

INVESTIGATION OF EFFECTS OF OIL ADDITIVE IN INTERNAL COMBUSTION ENGINE

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Abstract. Engine oil is one of the most important factors determining the reliability and longevity of an internal combustion engine, as it is directly involved in friction, heat transfer, and surface protection processes. The function of engine oil is not limited to lubrication alone; it also reduces mechanical wear, dampens vibrations, ensures sealing, and protects surfaces against corrosion and oxidation. Internal combustion engines operate under varying temperatures, surface stresses, and friction conditions. To improve engine oil quality, various additives are commonly used. With extended oil change intervals and increasingly stringent environmental regulations, the role of oil additives has become even more significant. Engine oil additives are intended to enhance or stabilize oil performance under different operating conditions. In addition to standard engine oils, supplementary additives with claimed revitalizing, surface restoration, or metal conditioning properties have become widespread on the market. These additives are often advertised as capable of reducing friction, compensating for wear, and improving overall engine performance. A properly balanced additive package can reduce direct metal-to-metal contact, stabilize friction processes, and limit surface degradation. However, the effects of such additives on the tribological properties of engine oil and their interaction with existing additive packages remain a subject of debate. The aim of the study is to analyse the influence of engine oil additives on the performance of a diesel engine. Experimental results showed that the equivalent continuous sound level (LAeq) emitted by the engine of the tested passenger car decreased by up to 2.5 dBA, corresponding to approximately 3% reduction, after the engine operation with the additive.

Keywords: diesel engine, oil additive, noise levels, friction.

Introduction

Modern machines contain many friction units that operate under different conditions and have varying parameters. Intensive material wear in tribopores occurs in boundary and mixed lubrication regimes, when direct contact exists between two surfaces [1]. To ensure high-quality and long-term engine operation, motor oils are used to separate friction surfaces, clean engine components, and provide additional cooling. The primary function of oil is to reduce friction and wear of moving engine parts, as well as to remove soot and combustion residues with the help of detergents contained in the oil [2]. Its quality is crucial due to the varying temperatures and loads acting on interacting engine components.

The purpose of engine oil is to lubricate the internal parts of the engine, remove combustion products, reduce friction, protect components from corrosion, and maintain their performance for as long as possible [3]. Engine oil is one of the main factors that ensure the smooth operation of mechanical systems [4]. It must adhere well to the surfaces of components, form a strong lubricating film, remove contaminants under various temperature conditions, and ensure effective lubrication.

Modern vehicles, as well as energy and agricultural machinery, rely on internal combustion engines. These systems are characterized by complex structures with numerous moving parts which, despite their high efficiency, are subjected to heavy loads, elevated temperatures, and significant friction. For this reason, the use of high-quality, carefully selected engine oil is essential – not only for basic lubrication but also for improving the engine durability, performance, and compliance with environmental requirements. The composition and performance of engine oil used in internal combustion engines depend on factors such as the crankshaft rotational speed, loads acting on engine components, operating temperature, and the by-products of fuel combustion. Viscosity is one of the key properties of engine oil [5]. The oil must maintain an adequate lubricating film between moving metal parts under varying temperatures and pressures, which directly affects the engine durability, friction losses, and ease of starting [6]. Improper maintenance of precision engine components and assemblies can lead to significant unplanned repair costs due to the complexity of the engine design. To minimize friction and wear, an effective lubrication system is essential, as insufficient lubrication leads to increased friction and accelerated wear. Lubricants play a key role in protecting the mating parts from wear and friction fatigue [2].

In addition to the properties inherent to base oil, the performance of engine oil is influenced by a system of various additives with specific functions, such as detergency, corrosion resistance, lubricity, and antioxidant properties. The anti-wear and extreme pressure additive properties studied have been found to show anti wear anti friction properties of lubricants under the exploitation condition [7]. During operation, the oil is exposed to high temperatures, contact with combustion products, effects of oxygen, and mechanical contamination (metal particles, soot, and dust). All these factors inevitably degrade the oil viscosity characteristics, reduce the effectiveness of additives, and diminish the protection of surfaces against friction and wear. As the oil ages, the wear of engine components increases, and the reliability of the machinery decreases.

