Oil, Iraq
[2,] Oil Products Distribution Company (OPDC), Salahuldeen Branch, Tikrit, Ministry of Oil, Iraq*
[3] Department of Petroleum Engineering, College of Engineering, Alnoor University, Mosul, Iraq
[4] Department of Petroleum and Refining Engineering, College of Petroleum and Mining Engineering, University of Mosul, Iraq

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Correspondence:
Mahmod A. Abdulqader
mahmodabdulkarem1978@gmail.com

ABSTRACT

This study aims to evaluate the effect of the density of petroleum products, including gasoline, kerosene, and gas oil, on selected quality control tests. Three types of petroleum products (gasoline, kerosene, and gas oil) obtained from the North Refineries Company (NRC), Baiji, were investigated. Three samples of each product were analyzed. The density of the petroleum products was determined using a hydrometer, while the octane number of gasoline was measured using a portable octane number analyzer. The flash point of kerosene and gas oil was determined using closed-cup and open-cup flash point testers. The results showed that the flash point of kerosene and gas oil increased with increasing density, whereas the octane number of gasoline decreased as density increased. Furthermore, the study recommends the periodic calibration of laboratory testing equipment and strict adherence to the specified upper and lower limits of quality control tests to ensure reliable and accurate results.

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تقييم تأثير الكثافة على بعض اختبارات ضبط الجودة للمنتجات النفطية في شركة مصافي الشمال/بيجي

عمر عبد حبيب [1]، محمود عبد القادر [2،3]*، منيف محمد محجوب [4]، محمد علي احمد [4]، احمد لبيب خلف [4]، يوسف صالح محمود [4]، عائشة نافع محمد[4]

[1]شركة مصافي الشمال بيجي، وزارة النفط، العراق

[2,3] شركة توزيع المنتجات النفطية، فرع صلاح الدين، تكريت، وزارة النفط، العراق*

[3] قسم هندسة النفط، كلية الهندسة، جامعة النور، الموصل، العراق

[4] قسم هندسة النفط والتكرير، كلية هندسة النفط والتعدين، جامعة الموصل، العراق

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المراسلة:

محمود عبدالكريم عبدلقادر

mahmodabdulkarem1978@gmail.com

الملخص

تهدف هذه الدراسة إلى تقييم تأثير كثافة المنتجات النفطية، وهي الكازولين والكيروسين وزيت الغاز، على بعض اختبارات ضبط الجودة. استُخدمت في هذه الدراسة ثلاثة أنواع من المنتجات النفطية (الكازولين، والكيروسين، وزيت الغاز) جُمعت من شركة مصافي الشمال/بيجي، مع إجراء ثلاث مكررات لكل منتج. حُسبت كثافة المنتجات النفطية اعتمادًا على الوزن النوعي، في حين تم تحديد رقم الأوكتان للكازولين باستخدام جهاز قياس رقم الأوكتان المحمول. كما تم قياس درجة الوميض للكيروسين وزيت الغاز باستخدام جهازي الكأس المغلق والكأس المفتوح. أظهرت النتائج أن درجة الوميض لكلٍ من الكيروسين وزيت الغاز تزداد بزيادة الكثافة، في حين ينخفض رقم الأوكتان للكازولين مع زيادة الكثافة. وتوصي الدراسة بضرورة المعايرة الدورية لأجهزة الفحص المختبرية، مع الالتزام بالحدود القياسية الدنيا والعليا لاختبارات ضبط الجودة لضمان دقة النتائج وموثوقيتها.

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Introduction

Crude oil is a complex liquid mixture composed of a vast number of hydrocarbon compounds consisting mainly of carbon and hydrogen in varying proportions. In addition, it contains small amounts of organic compounds containing sulfur, oxygen, nitrogen, and metals such as vanadium, nickel, iron, and copper (Ahmed Alwaise et al., 2023). The hydrogen-to-carbon ratio significantly affects the physical properties of crude oil. As the hydrogen-to-carbon ratio decreases, the density and boiling point of the hydrocarbon compounds increase. Conversely, a higher hydrogen-to-carbon ratio increases the value of crude oil for refinery processing. Crude oil is separated into various petroleum products through the distillation process. After the distillation of the most volatile fractions, such as naphtha, the first fuel oil fraction obtained is kerosene. The number of carbon atoms per molecule in kerosene

generally ranges from 10 to 16. The fraction remaining after distillation is highly viscous and consists mainly of high-molecular-weight hydrocarbons (Abdulqader et al., 2023).

