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Study on the Impact of Naphtha and Light Fuel Oil on Key Quality Indicators of Gasoline and Diesel

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Abstract

The blending of naphtha and light fuel oil with gasoline and diesel during pipeline batch transportation poses risks of quality non-compliance. This study experimentally investigates the impact of these contaminants on key quality indicators to establish quantitative blending thresholds. Based on a volume-gradient experimental design (0–50 vol% for naphtha, 0–15 vol% for light fuel oil), diesel blends were tested for pour point, flash point, and 95% recovery temperature, while gasoline blends were tested for final boiling point, all in accordance with Chinese national standards. Results demonstrate that light fuel oil contamination in gasoline causes a linear increase in the final boiling point ($y = 18.77x + 185.09$, $R^2 = 0.91$), exceeding the 205 °C limit at concentrations above 1.2 vol%. Naphtha contamination in diesel leads to a sharp linear decline in flash point ($y = -13.20x + 101.83$, $R^2 = 0.84$), falling below the 60 °C threshold at concentrations above 3.0 vol%. Diesel pour point increases linearly with light fuel oil concentration ($y = 0.39x - 26.41$, $R^2 = 0.88$) but remains within specification up to 15 vol%. These quantitative thresholds, derived from statistically significant regression models, provide a scientific basis for optimizing cut-point strategies and mitigating safety risks in product oil pipeline operations.

Keywords: naphtha; light fuel oil; quality indicators; batch transportation; blending oil experiment

1. Introduction

Product oil pipelines are critical infrastructure for long-distance oil transportation, and their efficient operation is essential for energy security and economic development. Through batch transportation technology, large-scale pipelines can achieve the optimal allocation of product oil resources. Given their similar physical properties such as density and viscosity, naphtha and light fuel oil can be transported in adjacent batches within existing product oil pipelines, alongside gasoline and diesel. This approach reduces standalone transportation costs and enhances pipeline utilization efficiency.

During batch transportation of multiple oil products, blended oil is inevitably generated at the interface between different products. The blending of naphtha or light fuel oil with gasoline and diesel may cause key quality indicators to deviate from relevant standard requirements. Previous research on blended oil primarily encompasses two aspects: the diffusion behavior of oil mixtures and the evaluation of blended oil quality. Studies on diffusion have focused on mixture length prediction [1–5] and concentration distribution

Academic Editors: Nikolaos C. Kokkinos and Olivier Mathieu

Received: 23 January 2026
Revised: 25 April 2026
Accepted: 11 May 2026
Published: 14 May 2026

Fuels **2026**, *7*, 32 https://doi.org/10.3390/fuels7020032

characteristics [6,7]. However, the variation patterns of oil quality indicators under different blending concentrations require experimental determination.

Recent studies have provided deeper insights into the mechanisms governing the stability and quality of blended fuels. Mitsuova et al. [8] investigated the stability of high-viscosity marine fuels produced from residual fuel oil, visbreaking residue, and catalytic cracking light gas oil. They demonstrated that mixtures of straight-run residual fuel oil and catalytic cracking light gas oil are stable, whereas blending visbreaking residue with the same light gas oil leads to significant sludge formation. This incompatibility arises from the disruption of the asphaltene solvate shell, a structural barrier that prevents asphaltene association. Dispersing additives were shown to restore stability by keeping asphaltenes in a finely dispersed state. Sultanbekov et al. [9] explored controlled deasphalting of marine residual fuels by inducing incompatibility through the addition of waxy components. When highly paraffinic gasoil was mixed with residual fractions, asphaltenes and resins precipitated, forming sludge that contained a 4.5 times higher sulfur concentration than the original fuel. After sludge removal, the resulting deasphalted fuel exhibited a 15% reduction in sulfur content, along with improvements in density, viscosity, and pour point.

Beyond stability, the impact of transportation and storage conditions on fuel properties has also been examined. Klimov et al. [10] systematically evaluated the electrical conductivity of jet fuels under various factors encountered during logistics, including temperature changes, filtration, contact with water of different pH, contamination with other petroleum products, and exposure to corroded surfaces. Their results revealed that contamination with heavier petroleum products increases conductivity proportionally to the contaminant’s boiling point, attributed to the higher concentrations of polar heteroatomic compounds. This underscores the sensitivity of fuel quality to cross-contamination during handling and storage.

Studies specifically addressing gasoline and diesel blending have identified critical quality indicators. He Guoxi [11] proposed dimensionless characteristic numbers to quantitatively analyze blending tailing, establishing a validated mathematical model considering wall adsorption and turbulence effects. Zhao Huijun et al. [12] established a coupled hydro-thermal-hydraulic model using adaptive grid technology. Zhao Haiyan [13] used Fluent to simulate the effects of flow velocity and transportation sequence in inclined pipes. Zhao Yunpeng [14] established a BP neural network model for terminal blended concentration prediction using operational data from multiple pipelines. Zhuang [15] conducted indoor blending experiments on gasoline, diesel, and jet fuel, showing that 5% mutual blending of jet fuel and diesel maintains quality, while 1% gasoline in diesel causes flash point failure. Wei Daming et al. [16] studied the impact of blending gasoline, naphtha, and diesel into jet fuel, finding that gasoline or naphtha should not exceed 0.75% and diesel should not exceed 0.2%. Li Huiduo et al. [17] carried out gasoline–diesel blending experiments, pointing out that flash point is the most sensitive indicator when gasoline is blended into diesel, while final boiling point changes most significantly when diesel is blended into gasoline. Zhao Yue et al. [18] obtained critical blending concentrations of 0.6% for gasoline in diesel and 3.5% for diesel in gasoline. Wang Peixian et al. [19] systematically studied jet fuel blended with gasoline and diesel, finding that Saybolt color, final boiling point, freezing point, and actual gum are greatly affected by diesel. Tang Dongdong [20] established a TPG calculation model for modifying blended oil quality indicators based on carbon number distribution. Han Dong [21] found that chromaticity is the most sensitive indicator to diesel blending in jet fuel.

