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OVERVIEW ON THE IMPORTANCE OF ADDITIVES IN INTERNAL COMBUSTION ENGINE LUBRICANTS

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Abstract: Additives are crucial components that enhance the performance and longevity of lubricants, ensuring optimal engine operation under various conditions. Due to the increasing complexity and diversity of engine oils and their additives, it is necessary to study them in detail, to be able to understand the additive mechanisms and the importance of the correct formulation of lubricants. In addition to the base oils, what manufacturers call „additive packages" appear automatically in the composition of a very wide range of commercial lubricants, and their purpose is to improve their performance. Depending on the applications for which the lubricants are manufactured, the percentage of additives in the composition varies from >1% to 25% and in some cases even a higher value. The manufacture of an oil that achieves optimal performance in the lubrication systems of internal combustion engines represents a complex process of combining and balancing the properties of the base oil and the performance of the additives used. This paper aims to present an overview of the types of additives in internal combustion engine oils, their functions and the additive process, highlighting their benefits for the lubricant.
Keywords: additives, engine oil, lubricant, internal combustion engine

1. INTRODUCTION

The use of lubricants is historically attested even before 900 BC, when animal or vegetable fats were used to lubricate wood or to facilitate the transport process. With the processing of petroleum, a new generation of mineral-based lubricants came to replace the old lubricants [1].

Engine oil is the first to determine the durability of an engine. It contains two basic components: base oils and additives (figure 1). Base oil is the main part of the oil. It lubricates the internal moving parts. Engine lubricant base oils can be composed of: petroleum, chemically synthesized materials, a combination of synthetic and petroleum materials [2].

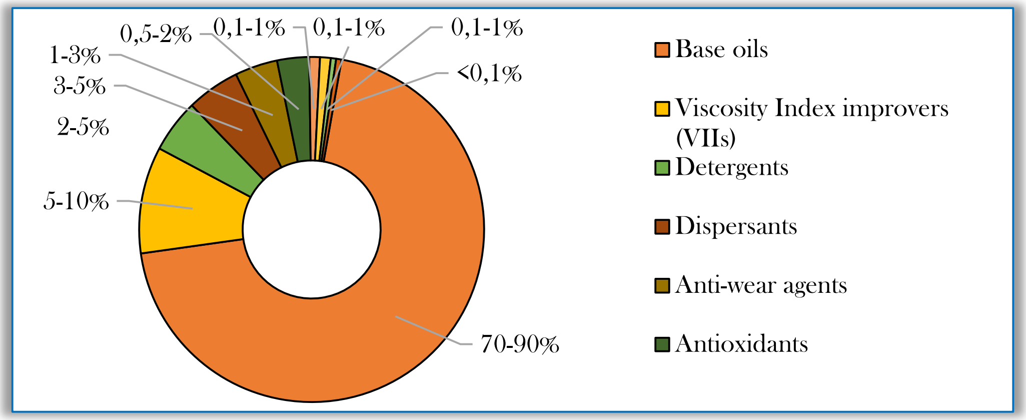

Figure 1. Composition of engine oil

The formation of the adherent film on the surface of the metal part is due to the phenomenon of absorption on the surface of the metal, a phenomenon that has two sides: one physical and one chemical (chemisorption). The physical side of the absorption consists in the appearance of attractive forces between the metal and the electropolar substances that are in the oil as a result of the existence of an electrostatic microfield on the surface of the metal over which the forces determined by the resonance of the fields due to the movement of electrons are superimposed. The chemical side is due to the change in oil concentration on the metal surface [2].

In addition to the base oils, what manufacturers call „additive packages" appear automatically in the composition of a very wide range of commercial lubricants, and their purpose is to improve their performance. Depending on the applications for which the lubricants are manufactured, the percentage of additives in the composition varies from >1% to 25% and in some cases even a higher value. The

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manufacture of an oil that achieves optimal performance in the lubrication systems of internal combustion engines represents a complex process of combining and balancing the properties of the base oil and the performance of the additives used [2].

The purpose of this paper is to provide a comprehensive overview of the role and significance of additives in internal combustion engine lubricants, detailing their types, mechanisms of action, benefits, challenges, and future trends to highlight their critical contribution to engine performance and longevity.

2. TYPES OF ADDITIVES

Engine oil additives are critical components that enhance the performance and longevity of lubricants used in internal combustion engines. These additives serve various functions, ensuring that the engine operates smoothly, efficiently, and with minimal wear and tear.