The chemical composition of fuel oils varies considerably. Petroleum fuels consist primarily of n-paraffins (straight-chain saturated hydrocarbons), isoparaffins (branched-chain saturated hydrocarbons), naphthenes (cyclic saturated hydrocarbons), and aromatics (cyclic unsaturated hydrocarbons such as benzene and toluene) (Xu et al., 2025). Olefins (alkenes) are generally absent from petroleum products under normal conditions and are mainly formed during thermal cracking or refining processes. Nevertheless, olefins may constitute up to 30% of the gasoline fraction by weight (Abbas et al., 2025).

Density is one of the most important physical properties of petroleum products and serves as a key indicator of their quality. The composition, texture, and general characteristics of petroleum products can be estimated from their density (Alias et al., 2025). Therefore, density measurements are essential for quality control, transportation, storage, and commercial trade. At present, hydrometer and pycnometer methods are the most commonly used techniques for measuring the density of petroleum products, with the hydrometer method being more widely adopted because of its simplicity, speed, and high accuracy (Saleh, Saleh, et al., 2026).

Density is defined as the mass of a liquid per unit volume at 15.6 °C, whereas relative density is the ratio of the mass of a given volume of liquid at 15.6 °C to the mass of an equal volume of pure water at the same temperature. Specific gravity is numerically equivalent to relative density, and these terms are often used interchangeably (Hoellein et al., 2024). Petroleum products are commonly bought and sold on either a mass or volume basis, making density measurements essential for accurate conversion between these units (Khalaf et al., 2026). Consequently, the terms density, relative density, gravity, and specific gravity are closely related and are frequently used interchangeably in petroleum engineering (Abdulqader, 2026b). Although every liquid possesses a measurable density, this property is particularly important in the petroleum industry because it is used to classify crude oils and petroleum products from light to heavy grades (Khaleel et al., 2026).

Oil density is a critical quality parameter for lubricants, gasoline, kerosene, gas oil, and other petroleum products. It is used both to characterize petroleum products and to calculate additional fuel properties (Jassam et al., 2026). Deviations in the density of petroleum products may adversely affect quality control parameters, including the octane number of gasoline and the flash point of kerosene and gas oil, resulting in lower product quality and potential safety risks. Therefore, this study investigates the effect of petroleum product density on fuel specifications and its influence on critical quality parameters (Abdulqader, 2026a). Specifically, the study aims to determine the densities of gasoline, kerosene, and gas oil and to evaluate their effects on key quality tests. Furthermore, it seeks to identify the optimum density ranges that ensure satisfactory product performance during storage and use. The findings are expected to provide practical guidance for improving the quality of petroleum products produced at the North Refineries Company (NRC), Baiji, thereby enhancing operational efficiency while minimizing potential hazards such as explosions.

Materials and Methods

The samples gasoline, kerosene, and gas oil employed in this work to calculating their density were presented in Table 1. These samples were brought from (NRC) Baiji Al-shamal refinery. The devices used to achieve this research were also described in Table 2, at laboratory of college of petroleum and mining engineering, University of Mosul.

Table 1. Gasoline, kerosene, and gas oil fuel samples were used in this research

Sample	Samples	Laboratory name
Gasoline	Three	Laboratory of college of petroleum and mining engineering, University of Mosul
Kerosene	Three	Laboratory of college of petroleum and mining engineering, University of Mosul
Gas oil	Three	Laboratory of college of petroleum and mining engineering, University of Mosul

Table 2. Laboratory devices employed in physicochemical properties

Device name	Test	Laboratory name
Hydrometer	Sp. gr	Laboratory of college of petroleum and mining engineering, University of Mosul
Thermometer	Temp.	Laboratory of college of petroleum and mining engineering, University of Mosul
Flash point	F.P	Laboratory of college of petroleum and mining engineering, University of Mosul
Octane number	ON	Laboratory of college of petroleum and mining engineering, University of Mosul

