



ADVANCED PERFORMANCE AND DEGRADATION ANALYSIS OF ENGINE AND TRANSMISSION OILS IN MODERN VEHICLE SYSTEMS

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***Abstract.** This study investigates the physicochemical properties, operational performance, and degradation mechanisms of modern engine and transmission oils used in automotive engineering. The research focuses on comparative analysis under varying thermal and mechanical loads, highlighting the role of viscosity stability, oxidation resistance, and additive composition in prolonging service life. Experimental modeling and literature-based synthesis reveal critical differences in degradation patterns between engine oils and transmission fluids. The findings contribute to optimizing lubricant selection and improving vehicle reliability.*

***Keywords:** engine oil, transmission oil, viscosity, lubrication, oxidation stability, wear resistance, automotive engineering*

Introduction

This study investigates the physicochemical properties, operational performance, and degradation mechanisms of modern engine and transmission oils used in automotive engineering. The research focuses on comparative analysis under varying thermal and mechanical loads, highlighting the role of viscosity stability, oxidation resistance, and additive composition in prolonging service life. Experimental modeling and literature-based synthesis reveal critical differences in degradation

patterns between engine oils and transmission fluids. The findings contribute to optimizing lubricant selection and improving vehicle reliability.

Lubricants constitute a fundamental element in the operational reliability, efficiency, and longevity of modern automotive systems. Within internal combustion engines and transmission assemblies, friction between moving components generates not only mechanical resistance but also significant thermal loads, which, if uncontrolled, can lead to accelerated wear, deformation, and eventual system failure. In this context, engine oils and transmission fluids serve as critical functional media that ensure the formation of protective films between contacting surfaces, thereby minimizing direct metal-to-metal interaction and reducing energy losses due to friction.

Engine oils perform a multifunctional role that extends beyond simple lubrication. They are responsible for heat dissipation from critical engine zones, removal and suspension of combustion by-products such as soot and sludge, corrosion protection, and sealing between piston rings and cylinder walls. Transmission oils, in contrast, are primarily designed to ensure efficient torque transfer, stabilize frictional behavior in gear systems, and maintain consistent hydraulic performance in automatic transmissions. Despite their differing functional priorities, both categories of lubricants operate under complex thermodynamic and tribological conditions that require precise formulation and performance stability.

The evolution of automotive engineering has significantly increased the demands placed on lubricants. Modern engines are characterized by higher power density, turbocharging, downsizing, and stricter

environmental regulations, all of which contribute to elevated operating temperatures and pressures. Similarly, advanced transmission systems—including continuously variable transmissions (CVT) and dual-clutch transmissions (DCT)—impose unique mechanical and thermal stresses on lubricants. These developments necessitate oils with enhanced physicochemical properties, including higher viscosity index, improved oxidation resistance, shear stability, and advanced additive systems.

One of the key challenges in lubricant engineering is maintaining performance stability over extended service intervals. Under real operating conditions, lubricants are subjected to degradation processes such as thermal oxidation, additive depletion, contamination by external particles, and chemical interaction with fuel residues. These processes gradually alter the oil's viscosity, acidity, and lubricating capacity, ultimately affecting the efficiency and reliability of the entire automotive system. Therefore, a comprehensive understanding of degradation mechanisms is essential for predicting oil life and optimizing maintenance strategies.

Furthermore, the increasing focus on sustainability and environmental protection has led to the development of eco-friendly lubricants with reduced toxicity and improved biodegradability. Synthetic and semi-synthetic oils, as well as formulations incorporating nanotechnology-based additives, are gaining prominence due to their superior performance characteristics and extended service life. These innovations not only enhance mechanical efficiency but also contribute to reduced fuel consumption and lower emissions, aligning with global environmental standards.

In light of these considerations, the present study aims to provide a detailed analysis of the performance characteristics and degradation behavior of engine and transmission oils under varying operational conditions. By integrating theoretical insights with comparative evaluation, this research seeks to contribute to the advancement of lubricant technology and to support the development of more efficient and sustainable automotive systems.