One of the methods used to improve the properties of lubricating oils is the application of surface-restoring additives. The use of these additives is becoming increasingly important due to their ability to form protective layers on metal surfaces. Oil additives can be classified into several types, such as ceramic or nanostructured particles, organic compounds, or metal oxides, which can interact with surfaces under high temperatures and pressures. A revitalizant is defined as an additive that helps restore surface coatings in friction zones. This additive is based on a natural material known as cermet. When introduced into the friction zone, the revitalizant acts as a catalyst for the formation of a new surface layer. A new protective layer is formed in high-energy zones with the participation of carbides. In the final stage, diffusion processes between the protective layer and the metal result in the formation of a strong cermet coating [8]. Atomic metal conditioners are firmly established in global markets as a means of reducing friction, wear and heat between metal parts in tribological contacts. The authors of the study confirm that they can extend the service life of engines and transmission systems, as well as reduce emissions and fuel consumption [9]. The authors of the study state that the development of multifunctional lubricant additives is of great importance in order to improve the performance and durability of internal combustion engines. The article examines the effect of an oil additive containing an atomic metal conditioner on the lubricating properties and surface wear characteristics of 5W-30 engine oil. Long-term tests showed that the oil with the metal conditioner additive showed significantly higher wear marks during the test phase. Under all conditions, the oil temperature had a strong relationship with the friction coefficient. Although some friction improvement was observed, no clear traces of surface regeneration of the revitalizer were detected under the conditions tested [10]. The authors studied the tribological properties of oils with graphene oxide nanoparticles. They investigated whether the synthesized nanoparticles and graphene oxide nanoparticles improve the tribological properties of lithium-containing lubricants. The results showed that nanolubricants have better tribological properties. They also found that the anti-wear and anti-friction properties of lubricants are not proportional to the amount of nanoparticles and the load [8].

The aim of the study is to analyse the influence of engine oil additives on the performance of diesel engines.

Materials and methods

The tests were conducted on a diesel passenger car: VW Golf IV, model year 1998. A synthetic engine oil, FINA Delta Super G SAE 5W-30, API SG, was used in the tests. An oil additive (revitalizant) was selected as the object of the study. It is a repair and restoration compound (metal conditioner). This additive is specifically designed for diesel engines in both passenger cars and trucks and is suitable for use with all types of engine oils. The additive granules dissolve in the oil at normal engine operating temperature. The revitalization process is completed after 1,000-1,500 kilometres of operation.

Before adding the regenerating additive to the oil, the engine noise was measured, and a sample was taken for tribological oil tests. In the test, the regenerating additive was added to the engine oil at operating temperature. After pouring the regenerating oil additive into the engine, the car was driven 1500 km, the engine noise was measured and a sample was taken.

The experimental study of the engine noise was carried out by measuring the noise levels before and after the experiment. During the tests, noise levels were measured at five positions around the engine compartment, at a distance of 10 cm from the vehicle contour and 1.25 m above the ground (Fig. 1). The noise measurements were performed using a precision sound level meter, Brüel & Kjær model 2230, equipped with a 1/3–1/1 octave filter module 1625.

Tribological tests of oil lubricity, with and without additives, were carried out using a four-ball tribology tester “MAST-1” in accordance with the DIN 51 350 standard [11]. The friction coefficient was measured using the same four-ball testing machine. Figure 2 shows a schematic diagram of the tribology tester used to evaluate the friction coefficient of the base oil and oils with additives [1].

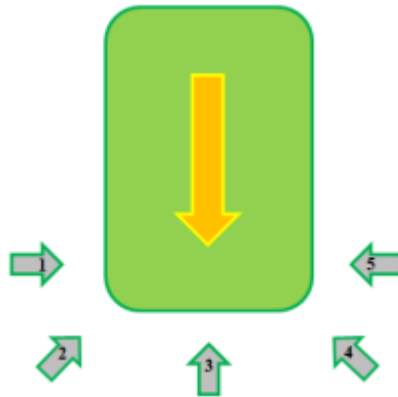


Fig. 1. **Measurement scheme:** 1, 2, 3, 4, 5 – measurement positions, respectively

During the tests, the oil temperature, ambient temperature, and the friction torque were recorded. Steel balls with a diameter of 12.7 mm were used. A total of 22 ml of the tested oil was poured into the test container, and the system was operated at a constant rotational speed of 1420 min^{-1} and 150 N load was used throughout the experiment. During the test, three balls were fixed at the bottom of the container, while the upper ball was rigidly mounted on the spindle. The upper ball was immersed in the oil and rotated against the three stationary balls, generating contact forces. At the initial stage of the test, the balls undergo wear and deformation at the contact points, forming a contact area. The test duration was 60 minutes to ensure reliable results. After the test, the wear scars formed on the steel balls were measured and evaluated (wear diameter, shape, depth, and the wear track on the rotating ball).