Specific gravity

The specific gravity of petroleum products is a critical parameter that reflects the density of these substances relative to water. It is a dimensionless quantity that provides valuable information about the composition and energy content of petroleum fuels. Specific gravity is essential for various applications, including the calculation of higher heating values and the design of processing equipment. In the most commonly used method (ASTM D-1298), the sample is brought to the prescribed temperature and transferred into a cylinder at approximately the same temperature. The appropriate hydrometer is then carefully lowered into the sample and allowed to settle. After thermal equilibrium is reached, the hydrometer reading is recorded together with the sample temperature. Typically, the specific gravity of gasoline ranges from 0.700 to 0.750, kerosene from 0.750 to 0.800, and gas oil from 0.800 to 0.850 (Hameed et al., 2026).

API gravity

The API gravity of crude oil is an important physical property because it determines its price commercially. The accurate determination of the API gravity of petroleum and its products is necessary for the conversion of measured volumes to volumes at the standard temperature of 60°F (15.6 °C). Gravity is a factor governing the quality of crude oils. However, the gravity of a petroleum product is an uncertain indication of its quality. Correlated with other properties, gravity can be used to give approximate hydrocarbon composition and heat of combustion. This is usually accomplished through use of the API gravity, which is derived from the specific gravity, and it is also a critical measure for reflecting the quality of petroleum. It is one of the standard tests. (ASTM D-287, ASTM D-1298) (Mohammed et al., 2024).

$$API = \frac{141.5}{SG} - 131.5 \quad (1)$$

Table 3. Classification of crude oil according to API grade (Alzarqani & Alduhaidahawi, 2022)

Definition	API ranges	Viscosity	Color	Composition
Heavy	10 to 22.5	Too viscosity	Black or dark	Asphalt
Medium	22.5 to 31.5	Medium	-	Diesel and kerosene
Light	31.3 to 47	Fluid	Yellow	Gasoline

Flash point

Information on the flash point of petroleum products is essential because it indicates the initial stage of vaporization and the potential fire hazards associated with the fuel. The flash point is the lowest temperature at atmospheric pressure (760 mmHg, 101.3 kPa) at which the vapors of a sample ignite momentarily when exposed to a test flame under specified test conditions. The Pensky–Martens apparatus, operated in either a closed- or open-cup configuration, is the standard instrument used for flash point determination. An alternative method that does not confine the vapor, namely the Cleveland Open Cup (COC) method (ASTM D-92), generally produces slightly higher flash point values. Figure 1 shows the Cleveland Open Cup (COC) apparatus used for flash point determination (Liaw, 2024).

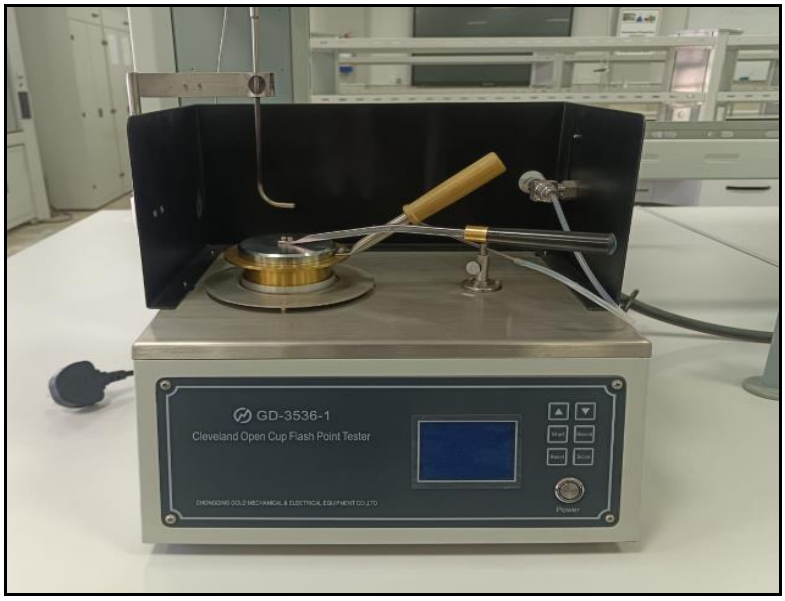


Fig. 1. Flash point open-Cup Cleveland open cup (COC)

The most common method of determining the flash point confines the vapor (closed cup method) until the instant the flame is applied ASTM D-93. The sample (kerosene or gas oil) was put in the cup, then put in the device, and the device started heating up and a flame was passed over it. When it flashes, it is the flash point. Fig. 2 shows the flash point Closed-Cup Pensky-Martens (PM) (Tugyi et al., 2024).