In summary, existing research has primarily focused on blending effects between gasoline and diesel, with relatively few studies on naphtha and light fuel oil combinations. This study investigates the impact of blending naphtha and light fuel oil on key quality indicators of gasoline and diesel, establishing quantitative correlation models to provide data support for batch transportation in product oil pipelines. It should be noted that while parameters such as octane number, cetane number, and kinematic viscosity are fundamental to the ultimate combustion performance of motor fuels in engines, the immediate operational priorities during pipeline batch transportation are safety and flow assurance. As such, in the context of pipeline logistics, indicators such as flash point (governing explosion risk), pour point (governing low-temperature flowability), and distillation limits are the primary and mandatory criteria used by operators to determine interface cutting strategies. Therefore, this study specifically targets these logistical quality indicators rather than end-use combustion parameters.

2. Materials and Methods

2.1. Experimental Framework

2.1.1. Experimental Standards

The key quality indicators of gasoline and diesel include pour point, flash point, and distillation range. The pour point was determined in accordance with the Standard Test Method for Pour Point of Petroleum Products (GB/T 510-2018) [22], and the pour point value was determined by controlling the oil temperature with a cooling bath and observing the liquid surface flow. The flash point was tested in accordance with the Determination of Flash Point—Pensky-Martens Closed Cup Method (GB/T 261-2021) [23], the heating rate was controlled as specified, and the initial flash temperature was recorded. The distillation range parameters were measured based on the Standard Test Method for Atmospheric Distillation Characteristics of Petroleum Products (GB/T 6536-2010) [24]. The entire distillation range of the oil was tested, and the distillation rate was kept stable to ensure the accuracy of the experimental results.

2.1.2. Data Acquisition and Processing

Data including blending concentration, pour point, flash point, recovery temperatures, and final boiling point were collected and organized. A multivariate regression analysis was employed to model the relationship between the blending concentrations and the key quality indicators. In this model, the concentrations of naphtha and light fuel oil served as the independent variables, while the pour point, flash point, 95% recovery temperature of diesel, and the final boiling point of gasoline were treated as the dependent variables.

To ensure the accuracy of the experimental results, the following measures were taken: (1) Graduated cylinders of different ranges were used to measure the volumes of the base oils (gasoline, diesel) and the blending components (naphtha, light fuel oil), respectively. (2) For the pour point and flash point experiments, each group of tests was repeated three times, and the results were averaged. (3) Abnormal data were inspected and eliminated to ensure data rationality.

2.2. Experimental Instruments and Methods

2.2.1. Pour Point Measurement

Pour point measurement was conducted using a SYD-510-1 petroleum product freezing point tester manufactured by Shanghai Changji Geological Instrument Co., Ltd., Shanghai, China, with the main apparatus including a round-bottom test tube, glass jacket, precision thermometer (0.5 °C division), support stand, constant temperature bath, coolant, and timer, as shown in Figure 1.

The test was performed according to GB/T 510-2018 [22] as follows: The oil sample was thoroughly shaken and poured into the test tube up to the marked line (approximately 15 mL), with a thermometer positioned vertically in the center of the tube and its bulb approximately 1 cm from the bottom. The test tube was placed in a water bath maintained at 50 °C until the sample became completely fluid. The coolant temperature was set to 7–8 °C below the expected pour point, and the test tube was inserted into the glass jacket and immersed in the coolant bath. When the temperature approached the expected pour point, the entire assembly was quickly tilted to 45° while kept immersed, then removed and held vertically to observe whether the liquid surface moved. If no movement was observed, the sample was reheated and tested with a coolant temperature 4 °C higher, and if movement occurred, the sample was reheated and tested with a coolant temperature 4 °C lower. This procedure was repeated until the critical temperature range was found, followed by finer adjustments (±2 °C) to determine the exact temperature at which the liquid ceased to flow, recorded as the pour point. Each measurement was repeated 3 times, and the average value was reported.

Figure 1. Experimental setup for measuring the pour point of oil products. The Chinese characters marked on the equipment represent the official brand and model name of the experimental instrument.

2.2.2. Flash Point Measurement

Flash point measurement was conducted using an SYD-5208D rapid closed cup flash point tester manufactured by Shanghai Changji Geological Instrument Co., Ltd., Shanghai, China, with the main apparatus including a sample cup, stirrer, heating plate, igniter, thermometer, barometer, and protective shield, as shown in Figure 2.

The test was performed according to GB/T 261-2021 [23] (the Pensky–Martens closed cup method) as follows: The sample cup was cleaned with gasoline and dried, the oil sample was shaken well and poured into the cup up to the marked line (approximately 2 mL), and after inserting the thermometer, the cup was placed on the heating plate with the ambient atmospheric pressure recorded. The igniter was adjusted to produce a flame of 3–4 mm in diameter. Heating was started at a constant rate with continuous stirring, and when the temperature reached 40 °C below the expected flash point, the heating rate was controlled to 2–3 °C per minute. When the temperature reached 10 °C below the expected flash point, the igniter was passed across the sample surface at each 1 °C increment to observe any flash, and the temperature at which the first blue flash occurred was recorded. If no further flash appeared after the initial ignition, the test was repeated with a fresh sample. Each test was repeated 3 times, and the average value (corrected to standard atmospheric pressure if necessary) was taken as the final flash point.

Figure 2. Experimental setup for determining the flash point of oil products. The Chinese characters marked on the equipment represent the official brand and model name of the experimental instrument.

2.2.3. Distillation Range Measurement

Distillation range measurement was conducted using an SYD-6536B-1 petroleum product distillation tester manufactured by Shanghai Changji Geological Instrument Co., Ltd., Shanghai China, with the main apparatus including a distillation flask (100 mL), condenser, graduated cylinder (100 mL), thermometer (0.5 °C division), heating source, support stand, and asbestos mat, as shown in Figure 3.

Figure 3. Experimental setup for measuring the distillation range of oil products. The Chinese characters marked on the equipment represent the official brand and model name of the experimental instrument.

The test was performed according to GB/T 6536-2010 [24] as follows: The condenser tube was cleaned, and tap water at ambient temperature (not exceeding 30 °C) was circulated through the condenser jacket. The oil sample was shaken well, and 100 mL of the sample (maintained at 20 ± 3 °C) was transferred into the distillation flask with a few boiling chips added; the thermometer was positioned with its bulb aligned with the lower end of the side tube, and the flask was connected to the condenser with a tight seal.

