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Research Status of Base Oil for Drilling Fluids in China

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Abstract: *With the rapid development of the domestic petroleum industry, the variety of base oils has increased continuously, and production processes have been constantly improved. According to the classification of base oils in internationally accepted standards, this paper elaborates the specific definitions of various base oils, discusses their application directions and scopes, reviews the development process of their production technologies, and analyzes product classification and quality control from multiple perspectives such as performance indicators and molecular structure.*

Keywords: *Drilling Fluids and Completion Fluids; Synthetic Base Oils; Ester-Based Biodiesel; Hydrocarbon-Based Biodiesel; Quality Control*

1. Introduction

With the issuance of the "Supervision and Management Measures for Energy Conservation and Ecological Environment Protection of Central Enterprises" by the State-owned Assets Supervision and Administration Commission in August 2022, corresponding specific policies have gradually been implemented. Environmental protection indicators have emerged accordingly. The environmental pressure on the traditional energy and chemical industries has increasingly intensified. Due to issues related to raw materials and refining processes, traditional mineral oils are subject to more and more restrictions. Meanwhile, emerging synthetic oils and bio-oils have gradually developed, giving rise to synthetic base oils and bio-based base oils. However, for existing base oils, especially high-end products such as poly alpha olefin (PAO) base oils, domestic independent production capacity remains weak. Regarding the raw material α-olefins, there are two internationally recognized production methods: the wax cracking method and the ethylene oligomerization method. Currently, China does not have ethylene oligomerization production facilities, and the production technology is monopolized by several foreign chemical companies, resulting in a high dependence on imports of high-quality domestic PAO base oils [1]. For example, producers such as ExxonMobil and Chevron Phillips hold more than half of the global sales share of synthetic base oils.

2. Classification of Base Oils for Drilling and Completion Fluids

The API 1509 Engine Oil Licensing and Certification System by the American Petroleum Institute, an internationally recognized classification standard [2], divides base oils into five major categories, as shown in Table 1.

Table 1 Classification of Base Oils in API 1509

Standard Type	API 1509 Engine Oil Licensing and Certification System		
Category	Sulfur Content	Total Saturates Content	Viscosity Index
I	>0.03%	<90%	80-120
II	≤0.03%	≥90%	80-120
III	≤0.03%	≥90%	≥120
IV	Poly Alpha Olefin (PAO)		
V	Other base oils outside Categories I to IV		

Category I base oils: Produced by conventional petroleum refining processes;

Category II base oils: Produced by modern petroleum refining processes, generally hydroprocessing;

Category III base oils: Produced by deep refining petroleum processes, generally hydrocracking or hydrotreating;

Category IV base oils: These are synthetic lubricants' base oils known as poly alpha olefin (PAO), generally polymerized from linear α-olefins;

Category V base oils: Include various types of organic compounds such as fatty acid esters, polyol esters, polymer esters, ethers, silicones, etc., generally used in blends with other base oils. For drilling fluid materials, ester-based base oils are more commonly applied and can be added to drilling fluid systems to serve as dispersants or lubricants.

2.1 Mineral Base Oils (Categories I–III)

White oil, a refined product of mineral base oils, serves as the foundation of lubricants [3]. Simply put, it can be divided into industrial grade, cosmetic grade, food grade, and medical grade. The industrial white oils are mainly classified according to viscosity properties, such as kinematic viscosity. Common grades include #5, #7, #10, #15, #22, #32, #46, #68, etc., totaling 12 grades, primarily used in synthetic fiber oils and lubricants for precision instruments.

2.2 Synthetic Base Oils (Category IV)

Synthetic base oil PAO refers to base oils obtained through synthetic processing of petrochemical products. PAO, as a high-performance base oil, is currently the best-performing synthetic lubricant base oil due to its wide liquid range, excellent viscosity-temperature performance, and high viscosity index [4].

2.3 Biodiesel (Category V)

According to chemical structure, biodiesel is divided into ester-based biodiesel and hydrocarbon-based biodiesel [5]. Based on recent development, it can be categorized into first-generation and second-generation biodiesel [6]. First-generation biodiesel generally refers to ester-based biodiesel. The "NB/T 13011-2024 Terminology of Biodiesel Industry" defines ester-based biodiesel as fatty acid monoalkyl esters produced by reacting animal or vegetable oils with alcohols (such as methanol or ethanol), with fatty acid methyl esters being the most typical. Second-generation biodiesel generally refers to hydrocarbon-based biodiesel. The National Energy Administration issued the "NB/T 10897-2021 Hydrocarbon Based Biodiesel" industry standard on December 22, 2021, which states that hydrocarbon-based biodiesel is a bio-liquid fuel suitable for compression ignition diesel engines, produced by direct hydrogenation or Fischer-Tropsch synthesis of animal and vegetable oils, waste oils or their derivatives, and other biomass raw materials to form alkanes.