The role of additives can be summarized as follows [2]:

- protection of metal surfaces (rings, bearings, gears, etc.);
- expanding the range of applicability of lubricants;
- prolonging the life of the lubricant;
- meeting the special requirements (specified parameters) of the vehicle manufacturer.

Viscosity index improvers

Viscosity index improvers (VIIs), which typically comprise about 5-10% of the oil composition, help maintain the oil's viscosity across a wide temperature range. This ensures optimal lubrication in both hot and cold conditions. VIIs are polymer-based compounds such as polymethacrylates (PMAs) and olefin copolymers (OCPs). These polymers expand at high temperatures to maintain viscosity and contract at low temperatures to improve flow. This temperature-dependent behavior allows the oil to provide consistent lubrication, reducing engine wear and improving efficiency [3].

Detergents and dispersants

Detergents, which typically constitute about 2-5% of the total oil composition, are essential for maintaining engine cleanliness by preventing the formation of deposits on engine surfaces. These deposits can form from various contaminants such as soot, metal particles, and other combustion by-products. Detergents work by neutralizing acidic by-products of combustion, which can cause corrosion and sludge formation. Commonly, metallic compounds such as calcium sulfonates, magnesium sulfonates, or overbased sulfonates are used. These compounds react with acidic materials to form neutral salts, which are then dispersed in the oil, keeping engine surfaces clean and free from harmful deposits [4].

Dispersants, which usually make up around 3-5% of the total oil composition, play a crucial role in keeping contaminants such as soot, dirt, and oxidation products in suspension. This prevents these particles from agglomerating and forming sludge or varnish, which can impair engine performance and longevity. Non-metallic, ashless compounds like polyisobutenyl succinimides are commonly used for this purpose. They work by encapsulating particles, thereby keeping them suspended in the oil for removal during oil changes. This suspension is vital for preventing the formation of large, damaging deposits on engine surfaces [4].

Anti-wear agents

Anti-wear agents, which generally make up about 1-3% of the oil composition, form protective films on metal surfaces to prevent direct metal-to-metal contact. This significantly reduces wear and extends the lifespan of engine components. Zinc dialkyldithiophosphate (ZDDP) is the most widely used anti-wear agent. When exposed to high temperatures and pressures, ZDDP decomposes to form a protective phosphate glass layer on metal surfaces. This layer serves as a barrier, preventing direct contact and wear between metal surfaces [5].

Antioxidants

Antioxidants, which typically constitute around 0.5-2% of the oil composition, inhibit the oxidation of the oil. Oxidation can lead to the formation of sludge and varnish, which degrade oil performance and can damage the engine. By preventing oxidation, antioxidants help maintain oil viscosity and performance over time. Phenolic and amine antioxidants are prevalent. Phenolic antioxidants interrupt the oxidation process by donating hydrogen atoms, while amine antioxidants trap free radicals, preventing further oxidation. This dual action helps extend the life of the oil and ensures it continues to perform effectively under various operating conditions [6].

- Corrosion inhibitors

Corrosion inhibitors, which generally constitute around 0.1-1% of the oil composition, protect engine components from rust and corrosion by forming a protective barrier on metal surfaces. Compounds such as amine phosphates and succinic acid derivatives are used for this purpose. These compounds adsorb onto metal surfaces, creating a hydrophobic layer that repels moisture and corrosive substances. This protective barrier prevents the engine's metal parts from reacting with water and other corrosive agents, thereby extending the life of the engine components [7].

- Friction modifiers

Friction modifiers, accounting for about 0.1-1% of the oil composition, are used to reduce friction between moving parts. This reduction in friction enhances fuel economy and improves the overall efficiency of the engine. Organic friction modifiers such as fatty acids, esters, and amides are commonly used. They adsorb onto metal surfaces, creating a low-shear layer that reduces friction. This low-shear layer allows engine parts to move more freely, reducing the energy required for operation and thus improving fuel efficiency [8].

- Pour point depressants

Pour point depressants, usually comprising about 0.1-1% of the oil composition, lower the temperature at which the oil becomes semi-solid and loses its flow characteristics. This is crucial for ensuring good cold start performance, especially in cold climates. Polyalkyl methacrylates and alkylated naphthalenes are typical pour point depressants. They modify the size and shape of wax crystals that form at low temperatures, preventing them from agglomerating and impairing oil flow. This ensures that the oil remains fluid at lower temperatures, allowing for easier starting and effective lubrication in cold conditions [9].