Heating was initiated with the atmospheric pressure and the start time recorded; when the first drop fell into the graduated cylinder the initial boiling point was recorded; and the heating rate was adjusted to maintain a collection rate of 4–5 mL per minute (approximately 2–3 drops per second). When the recovered volume reached 90 mL, the heating rate was increased to complete distillation within 5 min, and the final boiling point was recorded. Heating was stopped and the flask was allowed to cool for 5 min before disassembly, with carbon deposits not completely removed after each run but excessive deposits cleaned with a chromic acid solution. Due to the large number of test groups, long duration of each test (approximately 2–3 h per sample), and high oil consumption (approximately 150 mL per test), replicate measurements were not performed for distillation range parameters, however the stability and repeatability of the apparatus were verified using reference samples prior to testing.

2.2.4. Preparation of Blended Oil Samples

All blending concentrations in this study are expressed as volume fractions (vol%), a choice based on industrial practice: in pipeline batch transportation, the mixing ratio of different oil products is typically controlled and measured by volume, and using volume fractions ensures that the experimental results are directly applicable to engineering practice and facilitates comparison with pipeline operation data. Since the densities of the oils are similar, mixing by volume is appropriate, and the oils are mutually soluble; therefore, after measuring the required volumes of base oil (gasoline or diesel) and blending component (naphtha or light fuel oil) using graduated cylinders of appropriate ranges, the mixture was thoroughly agitated by mechanical stirring or vigorous shaking to ensure homogeneity.

The concentration gradients were designed using a dynamic adjustment strategy: initially, concentration points were planned at 1% intervals within the 0–10% blending range, with coarser gradients adopted for concentrations above 10%. During the experiment, the concentration points were flexibly adjusted based on the observed trends in the measured data—in regions where quality indicators changed rapidly with blending concentration, additional concentration points were introduced to more accurately capture the variation patterns; in regions where indicators changed gradually, the concentration intervals were appropriately widened to improve experimental efficiency. Through this dynamic adjustment strategy, a total of approximately 50 blending groups were planned to comprehensively cover the critical concentration ranges and accurately determine the threshold blending ratios for each quality indicator.

For each diesel blend group, approximately 150 mL of the mixed oil was prepared to allow for pour point, flash point, and distillation measurements (including repetitions and margin); for each gasoline blend group, approximately 100 mL was prepared for final boiling point measurement. Before each test, the blended sample was thoroughly shaken to ensure uniformity and accuracy.

2.3. Experimental Oil Samples

The oils used in the experiment include: 92# gasoline, 0# diesel oil, naphtha and light fuel oil. The oil sample used in the experiment was derived from SINOPEC Jingmen Branch.

The key physicochemical properties of the base oils (gasoline and diesel) and blending components (naphtha and light fuel oil) used in this study were characterized, as summarized in Table 1.

Table 1. Basic physical properties of the test oils.

Oil Type	Pour Point/°C	Flash Point/°C	95% Recovery Temperature/°C	Final Boiling Point/°C
Diesel	−26	86	347	
Gasoline				195
Naphtha	−60	<−31	129	139
Light Fuel Oil	−8	82	355	413

The carbon number distributions of the four oil samples were determined using gas chromatography. The analysis was performed on an Agilent GC-7890A gas chromatograph, Agilent Technologies (Shanghai) Co., Ltd., Shanghai, China, equipped with a flame ionization detector (FID) and an HP-5 capillary column. The injector and detector temperatures were both set at 350 °C. The oven temperature program was as follows: initial temperature 35 °C held for 10 min, then ramped at 8 °C/min to 310 °C and held for approximately 160 min. The identification of carbon number ranges was based on retention times of standard paraffin mixtures. The test method followed the relevant national standard procedures for hydrocarbon composition analysis, with the results presented in Figure 4.

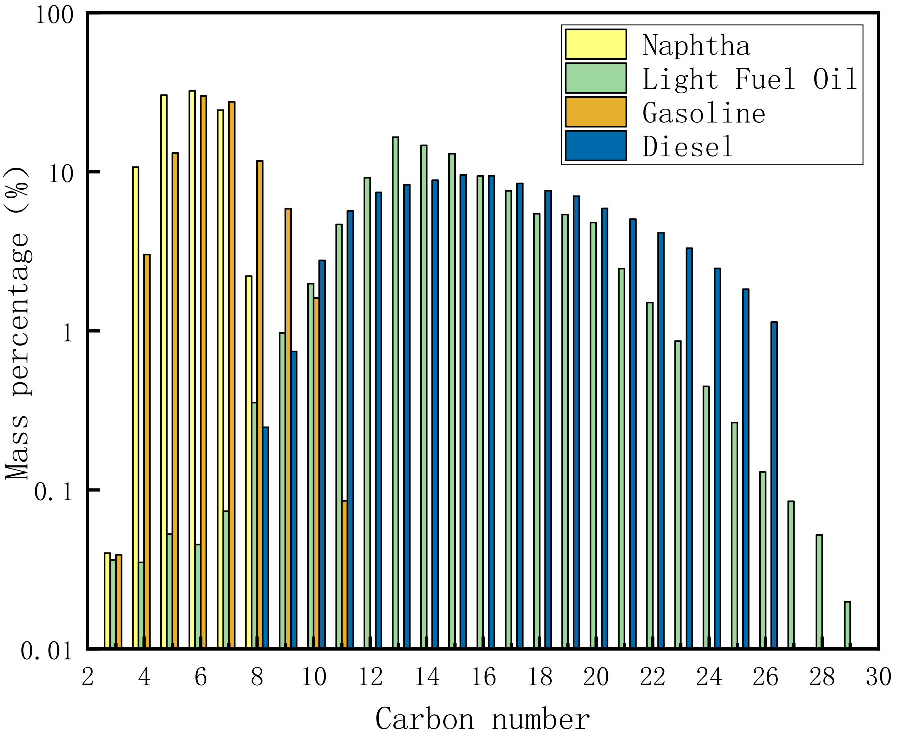


Figure 4. Experimental oil carbon distribution measurement results diagram.

The 92# gasoline and 0# diesel were used in the experiment. In accordance with Gasoline for Motor Vehicles (GB 17930-2016) [25] and Diesel for Motor Vehicles (GB 19147-2016) [26], the key quality indicator standards discussed in this study are as follows: the final boiling point of 92# gasoline must not exceed 205 °C; the pour point of 0# diesel must not exceed 0 °C, the flash point must be no less than 60 °C, and the 95% recovery temperature must not exceed 365 °C.

