

INVESTIGATION OF LUBRICITY ENHANCEMENT AND TRIBOLOGICAL PROPERTIES OF SYNTHETIC FUELS IN HIGH-EFFICIENCY PISTON DEVICES

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Abstract:

This paper reviews existing studies on enhancing the lubricity and tribological properties of synthetic liquid fuels used in high-efficiency piston devices. The effectiveness of ZnO and MoS₂ nanoparticles, organomolybdenum compounds, biodiesel, fatty acid methyl esters (FAME), and locally developed GTL-SN additives was analyzed. The studies show that additives reduce wear scar diameter (WSD), promote the formation of stable tribofilms on metal surfaces, and significantly improve the lubricating properties of synthetic fuels. Based on this review, functional additives are shown to enhance the performance and durability of piston devices operating under high-load and high-temperature conditions

Keywords: tribology, piston device, synthetic liquid fuel, friction, wear, lubrication, additives.

Introduction

Nowadays, high performance piston engines are extensively used in the transportation and power generation systems, because they have a capability of working under thermal and mechanical high loads (as well as possibility to provide increased fuel efficiency along with reduce in environmental hazardous). Automotive (synthetic) Liquid fuels AFT Synthetic liquid fuels, as particularly offered in the form of „Gas-to-Liquid“ (GTL) fuel, differ from fossil based gasoline and diesel primarily by a high cetan number low sulfur content no harmful components. However, a drawback of GTL fuels is

that they display low natural lubricity and this can also cause friction and metal wear in engine parts. Lubricity and tribological behavior have a direct impact on the performance, longevity and energy consumption of engines. Thus, to improve the lubricity of low-S and synthetic fuels is now a very urgent scientific task. Several researches have shown that the lubricity of GTL and diesel fuels can be substantially improved by nanoparticles (ZnO, MoS₂), organomolybdenum compounds, biodiesel, fatty acid methyl esters (FAME) as well as commercially available and locally developed additives. This work intends to review the literature and study the possibilities to enhance the tribological behavior of synthetic fuels by various additives and fuel mixtures. Among them, the goal of the study is to compare previous studies' results and find additives that exhibited good lubricity when added into fuel mixtures, and present the possibility of where they can be practically used in high-efficient piston devices.

Methodology

However, for high efficiency piston devices such as DI diesel engines the synthetic liquid fuels, especially GTL (Gas-to-Liquid) fuels have very attractive properties in terms of sulphur content, cetane number and clean combustion. However, their low inherent lubricity remains a critical limitation, which can lead to increased friction and wear in engine components. Consequently, numerous researchers have studied methods to enhance the lubricating properties of synthetic and low-sulfur fuels. Mousavi S., Heris S., and Estellé P. investigated the effect of adding ZnO and MoS₂ nanoparticles to diesel fuel to prepare nano-lubricant samples. Results showed that nanoparticles reduce the friction coefficient, improve pumpability, and have optimal concentrations of 0.4 wt% for ZnO and 0.7 wt% for MoS₂.

Result and Discussion

Shilpi Agarwal and colleagues analyzed the effectiveness of commercial additives in enhancing the lubricity of ultra-low sulfur diesel fuel. The study demonstrated that these additives form protective layers on metal surfaces, significantly reducing wear scar diameter (WSD) [1], [2].

Daniel P. Geller and John W. Goodrum examined the effects of biodiesel and specific fatty acid methyl esters (FAME) on diesel fuel lubricity using HFRR testing. Only methyl ricinoleate and methyl eicosanoate at 1% concentration achieved acceptable lubricity levels [3].

Young-Kwan Lim et al. studied blending GTL diesel with biodiesel, showing improved lubricity; however, achieving WSD values within international standards required $\geq 3\%$ biodiesel blends [4].

Patent CN1102172C presents a molybdenum disulfide-based stable lubricating fluid that maintains stable tribofilms under high temperature and load, significantly reducing WSD. Furthermore, a high friction-resistant and sediment-free stable molybdenum disulfide emulsion was prepared by Syu syao & Ji ming.

Domestically produced GTL-SN-1 and GTL-SN-2 additives based on Uzbekistan GTL at the concentration of 300 ppm reduced WSD to 280–305 μm ; images from electron microscopy verified formation of thin, resilient protective layers on metal surfaces. Additives with SLES or zinc acetate were also found to significantly improve the lubricity [5].