To ensure the reliability of the results, each test was tested three times under identical experimental conditions. The results were recorded and processed using the “Microsoft Excel” software, where statistical analysis was performed.

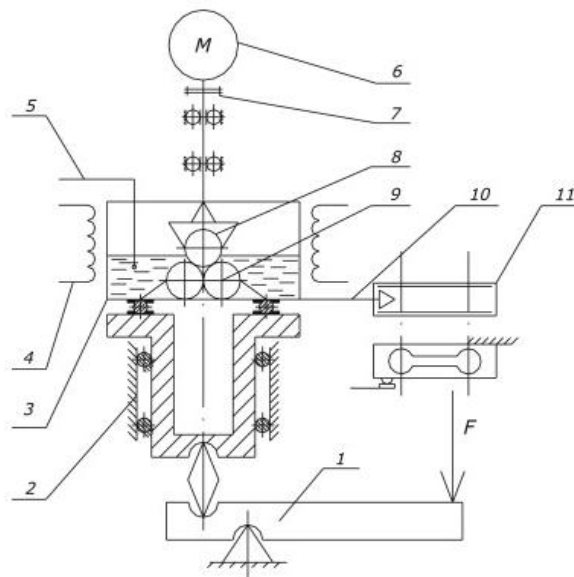


Fig. 2. **Schematic diagram of four-ball tester with friction torque measurement:** 1 – loading lever; 2 – vertical centering bearing; 3 – oil tank; 4 – oil heater; 5 – temperature sensor; 6 – electromotor; 7 – muff; 8 – rotating ball; 9 – fixed balls; 10 – communicator of friction torque; 11 – force sensor [1]

In order to analyse the wear scars, the balls were photographed during each test. Images of the wear traces were obtained using an optical microscope (Nikon Eclipse MA100). The images were captured at 200× magnification.

Results and discussion

Fig. 3 presents the results of the experimental study of the engine noise. As shown, the figure illustrates the engine noise levels measured at idle speed ($n = 900 \text{ min}^{-1}$) before and after using the revitalizant. The graph indicates that, at all measurement points, the engine noise was higher before applying the regenerating additive than after treatment. The results show that the greatest percentage reduction in the noise occurred at the first measurement point (4%), while at other points, the noise level decreased by 2.5-3.5% compared to the engine without the additive. Based on the noise measurements taken around the engine compartment at different positions, it can be inferred that this oil additive, by interacting with the surfaces of the engine components, may partially compensate for wear and improve the oil's lubricating properties. The overall sound pressure level (L_{Aeq}) in the engine decreased by up to 3 dBA.

The diameter of the wear marks is the main criterion for evaluating the lubricating properties of oils. The lubricating properties were evaluated by comparing the diameter of the wear mark on the balls and the magnitude of the friction moment. The duration of the engine oil service depends on its chemical stability, defined as the ability of the oil to retain its original properties and resist external influences under normal operating temperatures. Lubrication tests were conducted using 10W-40 oil with and without the additive, and the results are shown in Figure 4. Comparison of the oils indicates that, in tribological tests, the average wear diameter of the balls with the additive was 18% larger than that of the oil without the additive (Figure 4a).