3. Results

3.1. Effects of Blending on the Final Boiling Point of Gasoline

The experimental results of the final boiling point of gasoline are shown in Tables 2 and 3:

Table 2. Final boiling point data of gasoline blended with naphtha.

Naphtha Concentration in Gasoline/%	Final Boiling Point/°C	Naphtha Concentration in Gasoline/%	Final Boiling Point/°C
0	195	10	187
1	191	15	192
2	185	20	195
3	184	25	198
4	188	30	204
5	191	35	197
6	186	40	197
7	189	45	185
8	186	50	182
9	188		

Table 3. Final boiling point data of gasoline blended with light fuel oil.

Light Fuel Oil Concentration in Gasoline/%	Final Boiling Point/°C	Light Fuel Oil Concentration in Gasoline/%	Final Boiling Point/°C
0	195	1.5	211
1	199	1.6	210
1.2	200	2	220
1.3	216	3	252
1.4	208	4	259

As shown in Table 2, blending gasoline with naphtha at varying concentrations leads to certain changes in the final boiling point, which fluctuates around 190 °C without exhibiting a clear monotonic increasing or decreasing trend. Even at a naphtha concentration of 50%, the final boiling point remains below the limit specified in the national standard for gasoline. According to carbon number distribution measurements, gasoline consists primarily of C_4–C_{10} hydrocarbons, while naphtha falls within the C_4–C_8 range. Naphtha thus has a narrower carbon distribution and an overall lighter composition. Since the final boiling point of petroleum products is determined by the volatility of the heaviest components, naphtha theoretically has limited influence on the final boiling point of gasoline. Combined with the experimental data, it can be concluded that blending with naphtha does not cause the final boiling point of gasoline to exceed standard limits.

Table 3 indicates that the addition of light fuel oil significantly raises the final boiling point of gasoline. When the concentration of light fuel oil exceeds 1.2 vol%, the final boiling point surpasses the specified upper limit of 205 °C, rendering the gasoline non-compliant with the standard. Carbon number distribution results show that light fuel oil is composed mainly of C_{11}–C_{21} hydrocarbons. Therefore, blending light fuel oil increases the content of heavy components in gasoline, leading to a notable increase in its final boiling point.

3.2. Effects of Blending on Diesel Quality Indicators

3.2.1. Experimental Results of Naphtha Blending

The experimental results of the influence of naphtha blending on diesel's pour point, flash point, and 95% recovery temperature are shown in Table 4.

Table 4. Quality index data of diesel blended with naphtha.

Naphtha Concentration in Diesel/%	Pour Point/°C	Flash Point/°C	95% Recovery Temperature/°C
0	−26	86	347
1	−26	93	310
2	−26	75	335
3	−26	68	330
3.5	−26	41	331
4	−28	37	332
5	−28	25	334
6	−28	17	331
7	−27	12	323
10	−28	<10	333
15	<−30	<10	332

As shown in Table 4, within the tested concentration range, naphtha has a limited effect on the pour point of diesel, which exhibits a decreasing trend as the naphtha concentration increases. The flash point of diesel decreases linearly with higher naphtha content. When the naphtha content exceeds 3 vol%, the flash point falls below the safety threshold of 60 °C, failing to meet the standard requirement. Based on carbon number distribution, naphtha contains significantly more light components than diesel. Therefore, adding naphtha is expected to lower the 95% recovery temperature of diesel. With increasing naphtha blending concentration, the 95% recovery temperature of diesel generally shows a slight declining trend. Thus, it can be concluded that blending naphtha does not cause the 95% recovery temperature of diesel to exceed the specified limit.

3.2.2. Experimental Results of Light Fuel Oil Blending

The experimental results of the effects of light fuel oil blending on diesel quality indicators are shown in Table 5.

Table 5. Quality index data of diesel blended with light fuel oil.

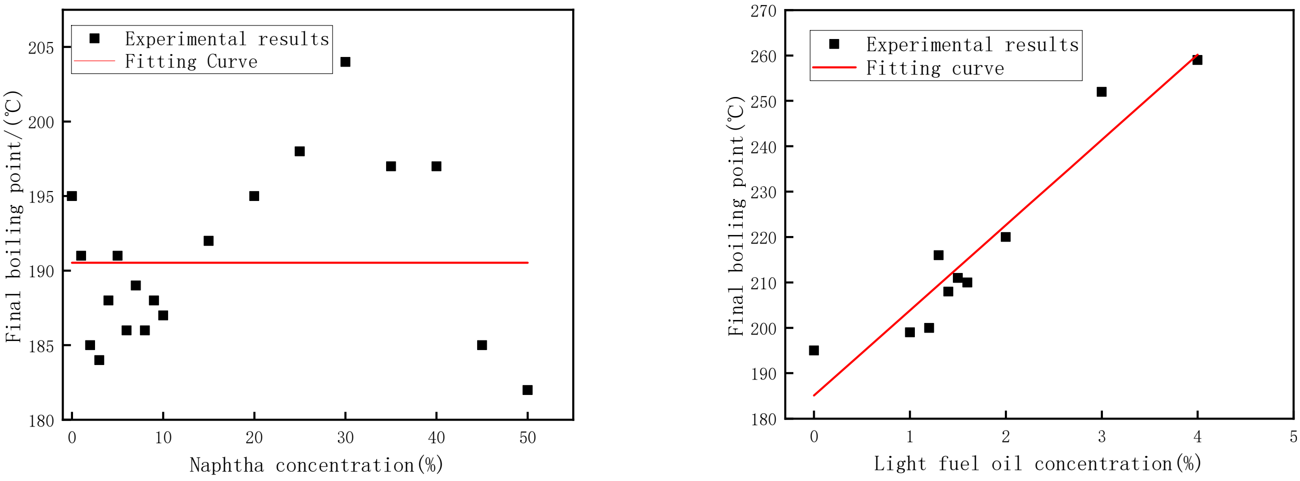
Light Fuel Oil Concentration in Diesel/%	Pour Point/°C	Flash Point/°C	95% Recovery Temperature/°C
0	−26	86	347
1	−26	82	329
2	−26	80	331
3	−25	79	330
4	−25	78	327
5	−25	81	329
6	−24	83	345
7	−24	82	347
8	−24	81	346
10	−21	83	336
15	−21	89	340

As shown in Table 5, the pour point of diesel increases gradually with higher concentrations of light fuel oil, yet remains within specification across the tested blending range of up to 15%. The flash point fluctuates irregularly around 80 °C with no clear upward or downward trend and does not exceed the standard limit. Similarly, the 95% recovery temperature varies around 340 °C without a distinct trend, consistently meeting the specification within the 0–15% light fuel oil blending range.