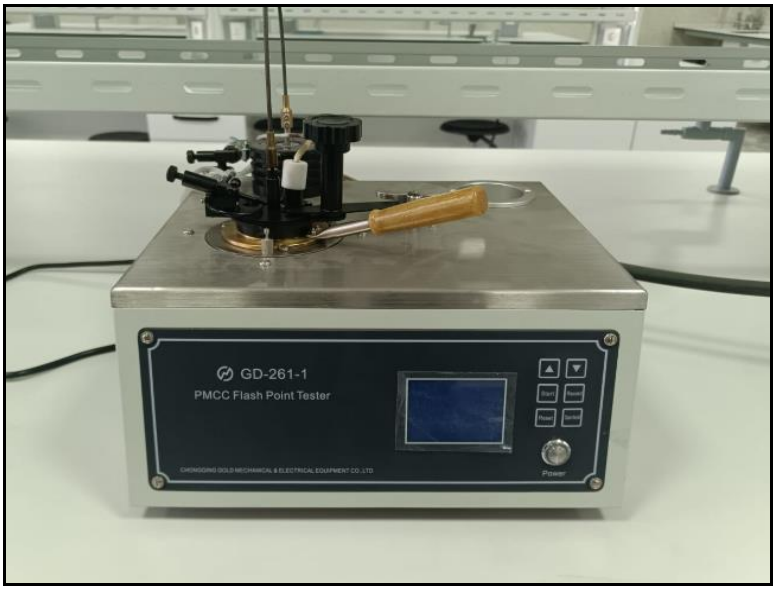


Fig.2. Flash point Closed-Cup Pensky-Martens (PM)

Octane number

Combustion in the spark-ignition engine depends chiefly on engine design and gasoline quality. Under ideal conditions, the flame initiated at the sparking plug spreads evenly across the combustion space until all the gasoline has been burned. The increase in temperature and pressure in the end gas zone causes the gasoline to undergo pre-flame reactions. The various types of hydrocarbons in gasoline behave differently in their pre-flame reactions and thus in their tendency to knock. The octane number can be measured using a portable octane number meter by placing the sample in the cup and turning it on. It gives MON and RON results, and the device works by measuring the dielectric properties of the sample compared to known information in memory and the octane number range (40-120) (Bamerni, 2024).



Fig. 3. Octane number device

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Results and discussions

Physical properties of gasoline fuel

The physical properties of gasoline fuel are presented in Table 4. The measured properties included density, specific gravity (Sp. gr.), American Petroleum Institute (API) gravity, and octane number (Research Octane Number, RON, and Motor Octane Number, MON). The density of the gasoline samples was measured in the laboratory at 51°F and corrected to the standard reference temperature of 60°F. Equation (1) was then used to calculate the API gravity. Previous studies reported that the specific gravity of gasoline typically ranges from 0.700 to 0.750 (Saleh, Ali, et al., 2026). Table 4 summarizes the measured physical properties of the gasoline fuel samples.

Table 4. Physical properties of gasoline fuel

Sample name	Density kg / m^3	Sp.gr	API	Octane Number	
				RON	MON
Gasoline 1	735.3	0.7353	60.94	93.8	84
Gasoline 2	733.3	0.7333	61.46	94.9	84.9
Gasoline 3	737.3	0.7373	60.42	92.8	83.7

Physical properties of kerosene fuel

The physical properties of kerosene are investigated in Table 5. This test included density, specific gravity (sp. gr.), American Petroleum Institute (API), and flash point. The density of kerosene samples was measured in the laboratory at a temperature of 51°F and corrected to the standard oil temperature of 60°F. Then, Equation No. 1 was applied to find API gravity. The previous studies showed the range of sp. gr. was 0.750-0.800 and the API gravity range of kerosene was 23.15-60 (ASTM D-3238) (Jassam et al., 2026). Table (5) shows the physical properties of kerosene fuel products.