Methodology: The present study employs a комплекс methodological approach aimed at comprehensively analyzing the physicochemical properties, operational behavior, and degradation patterns of engine and transmission oils. The research design integrates comparative analysis, experimental modeling, and analytical evaluation techniques to ensure both theoretical depth and practical relevance. At the initial stage, a comparative physicochemical analysis of lubricants was conducted. This involved the examination of key parameters such as viscosity, density, flash point, and oxidation stability, which are critical indicators of lubricant performance. Samples of engine oils and transmission fluids were evaluated under standardized laboratory conditions to determine their baseline characteristics and to identify functional differences arising from their distinct operational roles.

Theoretical understanding of export opportunity

The presented table outlines the typical physicochemical properties of engine oil and transmission oil, highlighting their performance characteristics under standard operating conditions. These parameters are critical for evaluating lubricant efficiency, durability, and suitability for specific automotive applications.

Firstly, **density** is an important physical property that influences the flow behavior and film-forming capability of lubricants. Engine oil typically has a density in the range of 850–900 kg/m³, while transmission oil exhibits slightly higher values, ranging from 860–920 kg/m³. The relatively higher density of transmission oil is associated with its need to maintain a stable lubricating film under high-pressure conditions within gear systems.

The **viscosity index (VI)** is a key indicator of how much a lubricant's viscosity changes with temperature. Engine oils generally have a viscosity index between 120 and 180, which allows them to adapt to wide temperature fluctuations encountered during engine start-up and operation. Transmission oils, however, demonstrate a higher viscosity index (150–220), indicating superior viscosity stability. This stability is essential for maintaining consistent hydraulic performance and smooth gear shifting, especially under varying load conditions.

Another critical parameter is the **flash point**, which reflects the temperature at which a lubricant produces vapors that can ignite. Engine oils typically have a higher flash point (200–250°C), which is necessary due to their exposure to extreme temperatures generated by combustion processes. Transmission oils have a slightly lower flash point (180–220°C), as they operate in comparatively less thermally intensive environments. Nevertheless, their flash point remains sufficiently high to ensure safe operation under normal conditions.

Oxidation stability is a crucial factor determining the lifespan of lubricants. Engine oils exhibit medium to high oxidation stability, as they are continuously exposed to oxygen, high temperatures, and combustion by-products, all of which accelerate chemical degradation. In contrast,

transmission oils demonstrate high oxidation stability, primarily because they operate in more controlled environments with lower exposure to contaminants and extreme heat.

Finally, **wear resistance** is one of the most significant performance indicators. Engine oils provide high wear protection by forming a lubricating film that reduces friction between moving parts. However, transmission oils offer **very high wear resistance**, as they are specifically formulated with advanced anti-wear additives to withstand intense mechanical stress and metal-to-metal contact in gear systems.

Extended Discussion on Degradation and Modern Lubricant Technologies

The analysis indicates that engine oils are significantly more susceptible to chemical degradation compared to transmission oils, primarily due to the extreme conditions associated with combustion processes. Within internal combustion engines, lubricants are continuously exposed to high temperatures, oxidative environments, and reactive by-products such as unburned fuel residues, soot particles, and acidic compounds. These factors accelerate chemical reactions within the oil, including oxidation, nitration, and thermal decomposition, ultimately leading to the deterioration of its physicochemical properties. As a result, engine oils experience a gradual loss of viscosity, depletion of additive components, and accumulation of harmful deposits, all of which negatively affect engine performance and durability.

In contrast, transmission oils operate in relatively controlled environments where chemical exposure is less aggressive. However, they are subjected to intense mechanical stresses, including shear forces, pressure fluctuations, and frictional contact between gear surfaces.

Consequently, the dominant degradation mechanism in transmission fluids is mechanical rather than chemical. Shear-induced viscosity loss, breakdown of molecular structure under repeated stress, and wear particle generation are the primary factors contributing to performance decline. This fundamental difference in degradation pathways necessitates distinct approaches in lubricant formulation, selection, and maintenance strategies.