The literature review demonstrates that, among the additives tested for GTL and low-sulfur fuels by lubricity tests, nanoparticles, organomolybdenum compounds, FAME/biodiesel blends as well as

commercial and locally prepared additives are most critical in improving lubricating properties. Furthermore, optimal species and concentrations of additives have been found through experimental works which guide the practical use of the additives in high-performance piston machines [6-7].

The lubricity of synthetic fuels is measured by means of more than one international and national standards. The following are the primary functions: ASTM D6078 — SLBOCLE (Scuffing Load Ball-on-Cylinder Lubricity Evaluator): This method is designed to determine the lubricating ability of fuel under high-load conditions. Readings are taken during the test, and scuffing is defined as the point where a rapid increase in the coefficient of friction is observed between a ball and a rotating bar. SLBOCLE is especially critical in the evaluation of boundary lubricity against synthetic fuels and correlates quite nicely with high pressure fuel systems which is an appropriate rating system [8].

ASTM D5001 — BOCLE (Ball-on-Cylinder Lubricity Evaluator):

In this process, the wear scar caused due to rubbing of ball and cylinder is quantified. While BOCLE is less sensitive than the HFRR technique, it is of value as an additional substrate on which to measure overall fuel lubricity. It is most beneficial for aviation fuels and for the determination of wear processes under oxidative conditions [9], [10].

ISO 12156-1 (HFRR High Frequency Reciprocating Rig):

This standard specifies the HFRR test method for measuring fuel lubricity [11]. It is conducted by subjecting a steel ball and flat metal plate to high-frequency, reciprocal (back-and-forth) motion under a specified load, at a controlled frequency and temperature. Once the test is completed, a wear scar diameter (Wear Scar Diameter – WSD) on the ball is measured with an optical microscope. This parameter provides a quantitative assessment of fuel lubricity. According to EN 590 standards, the wear scar diameter at 60 °C should typically not exceed 460 μm. HFRR tests are widely used to determine the inherent lubricity of synthetic fuels and to evaluate the effectiveness of lubricity-enhancing additives [12].

In addition to standard tests, tribometric studies are used to analyze the friction coefficient, wear rate, and microstructure of contact surfaces [13], [14]. Techniques such as electron microscopy and surface analysis are critical for evaluating the ability of fuels to form protective lubricating films, providing important scientific insight into fuel performance



Figure. High-Efficiency Piston Device for Evaluating the Lubricity of Synthetic Fuels.

For high-efficiency piston devices, synthetic fuels, especially GTL and BTL types bring environmental and operational advantages. Nevertheless, low intrinsic lubricity is the major drawback of these materials leading to wear and friction in engine parts [15]. It is concluded that literature and experimental results suggest that nanomaterials, molybdenumbased additives, mixed with biodiesel/FAME and commercial/local blends have potential for improved lubricity. Lubricity testing and the measurement of improvements with methods such as HFRR, SLBOCLE and BOCLE are well established techniques. An additive system and concentration, tailored to the high-pressure fuel pump and/or injector system help lower wear scar formation in these end-of-line devices, as well improving the life/mileage of piston type apparatus. Integrity against wear is important for the long-term, efficient and reliable operation of high-efficient piston/cylinder systems.

Conclusion

The addition of nanoparticle and molybdenum-based additives is recommended to increase the lubricity for low- sulfur GTL fuels and BTL because these kinds of fuel lack enough lubricity. Laboratory assessment is required to identify the best concentrations. 3% FAME and b5 concentrations of biodiesel blend generate WSD values within worldwide deadlines, and provide best performance results in high-efficiency piston appliances. Additive products, such as GTL-SN-1 and GTL-SN-2 can be locally produced, have performed on well in laboratory studies, and may be implemented at industrial sites. HFRR should be applied as the basic method to rate lubricity of synthetic fuels with SLBOCLE and BOCLE used as support methods. More testing using high efficiency piston devices should verify new additives and compounds under practical conditions, while tribometric and microscopic investigations offer vital dynamics of the lubrication mechanisms.

For synthetic fuels, even though they have low sulfur contents and cleaner combustion, those require controlling of the lubricating properties for high efficient piston machines. Experimental findings and literature surveys indicate that additives, such as nanoparticles, organomolybdenum compounds and biodiesel/FAME blends significantly improve lubricity and have protective effect on the engine components by reducing wear. The rating of the lubricity improvements is now by use of standard testings (HFRR, SLBOCLE, BOCLE). Proper selection and dosing of lubricity-enhancing additives ensure the reliable and efficient performance of high-pressure fuel systems and pistons, supporting the

long-term operation of modern high-efficiency engines.

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