- Foam inhibitors

Anti-foaming agents, typically making up about 0.001-0.1% of the oil composition, prevent the formation of foam, which can reduce the effectiveness of the lubricant and cause cavitation in the oil pump. Silicone-based compounds and organic polymers are common anti-foaming agents. These compounds work by reducing surface tension, allowing foam bubbles to coalesce and dissipate more quickly. This ensures that the oil maintains its lubricating properties and can circulate effectively within the engine, preventing damage from air pockets and maintaining consistent lubrication [10].

3. MECHANISMS AND BENEFITS OF ADDITIVE ACTION

Engine oil additives interact with lubricants and engine components in specific ways, utilizing both chemical and physical mechanisms to enhance lubricant performance, as follows:

- Viscosity index improvers function through physical mechanisms, by expanding and contracting in response to temperature changes. At low temperatures, these polymers remain compact, allowing the oil to flow easily. As temperatures rise, the polymers elongate, increasing the oil’s viscosity [3].
- Detergents function primarily through chemical reactions. They are mainly responsible for maintaining engine cleanliness by neutralizing acidic by-products of combustion. They achieve this through chemical reactions involving alkaline components, commonly metallic compounds such as calcium or magnesium sulfonates. These compounds react with acidic substances to form neutral salts, which are then dispersed in the oil, preventing the formation of corrosive deposits on engine surfaces [4].
- Dispersants operate mainly through physical mechanisms, keeping particulate contaminants such as soot and oxidation products in suspension through encapsulation. This action ensures that contaminants remain suspended and are removed during oil changes, preserving engine cleanliness and performance [4].
- Anti-wear agents like Zinc dialkyldithiophosphate (ZDDP) operate through both chemical and physical mechanisms. Chemically, ZDDP decomposes under high temperature and pressure conditions to form a phosphate glass layer on metal surfaces. This protective layer prevents direct

metal-to-metal contact, reducing wear. Physically, the film acts as a barrier, absorbing the load and preventing surface damage, which extends the life of engine components [5].

- Antioxidants function through chemical mechanisms to inhibit oil oxidation. Phenolic antioxidants work by donating hydrogen atoms to free radicals, terminating the oxidation chain reaction. Amine antioxidants, on the other hand, react with and neutralize free radicals, preventing further oxidation [6].
- Corrosion inhibitors protect engine components by forming a chemical barrier on metal surfaces. They adsorb onto metal surfaces to create a hydrophobic layer. This layer repels moisture and corrosive substances, preventing chemical reactions that can lead to rust and corrosion [7].
- Friction modifiers reduce friction between moving parts primarily through physical adsorption. They adsorb onto metal surfaces, forming a low-shear strength layer. This layer allows surfaces to slide over each other more easily [8].
- Pour point depressants work through physical mechanisms by modifying wax crystal formation. They alter the size and shape of wax crystals that form at low temperatures. These modifications prevent wax crystals from agglomerating, allowing the oil to remain fluid at lower temperatures [9].
- Foam inhibitors operate through physical mechanisms. Silicone-based compounds and organic polymers reduce the surface tension of the oil, allowing foam bubbles to coalesce and dissipate more quickly [10].

4. CHALLENGES, FUTURE TRENDS AND DEVELOPMENTS

Challenges

As could be seen, engine oil additives play a crucial role in enhancing the performance and longevity of engines by providing improved lubrication, reducing wear, preventing corrosion, and maintaining cleanliness. However, these additives can also have potential negative effects on both engines and the environment.

One significant concern is the formation of deposits (figure 2). Certain additives, especially when used in high concentrations or under extreme operating conditions, can lead to the formation of sludge, varnish, and other deposits within the engine. These deposits can impair oil flow, clog filters, and reduce the overall efficiency of the engine, potentially leading to increased wear and tear [11].

Figure 2. Deposits on engine components [12]

Another issue is the chemical compatibility of additives with various engine components. Additives that are not properly formulated can react negatively with materials such as seals, gaskets, and metal surfaces, causing deterioration or degradation. For instance, some detergent and dispersant additives might contribute to the corrosion of non-ferrous metals, such as copper and aluminum, used in engine components. Over time, the degradation products of certain additives can result in the generation of harmful by-products. These by-products can alter the oil's viscosity, reducing its effectiveness as a lubricant and leading to increased friction and wear [4].