4. Discussion

4.1. Fitting Analysis Between Gasoline's Final Boiling Point and Blended Oil Concentration

It can be considered that naphtha has no effect on the final boiling point of gasoline, so a straight line with a slope of 0 is used for fitting; the blending of light fuel oil will cause the final boiling point of gasoline to increase. The fitting of experimental results on the influence of naphtha and light fuel oil blending on gasoline's final boiling point is shown in Figure 5.



(**a**) (**b**)

Figure 5. Correlation fitting curves between gasoline's final boiling point and blending concentration; (**a**) naphtha blending system; (**b**) light fuel oil blending system.

The fitting formulas and related data are shown in Table 6.

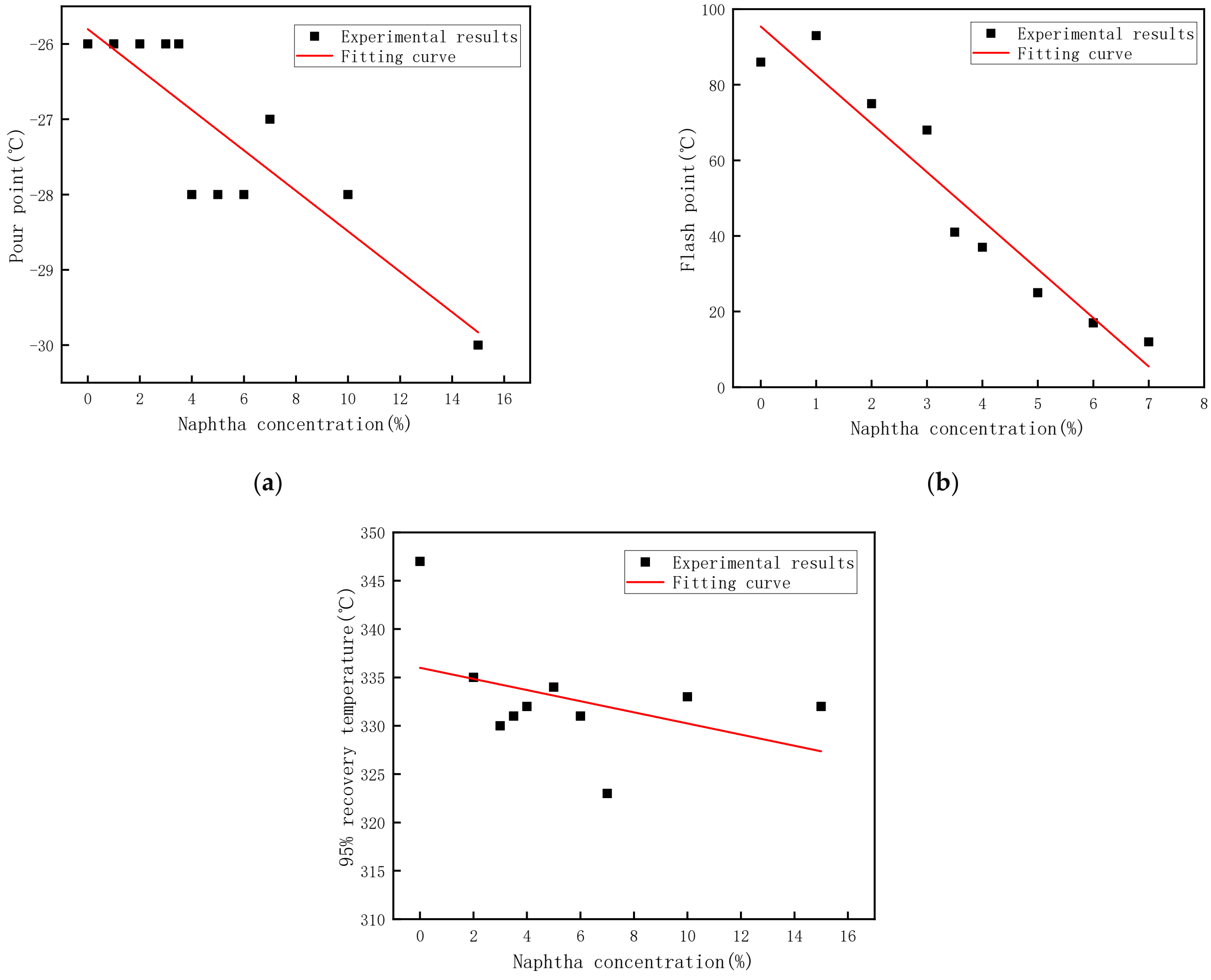
Table 6. Fitting formula table of gasoline final boiling point with the change in blending concentration of naphtha and light fuel oil.

Quality Indicator	Fitting Formula	Relevant Parameters	R^2
Naphtha	$y = a + bx$	a = 190.52632, b = 0;	
Light Fuel Oil	$y = a + bx$	$a = 185.08636 \pm 4.18041$, $b = 18.77273 \pm 2.09282$;	0.90957

According to the fitting results, after blending naphtha with a concentration of 0–50% into gasoline, the average final boiling point is about 190.5 °C, slightly lower than the final boiling point of pure gasoline (195 °C). The final boiling point of gasoline changes approximately linearly with the concentration of blended light fuel oil.

4.2. Fitting Analysis Between Diesel's Quality Indicators and Blended Naphtha Concentration

The fitting of the experimental results of the physical property measurements of diesel blended with naphtha is shown in Figure 6.



(**a**) (**b**)

(**c**)

Figure 6. Correlation fitting curves between diesel's critical quality indicators and naphtha blending concentration; (**a**) pour point; (**b**) flash point; (**c**) 95% recovery temperature.

The fitting formulas and related data are shown in Table 7.