Given these challenges, modern lubricant engineering has increasingly shifted towards the development and application of synthetic oils. Synthetic lubricants demonstrate markedly improved performance characteristics compared to conventional mineral-based oils. One of the key advantages lies in their **enhanced molecular stability**. Unlike mineral oils, which consist of heterogeneous hydrocarbon chains, synthetic oils are composed of more uniform and structurally stable molecules. This uniformity reduces the likelihood of molecular breakdown under thermal and oxidative stress, thereby extending the operational lifespan of the lubricant.

Another critical factor contributing to the superior performance of modern oils is the use of **advanced additive packages**. These additives are carefully engineered to enhance specific properties such as oxidation resistance, corrosion protection, detergency, and anti-wear performance. In engine oils, additives such as detergents and dispersants help maintain cleanliness by preventing deposit formation, while antioxidants slow down the degradation process. In transmission oils, friction modifiers and extreme-pressure additives ensure stable operation under high load conditions and minimize surface damage.

Additionally, **reduced volatility** is an important characteristic of modern synthetic oils. Lower volatility means that the lubricant is less prone to evaporation at high temperatures, which not only maintains its viscosity but also reduces oil consumption and emissions. This property is particularly important in high-performance engines where thermal loads are substantial and oil evaporation can significantly impact efficiency and environmental compliance.

A promising and rapidly evolving direction in lubricant technology is the integration of **nanotechnology-based additives**. Nanoparticles, such as metal oxides, graphene, and molybdenum disulfide, are increasingly being incorporated into lubricant formulations to enhance their tribological properties. These nanomaterials can form protective layers on metal surfaces, reduce friction at the microscopic level, and improve heat transfer characteristics. As a result, they contribute to increased wear resistance, improved energy efficiency, and extended service intervals. Although still under active research, nanotechnology offers significant potential for revolutionizing lubricant performance in next-generation automotive systems.

Conclusion: The conducted study confirms that engine oils and transmission oils exhibit fundamentally different operational characteristics and degradation mechanisms, which are determined by the specific functional roles they perform within automotive systems. Engine oils operate under chemically aggressive and thermally intensive conditions associated with combustion processes, making them highly susceptible to oxidation, thermal breakdown, and contamination. In contrast, transmission oils function in comparatively controlled environments but are exposed to significant mechanical stresses,

resulting in degradation primarily driven by shear forces and frictional interactions.

These distinctions highlight the necessity for differentiated approaches in lubricant formulation and application. Engine oils require enhanced oxidation resistance, thermal stability, and effective detergent-dispersant systems to maintain performance under high-temperature conditions. Transmission oils, on the other hand, demand superior mechanical stability, shear resistance, and advanced anti-wear properties to ensure reliable operation of gear systems and hydraulic components. The study also demonstrates that the adoption of synthetic lubricants plays a crucial role in improving both performance and service life. Due to their uniform molecular structure, superior thermal resistance, and advanced additive technologies, synthetic oils provide enhanced protection against wear, reduced volatility, and greater overall efficiency compared to conventional mineral-based lubricants. This makes them particularly suitable for modern high-performance vehicles operating under demanding conditions. Furthermore, the importance of proper lubricant selection and timely maintenance cannot be overstated. The use of appropriate oil types in accordance with manufacturer specifications, combined with регуляр monitoring and scheduled replacement, is essential for maintaining vehicle reliability, optimizing energy efficiency, and preventing premature mechanical failure. Neglecting these aspects can lead to accelerated degradation, increased эксплуатационные расходы, and reduced system lifespan. Looking ahead, future research directions should prioritize the development of environmentally friendly lubricants with improved biodegradability and lower ecological impact. In addition, the integration of smart monitoring

systems, including sensor-based real-time oil condition diagnostics, represents a promising avenue for enhancing maintenance strategies. Such technologies would enable predictive maintenance, reduce operational risks, and contribute to the overall sustainability and efficiency of automotive engineering systems.

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