The use of engine oil additives also raises several environmental concerns, primarily due to the potential for toxicological and ecological impacts. Many traditional additives contain heavy metals, such as zinc, phosphorus, and molybdenum, which can be harmful to aquatic and terrestrial ecosystems when they enter the environment through oil leaks, spills, or improper disposal. Additionally, some additives, such as organometallic compounds, can persist in the environment and bioaccumulate, posing long-term risks to wildlife and humans. The production and disposal of these additives also contribute to environmental pollution. For example, the refining and manufacturing processes for certain chemical additives can release volatile organic compounds (VOCs) and other pollutants into the atmosphere [4].

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Future trends and developments

In response to the challenges and environmental concerns associated with traditional additives, significant innovations in additive technology are being developed. These advancements aim to enhance the performance of engine oils while minimizing their negative impacts.

One of the key areas of innovation is the development of ashless additives. Unlike traditional metal-based additives, ashless additives do not produce ash during combustion, thereby reducing the risk of deposit formation and minimizing environmental pollution. These additives typically include organic compounds such as amines, esters, and organic acids, which provide similar performance benefits without the associated drawbacks [13].

Nanotechnology is another promising field in additive development. Nanoparticles, due to their small size and high surface area, can provide superior lubrication and anti-wear properties. For example, the use of nano-sized ceramic particles in engine oils has shown potential in reducing friction and wear, improving fuel efficiency, and extending oil life. Moreover, these nanoparticles can be engineered to be environmentally benign, addressing both performance and ecological concerns [14].

The development of sustainable and environmentally friendly additives is a critical focus in the field of engine oil technology. These additives aim to provide the necessary performance enhancements while minimizing environmental impact and promoting sustainability. One approach to achieving this goal is the use of renewable resources. For instance, additives derived from plant-based oils, such as soybean or rapeseed oil, offer a renewable and biodegradable alternative to petroleum-based additives. These bio-based additives can provide effective lubrication and wear protection, while their biodegradability ensures that they do not persist in the environment [4].

Another strategy is the incorporation of environmentally benign elements. For example, the use of calcium and magnesium-based detergents and dispersants can replace traditional zinc and phosphorus compounds, reducing the toxicity and environmental impact of the additives. These alternatives can still provide effective cleaning and deposit control, ensuring engine performance and longevity. Moreover, advancements in green chemistry are enabling the design of additives that are less harmful to the environment. Green chemistry principles, such as the use of non-toxic solvents, renewable feedstocks, and energy-efficient processes, are being applied to the development of engine oil additives. This approach not only reduces the environmental footprint of the additives but also enhances their sustainability [4].

The engine oil additive industry is increasingly moving towards the development of multi-functional additives. These additives are designed to provide multiple benefits, reducing the need for separate additives and simplifying the formulation of engine oils. One trend in this direction is the development of additives that combine anti-wear, anti-corrosion, and friction-reducing properties. For example, certain advanced organometallic compounds can provide excellent wear protection while also acting as effective friction modifiers and corrosion inhibitors. This multifunctionality can enhance the overall performance of the engine oil, reducing the need for additional additives [15].

Another trend is the integration of fuel-saving and emission-reducing properties into engine oil additives. Additives that improve the efficiency of combustion and reduce friction can contribute to lower fuel consumption and reduced emissions. For instance, the use of advanced friction modifiers, such as molybdenum dithiocarbamates, can improve fuel economy and reduce greenhouse gas emissions, addressing both performance and environmental goals. The trend towards more stringent environmental regulations is driving the development of low- and zero-ash additives. These additives are designed to meet regulatory requirements while providing the necessary performance benefits. The use of advanced synthetic esters and other organic compounds is an example of how the industry is responding to these challenges [16].

5. CONCLUSIONS

In conclusion, the use of additives in internal combustion engine lubricants is crucial for enhancing performance, ensuring engine longevity, and meeting stringent environmental standards. This article has provided an extensive overview of the types of additives, their mechanisms of action, and the challenges and future trends associated with their use.

The continued evolution of additive technology is essential for meeting the performance and environmental demands of modern internal combustion engines. As research and development efforts persist, we can anticipate further innovations that will lead to more efficient, sustainable, and high-performing lubricants. The integration of advanced additives will remain a cornerstone in the quest to optimize engine operation, extend engine life, and reduce the environmental impact of automotive and industrial applications.

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