Ester-based biodiesel, as a green fuel, is mainly applied in the transportation sector and is also a high-performance base fluid for drilling fluids [7]. Hydrocarbon-based biodiesel can be blended with petrochemical petroleum in certain proportions and is also used to produce high-end solvent oils, bioplastics, bio-plasticizers, bio-waxes, bio-surfactants, and other products [8].

3. Production Processes

Base oils are mostly derived from crude oil raw materials. After simple process separation, mineral base oils can be obtained, which are then further refined or blended with special additives to meet user requirements.

3.1 Mineral Base Oil Process (Categories I–III)

Mineral base oils are primarily obtained from crude oil through processes such as atmospheric and vacuum distillation, solvent refining, solvent dewaxing, and solvent deasphalting. The resulting base oil fractions are then subjected to different production processes like desulfurization and hydrogenation to produce the final base oils [9].

3.2 Synthetic Base Oils (Category IV)

Category IV lubricants are long-chain alkane base oils produced by oligomerization and

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hydrogenation saturation reactions of α-olefins under the action of catalysts. The main catalysts include $AlCl_3$ catalysts, BF_3 catalysts, Ziegler-Natta catalysts, chromium-based catalysts, and metallocene catalysts [10]. Especially, metallocene catalysts, due to their high catalytic activity, narrow molecular weight distribution of produced polymers, and controllable polymer structure [11], have greatly accelerated the development of the polyolefin industry. Different grades of PAO base oils also use different catalytic systems [12].

3.3 Biodiesel Production Processes (Category V)

Biodiesel is a green and renewable resource that has attracted considerable attention due to its excellent properties, characterized by a high cetane number, sulfur-free content, and a significant reduction of harmful substances in combustion products.

3.3.1 Ester-Based Biodiesel Process

Ester-based biodiesel is a renewable fuel produced from high-quality raw materials. Its preparation methods include transesterification, enzymatic processes, supercritical methods, and high-temperature cracking [13]. Among these, transesterification and enzymatic methods are widely used due to their mature technology and higher yields.

3.3.2 Hydrocarbon-Based Biodiesel Process

Hydrocarbon-based biodiesel, classified as second-generation biodiesel, is composed mainly of hydrocarbons obtained via catalytic hydrogenation. Its production technologies mainly include reactions such as double bond addition, hydrodeoxygenation, and isomerization, with hydrodeoxygenation being the key step. Catalysts are the focus of research in this process [14].

4. Quality Control

Due to the differences in chemical structure, production processes, and application scopes of various base oils, it is difficult to use a single fixed analytical or testing method to control the quality of different types of chemical products. Therefore, selecting chemical analysis equipment based on their specific structures, or using performance indicators within the industrial applicable range for production process control or finished product quality control, has become a major development trend in recent years.

4.1 Quality Control of Mineral Base Oils (Categories I–III)

Mineral base oils have developed over many years, and the domestic and international testing methods and means are relatively unified. They exhibit high ecotoxicity and low biodegradability [15]. To respond to increasingly stringent environmental protection standards domestically and abroad, on December 27, 2017, the National Energy Administration issued the "NB/SH/T 0006-2017 Industrial Mineral Oil" petrochemical industry standard of the People's Republic of China. This standard not only includes performance indicators such as kinematic viscosity and flash point but also adds environmental protection indicators such as aromatic content, sulfur content, and nitronaphthalene content.

Generally, the aromatic hydrocarbon content in diesel fuel is one of the important factors affecting fuel exhaust emissions and combustion performance. With increasingly stringent domestic and international requirements on atmospheric pollutant emissions, the limits on total aromatic hydrocarbon content in diesel, especially polycyclic aromatic hydrocarbons (PAHs), have become more rigorous. On May 13, 2022, the National Energy Administration issued the standard "NB/SH/T 0806-2022 Determination of Aromatic Hydrocarbon Types in Middle Distillates - High Performance Liquid Chromatography Method with Refractive Index Detector." This standard specifies the testing method using high-performance liquid chromatography to determine mono-aromatic hydrocarbons, di-aromatic hydrocarbons, tri-aromatic hydrocarbons, and polycyclic aromatic hydrocarbons in diesel and petroleum distillates with a boiling range of 150–400 ℃.The method uses n-heptane as the mobile phase, an amino-bonded silica gel stationary phase column, and a refractive index detector.