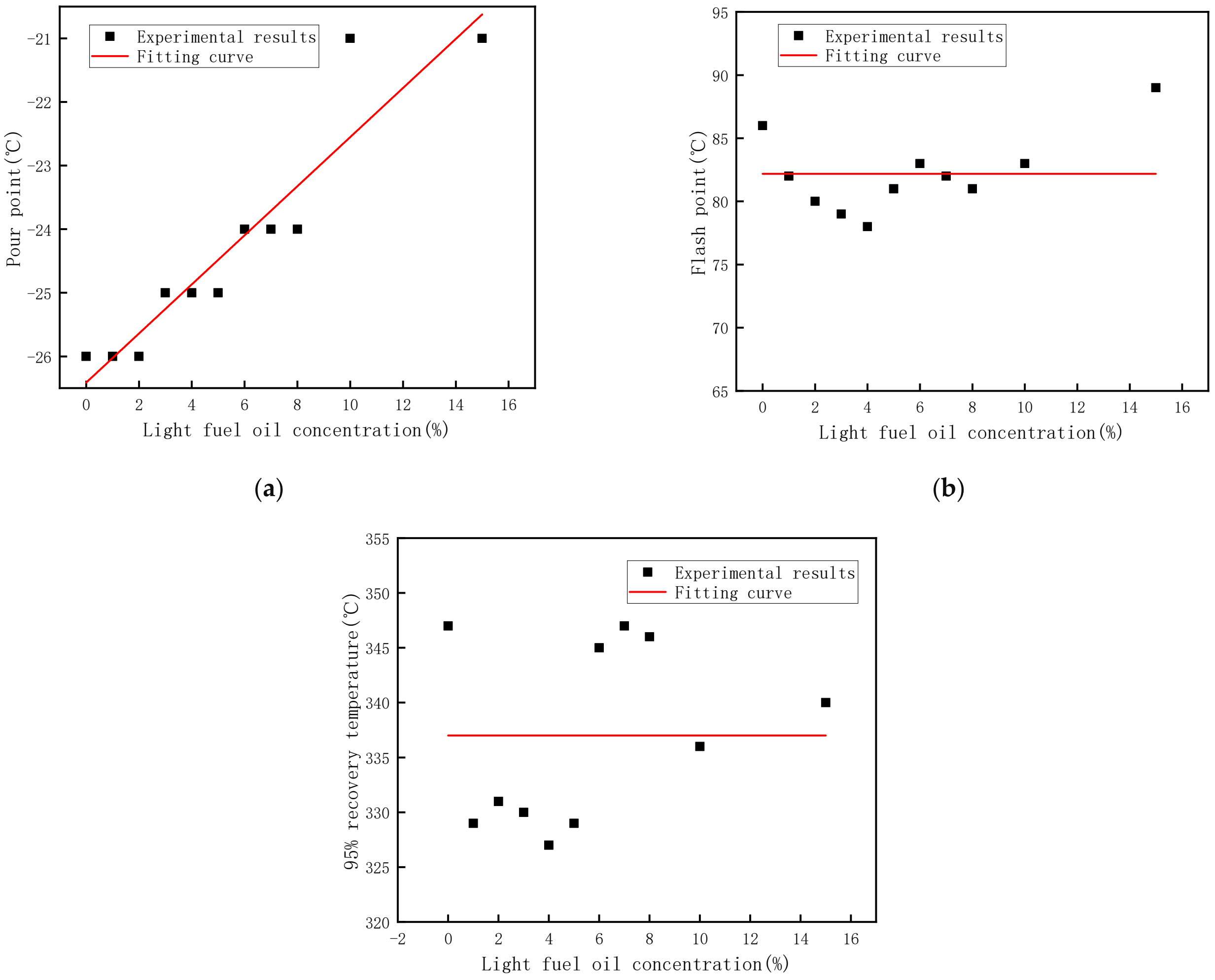
Table 7. Fitting formula table of diesel oil quality index with the change in naphtha blending concentration.

Quality Indicator	Fitting Formula	Relevant Parameters	R^2
Pour Point	$y = a + bx$	$a = -25.80255 \pm 0.327$, $b = -0.26853 \pm 0.04964$;	0.76476
Flash Point	$y = a + bx$	$a = 101.82518 \pm 4.98889$, $b = -13.20015 \pm 1.14049$;	0.83826
95% Recovery Temperature	$y = a + bx$	$a = 335.99688 \pm 3.05528$, $b = -0.57601 \pm 0.44273$;	0.17464

The linear fitting of the changes in pour point, flash point, and 95% recovery temperature when diesel is blended with naphtha of different concentrations is shown in Figure 6a–c. All three indicators show a decreasing trend with the blending of naphtha.

4.3. Fitting Analysis Between Diesel's Quality Indicators and Blended Light Fuel Oil Concentration

Since the flash point has no obvious change trend, a straight line with a slope of 0 is used for fitting. According to the carbon distribution, the carbon distributions of diesel and light fuel oil are close. With the addition of light fuel oil, the theoretical change trend of the 95% recovery temperature is unchanged or slightly decreased, so a straight line with a slope of 0 is used for fitting. The fitting of the experimental results of physical property measurement of diesel blended with light fuel oil is shown in Figure 7.



(**a**) (**b**)

(**c**)

Figure 7. Correlation fitting curves between diesel's critical quality indicators and light fuel oil blending concentration; (**a**) pour point; (**b**) flash point; (**c**) 95% recovery temperature.

The fitting formulas and related data are shown in Table 8.

Table 8. Fitting formula table of diesel oil quality index with the change in light fuel oil blending concentration.

Quality Indicator	Fitting Formula	Relevant Parameters	R^2
Pour Point	$y = a + bx$	$a = -26.41373 \pm 0.32422$, $b = 0.38608 \pm 0.04675$;	0.88341
Flash Point	$y = a + bx$	$a = 82.18182 \pm 0.94213$, $b = 0$;	
95% Recovery Temperature	$y = a + bx$	$a = 337 \pm 2.46429$, $b = 0$;	

As shown in Figure 7a, the linear fit for the pour point in the diesel–light fuel oil blending experiment is satisfactory, indicating that the pour point of diesel increases with the concentration of blended light fuel oil. This rise can be attributed to the wider carbon number distribution of light fuel oil compared to diesel, as seen in Figure 4, which includes a notable proportion of C_{27+} components.