Table 5. Physical properties of kerosene fuel

Sample name	Density kg / m^3	Sp.gr	API	F. P
Kerosene 1	787.6	0.7876	48.16	53
Kerosene 2	790.6	0.7906	47.48	55
Kerosene 3	789.6	0.7896	47.7	52

Physical properties of gas oil fuel

The physical properties of gas oil fuel are presented in Table 6. The measured properties included density, specific gravity (Sp. gr.), American Petroleum Institute (API) gravity, and flash point. The density of the gas oil samples was measured in the laboratory at 51°F and corrected to the standard reference temperature of 60°F. Equation (1) was then used to calculate the API gravity. Previous studies reported that the specific gravity of gas oil typically ranges from 0.800 to 0.850, while the API gravity generally ranges from 23.15 to 60. Table 6 summarizes the measured physical properties of the gas oil fuel samples.

Table 6. Physical properties of gasoil fuel

Sample name	Density kg / m^3	Sp.gr	API	F. P
Gasoil 1	809.7	0.8097	43.26	62
Gasoil 2	808.5	0.8085	43.52	60
Gasoil 3	818.7	0.8187	41.33	63

The effect of gasoline density on the octane number

The laboratory tests conducted on the gasoline samples at the College of Petroleum and Mining Engineering showed that the octane number increases as density decreases (i.e., the lower the density, the higher the octane number). In general, the octane number decreases with an increase in the boiling range (Abdulqader et al., 2021). An increase in the initial boiling point (I.B.P.) tends to reduce octane quality because the lighter components in gasoline have lower density and higher blending octane values. Therefore, increasing the I.B.P. significantly decreases the octane number (Saleh, Ali, et al., 2026). Figure 4 illustrates the inverse relationship between gasoline density and octane number.

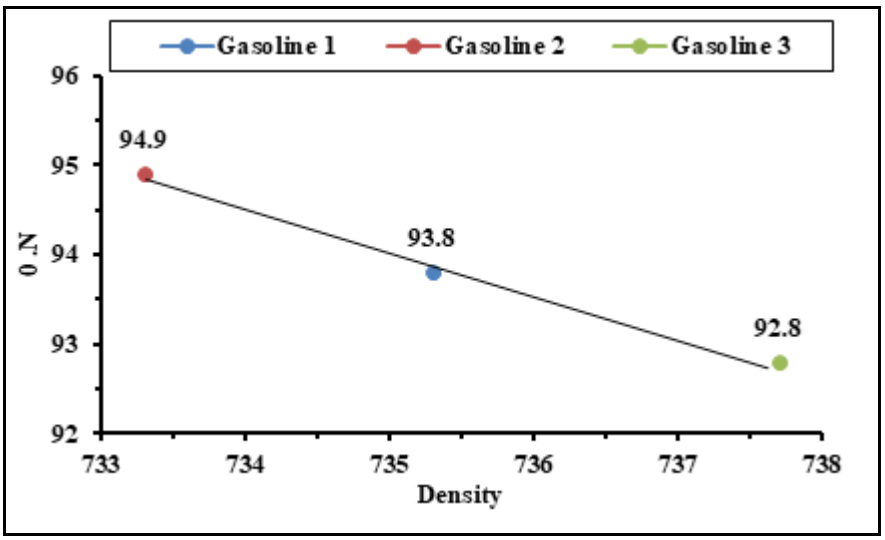


Fig. 4. Relationship between the density of the gasoline and the octane number

The effect of density on the flash point

Figures 5 and 6 present the laboratory test results for kerosene and gas oil samples analyzed at the College of Petroleum and Mining Engineering. The results show that samples with lower densities generally exhibited lower flash points, whereas samples with higher densities exhibited higher flash points (Mohammed & Al-Jubouri, n.d.). This positive relationship indicates that the flash point of petroleum products tends to increase with increasing density, which is consistent with previous studies (Abdulqader et al., 2021).