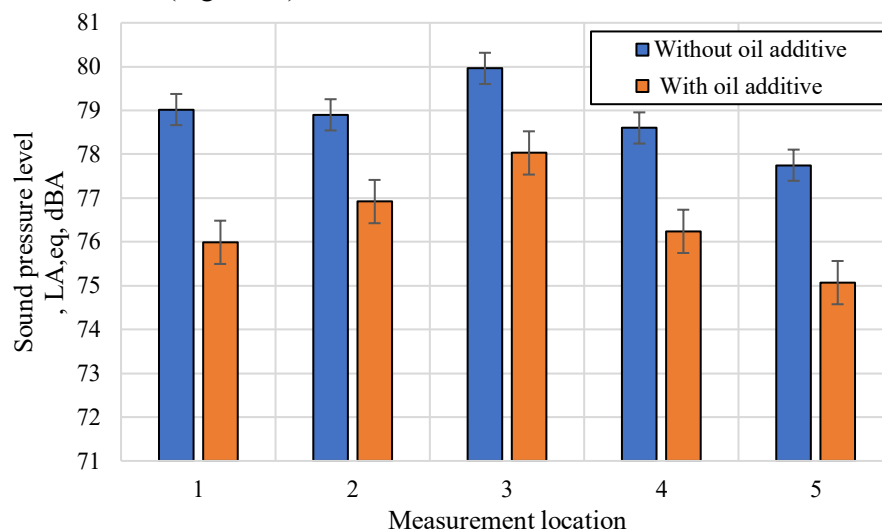


Fig. 3. Measured engine noise levels at various locations around the engine

Fig. 4b shows the friction coefficient data for lubrication with oil without additives and with oil containing the additive. As shown, when using the oil without additives, the friction coefficient remains stable at approximately 60 mNm. The graph also indicates that, during lubrication with the oil without additives, the temperature increased continuously until the end of the test. Comparing the results, it can be seen that separate mixtures have different effects on wear.

After adding the oil-improving additive, it is observed that the effect of the additive gradually becomes apparent, and the friction torque clearly decreases throughout the test, reaching 35.98 mNm at the end. When lubricating with the oil containing the additive, the oil temperature stabilizes after approximately 2,500 seconds. Comparison of the temperature profiles shows that, although the overall temperature trends are similar for both the oil without additives and the oil with the additive, the temperature fluctuations are smaller when using the oil with the additive.

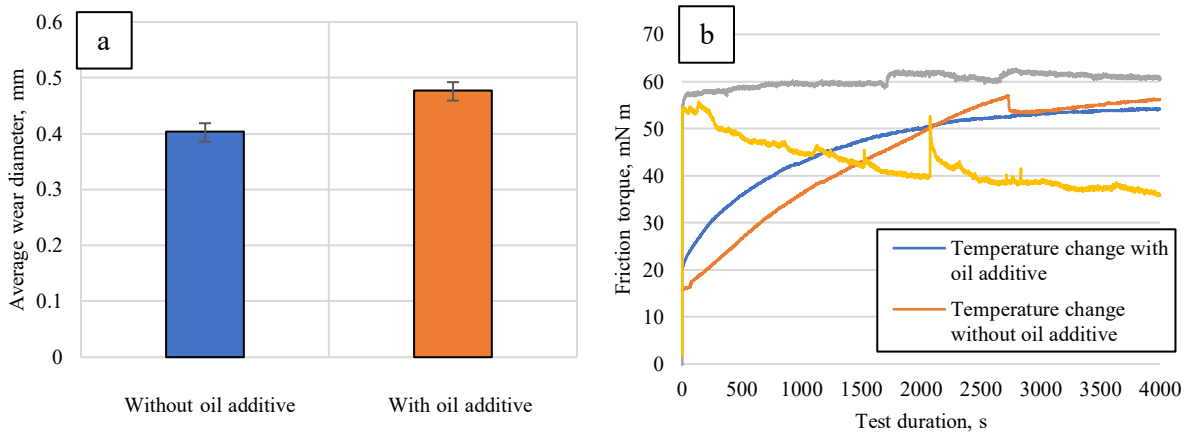


Fig. 4. Average wear diameter and friction torque graphs of base oil and oils with additives

Fig. 5 shows images of the balls obtained using an optical microscope, which was used to analyse wear scars. The study recorded photographs of friction traces to evaluate the wear patterns when lubricating with the engine oil without additives (a) and with additives (b). Significant differences between the wear patterns are observed. Although the diameters of the wear scars differ only slightly (a – 0.4037 mm, b – 0.4772 mm), the contact surface of the ball lubricated with the oil without additives (a) exhibits distinct features compared to the ball lubricated with the oil containing the additive.