For mineral base oils, testing methods have gradually increased. Standards such as SH/T 0410-1992, NB/SH/T 0889-2014, and NB/SH/T 0653-2021 [16–18] all incorporate gas chromatography testing procedures. These use 5% phenyl methyl silicone as the stationary phase in the chromatographic

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column. During programmed temperature ramping in the column oven, components are separated, and the eluted components are detected by a hydrogen flame ionization detector, producing corresponding signals. By comparing the retention times of hydrocarbons with specific carbon numbers to those of qualitative standard substances, qualitative identification can be performed. Meanwhile, the relative correction factors for each normal alkane are determined by calculating the peak areas of each normal alkane. Using the relative correction factors, peak areas, and the mass and peak area of the internal standard in the corresponding formula, the contents of normal alkanes and branched alkanes, as well as carbon number distribution information, can be obtained. This method allows for more precise judgment based on molecular structure.

4.2 Quality Control of Synthetic Base Oils (Category IV)

Since the raw materials of synthetic base oils are relatively simple, generally fixed-carbon-number α-olefins, the quality control process is comparatively straightforward. Liu Lijun et al. proposed a hydrocarbon composition analysis method for PAO base oils. The PAO base oil is dissolved in a certain mass of CS_2 and analyzed by gas chromatography–mass spectrometry (GC-MS) with a full scan to obtain characteristic ion chromatograms of each component, determining the carbon number range of the components. Meanwhile, normal alkanes of corresponding carbon numbers are used as standards. The mixture is detected by gas chromatography, and the hydrocarbon content of each carbon number in the PAO base oil is obtained by the area normalization method [19].

4.3 Quality Control of Biodiesel (Category V)

With the rapid development of biodiesel in recent years, its testing methods have been continuously updated, gradually evolving from macroscopic performance indicators to microscopic molecular structure indicators. Testing equipment has progressed from basic physical-chemical instruments such as viscometers and densitometers to advanced analytical instruments such as chromatography and mass spectrometry.

4.3.1 Ester-Based Biodiesel

Internationally, the European Union standard EN14214 "Automotive fuels - Fatty acid methyl esters (FAME) for diesel engines - Requirements and test methods" is mainly referenced. Its core indicators include fatty acid methyl ester content, density, and viscosity.

The international standard BS EN 14078:2014 "Liquid petroleum products - Determination of fatty acid methyl ester (FAME) content in middle distillates - Infrared spectrometry method" corresponds closely to the domestic standards NB/SH/T 0916-2015 "Determination of biodiesel (fatty acid methyl ester) content in diesel fuels - Infrared spectrometry method" and GB/T 23801-2021 "Determination of fatty acid methyl ester (FAME) content in middle distillates - Infrared spectrometry method." All these methods use a solvent with no absorption peak around $1745\ cm^{-1} \pm 5\ cm^{-1}$, employ an external standard method to establish a calibration curve for the ester absorption peak using standard substances (generally B5 diesel with fatty acid methyl ester mass fraction not less than 96.5%), and calculate the FAME content of samples by measuring the ester absorption peak. Meanwhile, NB/SH/T 0831-2010 "Test method for determination of fatty acid methyl esters and linolenic acid methyl ester contents in biodiesel by gas chromatography" uses polyethylene glycol-based gas chromatographic columns for separation and hydrogen flame ionization detectors for detection to determine fatty acid methyl ester content. This method mainly targets C14–C24 fatty acid methyl esters. The chromatogram can effectively separate ten fatty acid methyl esters, including methyl myristate, and quantification of each component is performed by area percentage method.

Acid number refers mainly to free fatty acids in biodiesel. Excessive acid number can corrode engines and significantly affect engine oil and oxidation stability, which are important diesel indicators. On September 7, 2017, the General Administration of Quality Supervision, Inspection and Quarantine of China issued GB 25199-2017 "B5 Diesel Fuels," which strictly regulates more than ten indicators of biodiesel.

4.3.2 Hydrocarbon-Based Biodiesel

On December 22, 2021, the National Energy Administration issued the standard "NB/T 10897-2021 Hydrocarbon Based Biodiesel." This standard specifies that qualified hydrocarbon-based biodiesel must contain at least 70% C15–C18 alkanes and no more than 2% fatty acid methyl esters. These indicators directly reflect the degree of hydrogenation reduction of the raw materials, and also include

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environmental indicators such as polycyclic aromatic hydrocarbons content and total contaminants.

The standard "NB/SH/T 0606-2019 Standard Test Method for Determination of Hydrocarbon Types in Middle Distillates by Mass Spectrometry" provides a method using gas chromatography-mass spectrometry (GC-MS) to determine the hydrocarbon composition of biodiesel blending fuels with a boiling range of 170–365 ℃. It includes eleven classes of hydrocarbons such as paraffins, naphthenes, and alkyl benzenes, which can be used to confirm process parameters and control product quality.

5. Conclusion

Different types of base oils vary in molecular structure and composition, leading to different application scopes. Whether from transportation to drilling fluid base oils, or from engine lubricants to aerospace greases, from the perspective of industrial production, future research needs to focus deeply on raw materials and catalysts to enhance market competitiveness.

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