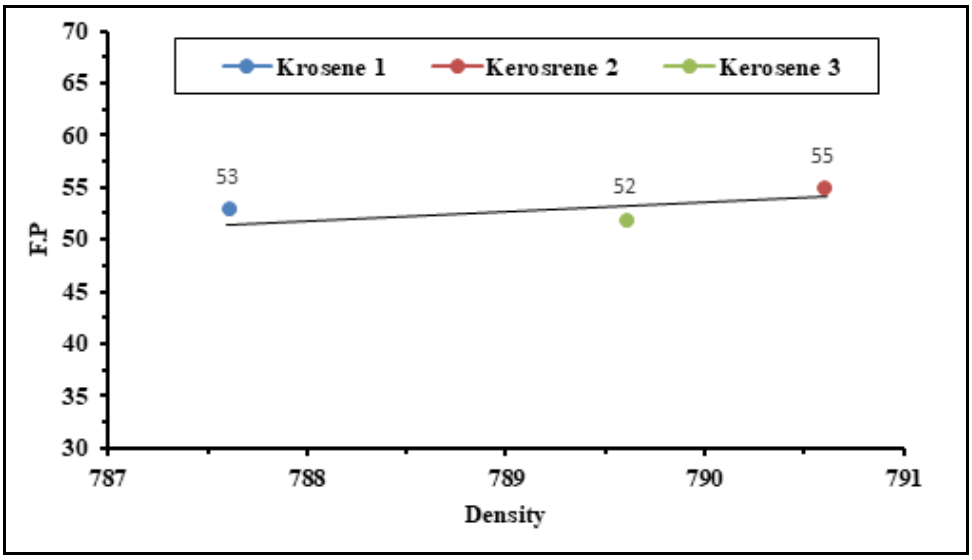


Fig. 5. Relationship between the density of kerosene and the flash point

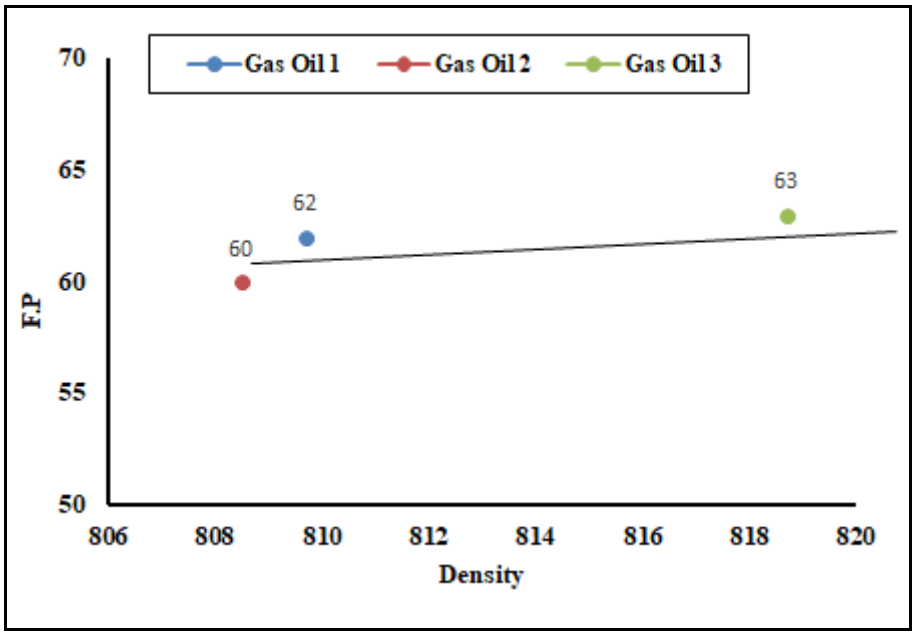


Fig. 6. Relationship between the density of gas oil and the flash point

Conclusions

The results showed that gasoline samples with lower density generally exhibited higher octane numbers, although this relationship also depends on the hydrocarbon composition. In contrast, the presence of light volatile hydrocarbons in kerosene and gas oil reduced the flash point, which may result in products failing to meet the required specifications. Therefore, when low flash point values are observed, distillation analysis should be performed to verify that the Initial Boiling Point (IBP) and End Boiling Point (EBP) comply with the standard specifications. The study also emphasizes the importance of maintaining the efficiency of the atmospheric distillation column, stripping towers, and stabilizer tower to ensure effective removal of light hydrocarbons. Finally, refinery laboratories should perform periodic

calibration of testing instruments in accordance with ASTM standards and conduct routine quality control tests to ensure reliable and accurate results.

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