Figure 7b shows that the flash point of diesel fluctuates irregularly around 82 °C after blending with light fuel oil. Meanwhile, Figure 7c indicates that the 95% recovery temperature exhibits a slight initial decrease followed by stabilization, generally remaining around 337 °C as the blending concentration increases. Even at higher blending concentrations, light fuel oil does not cause the flash point or 95% recovery temperature of diesel to exceed specification limits.

Linear regression models were employed in this study to characterize the relationships between blending concentration and quality indicators. This choice was based on three considerations: (1) for critical indicators such as gasoline final boiling point with light fuel oil and diesel pour point with light fuel oil, the data exhibited clear linear trends with high coefficients of determination ($R^2 > 0.88$); (2) within the concentration ranges where quality non-compliance occurs (0–5 vol%), linear models adequately captured the trends and were sufficient for determining safe blending thresholds; and (3) linear models offer simplicity and practical utility for pipeline operators, enabling the rapid estimation of quality changes without complex computations. For indicators with weaker correlations (e.g., 95% recovery temperature with naphtha), the low R^2 values indicate that naphtha blending has no significant practical effect, and linear models remain appropriate for demonstrating this lack of relationship.

4.4. Limitations and Future Work: Real-Time Proxies vs. End-Use Performance

A limitation of this study is the absence of definitive engine performance parameters, such as octane number, cetane number, and kinematic viscosity. While these parameters are crucial for assessing the ultimate combustion quality, they typically require complex bench tests and present significant “measurement lag” in industrial settings. Consequently, they cannot be used for high-frequency, real-time decision-making during pipeline interface tracking.

In contrast, logistics-related indicators—such as flash point, pour point, and distillation limits—serve as rapid, operational proxy variables for pipeline dispatchers. The scientific contribution of this study lies in quantifying the relationship between cross-contamination and these real-time proxies, establishing actionable safety boundaries for batch transportation. Future research should aim to couple these logistics proxy variables with comprehensive engine-bench tests, mapping the real-time operational thresholds directly to engine performance deterioration curves.

5. Conclusions

Systematic blending experiments and regression analysis were conducted to investigate the influence of naphtha and light fuel oil on key quality indicators of gasoline and diesel during batch transportation. The main conclusions are as follows.

Light fuel oil contamination in gasoline causes a linear increase in final boiling point ($y = 18.77x + 185.09$), exceeding the 205 °C national standard limit at concentrations above 1.2 vol%. This is attributed to the introduction of heavy components (C_{11}–C_{21}) from light fuel oil, as confirmed by carbon number distribution analysis.

Naphtha contamination in diesel leads to a linear decline in flash point ($y = -13.20x + 101.83$), falling below the 60 °C mandatory limit at concentrations above 3.0 vol%. This decline results from light hydrocarbons (C_4–C_8) increasing vapor pressure according to Raoult’s law. Pour point also decreases linearly ($y = -0.27x - 25.80$), while 95% recovery temperature shows no significant change.

Light fuel oil contamination in diesel increases pour point linearly ($y = 0.39x - 26.41$) due to C_{27+} heavy components, but remains within 0 °C specification up to 15 vol%. Flash point and 95% recovery temperature show no significant trends within the tested range.

Based on these quantitative thresholds, it is recommended that naphtha be placed adjacent to gasoline and light fuel oil adjacent to diesel in pipeline batch transportation, avoiding direct interface contact between incompatible pairs. The regression models enable operators to predict quality changes and optimize cut-point strategies.

Author Contributions: Conceptualization, W.Y. and C.L.; methodology, W.Y. and C.L.; software, J.L. and L.Z.; validation, J.L. and L.Z.; formal analysis, J.L. and L.Z.; investigation, T.L.; resources, C.L.; data curation, W.Y.; writing—original draft preparation, W.Y. and T.L.; writing—review and editing, C.L. and T.L.; visualization, T.L.; supervision, W.Y.; project administration, W.Y. and C.L.; funding acquisition, W.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no potential commercial or financial conflicts of interest with National Oil and Gas Pipeline Network Group Co., Ltd. All research design, data collection, analysis, interpretation of results, manuscript writing, and the decision to publish this paper were completed independently by the authors without any intervention or restriction from the affiliated enterprise. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

BP	Back Propagation
TPG	Three-Parameter Gamma
GB	Guobiao (Chinese National Mandatory Standard)
GB/T	Guobiao Tuijian (Chinese National Recommended Standard)
R^2	Coefficient of Determination

References

1. Yuan, Z.Y.; Chen, L.; Liu, G.; Zhang, Y. Knowledge-informed Variational Bayesian Gaussian mixture regression model for predicting mixed oil length. *Energy* **2023**, *285*, 129248. [CrossRef]
2. Yuan, Z.Y.; Chen, L.; Liu, G.; Shao, W.; Zhang, Y.; Ma, Y. Physics-informed Student's t mixture regression model applied to predict mixed oil length. *J. Pipeline Sci. Eng.* **2023**, *3*, 100105. [CrossRef]
3. Yuan, Z.Y.; Chen, L.; Shao, W.; Zuo, Z.; Zhang, W.; Liu, G. A robust hybrid predictive model of mixed oil length with deep integration of mechanism and data. *J. Pipeline Sci. Eng.* **2021**, *1*, 459–467. [CrossRef]
4. Yuan, Z.Y.; Chen, L.; Liu, G.; Shao, W.; Zhang, Y.; Yang, W. Physics-based Bayesian linear regression model for predicting length of mixed oil. *Geoenergy Sci. Eng.* **2023**, *223*, 211466. [CrossRef]
5. Yuan, Z.Y.; Liu, G.; Chen, L.; Shao, W.; Zhang, Y. Predictive model of mixed oil length for sequential transportation of multi-product pipeline by combining mechanism and Gaussian mixture regression algorithm. *J. China Univ. Pet. (Ed. Nat. Sci.)* **2023**, *47*, 123–128.
6. Yuan, Z.Y.; Chen, L.; Liu, G.; Li, Z.; Pan, Y.; Wu, Y.; Ji, H. A 1+ mechanism model for predicting the mixed oil concentration in multi-product pipelines. *SPE J.* **2024**, *29*, 5487–5501. [CrossRef]
7. Du, J.; Zheng, J.; Liang, Y.; Xu, N.; Klemeš, J.J.; Wang, B.; Liao, Q.; Varbanov, P.S.; Shahzad, K.; Ali, A.M. Deeppipe: A two-stage physics-informed neural network for predicting mixed oil concentration distribution. *Energy* **2023**, *276*, 127452. [CrossRef]
8. Mitusova, T.N.; Kondrasheva, N.K.; Lobashova, M.M.; Ershov, M.A.; Rudko, V.A.; Titarenko, M.A. Determination and Improvement of Stability of High-Viscosity Marine Fuels. *Chem. Technol. Fuels Oils* **2018**, *53*, 842–845. [CrossRef]
9. Mitusova, T.N.; Kondrasheva, N.K.; Lobashova, M.M.; Ershov, M.A.; Rudko, V.A.; Titarenko, M.A. Reduction of Sulphur in Marine Residual Fuels by Deasphalting to Produce VLSFO. *J. Mar. Sci. Eng.* **2022**, *10*, 1765. [CrossRef]