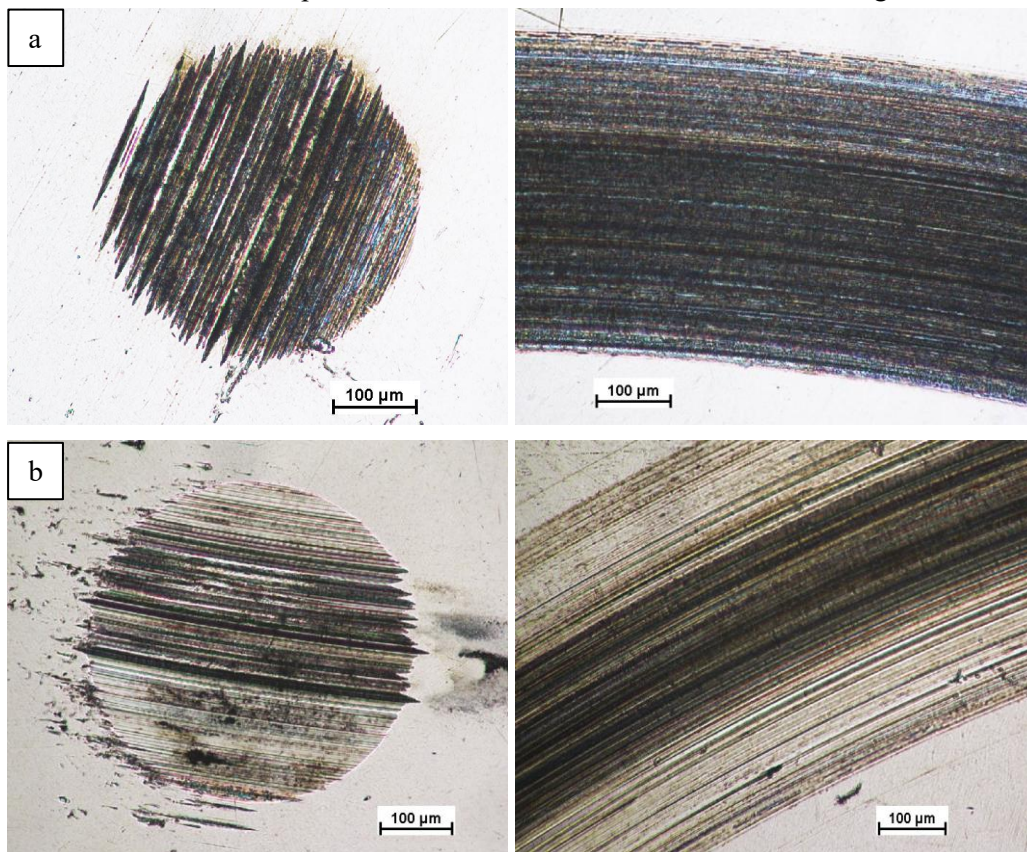


Fig. 5. Images of wear traces on the balls: (a) lubricated with oil without additives; (b) lubricated with oil containing the additive, under a load of 150 N

Analysis of the images of the balls lubricated with the oil containing the additive shows that the wear tracks increase, and the grooves formed indicate a slight deterioration in lubricating properties. However, although the ball lubricated with the additive develops deeper grooves, it maintains its overall shape. However, it can be seen that when using the oil additive, a sharp scratch is visible in the centre of the scratch mark. By the way, the results of the study indicate that more pronounced wear does not necessarily lead to a proportionally higher friction torque.

The reliability of machines and mechanisms directly depends on the friction and wear processes occurring on their friction surfaces. Improving lubrication properties is one of the most effective ways to extend the service life of machines and mechanisms, increase the wear resistance of parts and reduce energy consumption. Summarizing the results, it can be stated that a protective film is formed between the friction surfaces, which affects the friction parameters, but in order to clarify its nature, complex studies should be conducted.

Conclusions

After the tests, it was determined that the engine sound pressure level (LAeq) of the tested passenger car decreased by 3 dBA.

The tests conducted under a load of 150 N showed that using synthetic oil without the regenerating additive resulted in 18% less ball wear.

Analysis of the worn surface images shows that, when using oil with the regenerating additive, the wear tracks increase, and the formed grooves indicate a slight deterioration in lubricating properties.

Author contributions

Povilas Šaulys (P.Š.), Rytis Zautra (R.Z.), Tomas Mickevičius (T.M.). Conceptualization, P.Š., R.Z. and T.M.; methodology, P.Š., R.Z. and T.M.; software, P.Š., R.Z. and T.M.; validation, P.Š., R.Z. and T.M.; formal analysis, P.Š., R.Z. and T.M.; investigation, P.Š., R.Z. and T.M.; data curation, P.Š., R.Z. and T.M.; writing – original draft preparation, P.Š., R.Z. and T.M.; writing – review and editing, P.Š., R.Z. and T.M.; visualization, P.Š., R.Z. and T.M.; project administration, T.M.; funding acquisition, T.M. All authors have read and agreed to the published version of the manuscript.

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