10. Klimov, N.A.; Burov, N.O.; Lobashova, M.M.; Savelenko, V.D.; Makhova, U.A.; Tikhomirova, E.O.; Mukhina, D.Y.; Ilin, A.V.; Shevtsov, A.A.; Moiseeva, T.N.; et al. Evaluation of electrical conductivity stability in jet fuels under transport and storage conditions. *Fuel* **2025**, *406*, 137041. [CrossRef]
11. He, G.X. Study on the Oil Mixing Characteristics and Leakage Estimation Method During Batch Transportation Process in a Multi-Product Pipeline. Ph.D. Thesis, China University of Petroleum (Beijing), Beijing, China, 2018. [CrossRef]
12. Zhao, H.J. Study on the Characteristics of Batch Transportation of Multi-Product Pipeline. Ph.D. Thesis, China University of Petroleum, Beijing, China, 2008. Available online: https://kns.cnki.net/kcms2/article/abstract?v=vxt3_kKBHYMI9Q1kPzawgXj-vtgrcY6BC-ge61x_nHpLhgfmEm2pwWP7uzgNx_ml5OIfXj8fFghiv3Ra-UWWuVBylgWFkPNPPzMuz-x8IsVzDcdZPbw56Sy6l0AiDBO0Mw2-ydgVnrktLLspAiaE26CSEZZ059-dFu9m5TCHL1ojF7X6O1TpYA==&uniplatform=NZKPT&language=CHS (accessed on 19 November 2025).
13. Zhao, H.Y. CFD Simulation of Contamination on Batch Transportation Pipeline. Master's Thesis, Daqing Petroleum Institute, Daqing, China, 2010. Available online: https://kns.cnki.net/kcms2/article/abstract?v=vxt3_kKBHYOetvhUNRj1qSLYdKmxWSQDHOCzNNRIU9GmMx6oq4reNEONIKP-2PVjSyBdKxF3ozn29EdrsA1Q11doeQcT1qrIUfJ9kb14y2WjeZkxlrDaAx-Ea5ScaKYcnfD8pKJ7_OSnT2Pr06Yby88JvIQe-8Bl7oxkaaGEuyQj9AZzFxI3bw==&uniplatform=NZKPT&language=CHS (accessed on 19 November 2025).
14. Zhao, Y.P. Study on the Characteristics of Oil Mixing in Multi-Product Pipelines Based on Data Analysis. Master's Thesis, China University of Petroleum (Beijing), Beijing, China, 2020. [CrossRef]
15. Jing, J.Z. Research on Sequential Transportation of Domestic and Foreign Refined Oil Pipelines. *Pipeline Tech. Equip.* **1995**, *5*, 34–36.
16. Wei, D.M.; Li, M. Impact on Jet Fuel Properties of Multi-product Pipelines. *Pipeline Tech. Equip.* **2007**, *5*, 15–17.
17. Li, H.D.; Liang, J.H.; Zhu, F.; Huo, L.F.; Zhang, Z.J.; Guo, Y. Mixing Experiment and Critical Proportion Calculation for Contamination of Products. *Oil Gas Storage Transp.* **2011**, *30*, 180–182.
18. Zhao, Y.; Ma, L.T.; Lan, D.W.; Liu, Y.Y. Experimental Study and Analysis of Characteristics of Contaminated Product Oil. *Contemp. Chem. Ind.* **2020**, *49*, 859–862. [CrossRef]
19. Wang, P.X.; Ding, K.; Wang, X.S.; Wang, W.; Sun, X.Z.; Li, M.Y. Study on Sequential Transport and Blending Experiment for Aviation Kerosene. *Contemp. Chem. Ind.* **2021**, *50*, 1530–1534. [CrossRef]
20. Tang, D.D. On-line Prediction of Mixed Oil Concentration in Product Oil Pipelines and Study on Cutting Method Based on Quality Index. Master's Thesis, China University of Petroleum (Beijing), Beijing, China, 2019. [CrossRef]
21. Han, D. Study on the Variation Law of Jet Fuel Quality Indicators in Sequential Transportation Pipelines. Master's Thesis, China University of Petroleum (Beijing), Beijing, China, 2020. [CrossRef]
22. *GB/T 510-2018*; National Technical Committee for Standardization of Petroleum Products and Lubricants (SAC/TC 280). Determination of Pour Point of Petroleum Products. Standards Press of China: Beijing, China, 2018.
23. *GB/T 261-2021*; National Technical Committee for Standardization of Petroleum Products and Lubricants (SAC/TC 280). Determination of Flash Point—Pensky-Martens Closed Cup Method. Standards Press of China: Beijing, China, 2021.
24. *GB/T 6536-2010*; National Technical Committee for Standardization of Petroleum Products and Lubricants (SAC/TC 280). Standard Test Method for Distillation Characteristics of Petroleum Products at Atmospheric Pressure. Standards Press of China: Beijing, China, 2010.
25. *GB 17930-2016*; Petroleum Fuels and Lubricants Subtechnical Committee, National Technical Committee for Standardization of Petroleum Products and Lubricants (SAC/TC 280/SC 1). Gasoline for Motor Vehicles. Standards Press of China: Beijing, China, 2016.
26. *GB 19147-2016*; Petroleum Fuels and Lubricants Subtechnical Committee, National Technical Committee for Standardization of Petroleum Products and Lubricants (SAC/TC 280/SC 1). Diesel Fuel for Motor Vehicles. Standards Press of China: Beijing, China, 2016.