Development of niche automotive lubricants: Optimization opportunities

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ABSTRACT

It is widely known in engineering that vehicle mechanical systems generate very severe operating conditions for their internal components, requiring them to have robust characteristics to be used in this type of application. As key components in these systems, lubricating oils are also subject to the same challenges, and therefore need to be carefully developed in order to adequately fulfill their functions.

Standardizing organizations in the automotive sector promote committees with various participants in the production chain of this segment in order to map and understand this severe environment in which oil operates, so that the minimum performance requirements that vehicle lubricants must have are specified. Lubricant companies then use these specifications as a guide to develop the necessary properties in their products. However, in certain cases, standard specifications may not optimally meet segments with peculiar characteristics. The objective of this work is to identify this technical gap and propose solutions for the development of new oils that present the best possible performance in the segments for which they are intended.

RESUMO

É de amplo conhecimento na engenharia que os sistemas mecânicos veiculares geram condições de operação bastante severas para seus componentes internos, exigindo que estes possuam características robustas para serem utilizados neste tipo de aplicação. Como componentes fundamentais nestes sistemas, os óleos lubrificantes também são submetidos aos mesmos desafios, e assim precisam ser desenvolvidos cuidadosamente a fim de cumprirem adequadamente suas funções.

Organizações normatizadoras do setor automotivo promovem comitês com diversos participantes da cadeia produtiva deste segmento a fim de mapear e entender esse ambiente severo de atuação do óleo, para que sejam especificados os requisitos mínimos de desempenho que os lubrificantes veiculares precisam ter. As empresas de lubrificantes então utilizam estas especificações como guia para desenvolver as propriedades necessárias em seus produtos. No entanto, em certos casos, as especificações padrão podem não atender de forma otimizada a segmentos com características peculiares. O objetivo deste trabalho é identificar essa lacuna técnica e propor soluções para o desenvolvimento de novos óleos que apresentem o melhor desempenho possível nos segmentos a que são destinados.

INTRODUCTION

Engine oils have to deal with a wide range of challenges, therefore, they have a lot of functions in engines. The main task consists of reducing friction by separating the moving surfaces through a lubricant film to guarantee the system’s functional reliability in all operating conditions. Apart from this, they also must cool the system, seal the cylinder, protect the surfaces from corrosion and several other functions. The movement of surfaces can diverse between the alternative up-and-down sliding of the piston inside the cylinder-bore to the 3.000-5.000 average rpm rotation movements between the bearings of the connecting rod and the crankshaft and up to the extreme dynamic conditions found in advanced turbochargers with rotating speeds of up to 200.000 rpm with tolerances of micron scales [1].

Lubricants have the essential task of reducing friction and minimizing wear in challenging scenarios, such as during extremely cold start-ups in the Arctic regions and when the oil and the lubricating film are exposed to elevated temperatures of up to 300°C under the piston crown and high pressures in bearings and around the piston rings. The oil needs to maintain good flowability and remain pumpable at low temperatures to prevent direct metal-to-metal contact during cold start-ups. Even in extreme cold conditions, additives must not precipitate, and the oil must not freeze. On the other hand, at higher temperatures, the oil must exhibit significant resistance to thermal ageing and mechanical shear. Additionally, the stability of the lubricating film should not be compromised by higher temperatures or fuel dilution up to a certain degree [1].

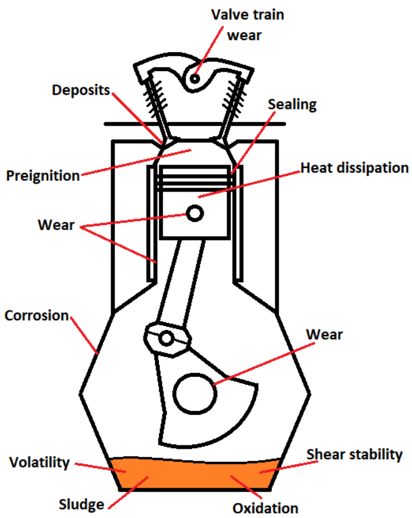

Figure 1. Engine parts and some examples of challenges for engine oils

During the process of combustion, the engine oil plays an important role in creating a seal between the piston and cylinder to maintain the optimum pressure and produce work more efficiently. Simultaneously, it must burn away completely on the cylinder wall leaving no residue behind and needs to also remove heat from the piston, effectively cooling it down to maintain the correct temperature of the engine [1].

Blow-by gases produced from the fuel combustion along with their resulting by-products need to be neutralized. Incomplete combustion forms soot and sludge particles that can clog the internal galleries, prejudice the heat exchange capacity of the engine and the oil pumpability, thus the lubricant must keep them finely dispersed and in suspension so they can be removed by the oil filter. In a similar way, any dirt or particles that have been worn away must be carried out by the oil to the oil filter and removed as well [1].

Additionally, any water that forms during the combustion process should mix with the oil to create an emulsion, and in instances of higher concentrations of water, when the oil and water separate as the temperature drops, the oil should protect the equipment against corrosion. Particularly during short-distance operations of the engine, the oil can become acidic and lead to corrosive damage. Recent efforts to reduce CO_2 emissions have led to increased ethanol content in gasoline, necessitating even higher performance standards for engine oils in terms of water compatibility and corrosion prevention [1].

THE NORMATIVE ORGANIZATIONS

To ensure that all the necessary properties for a lubricant are met, associations and entities related to the automotive sector created the minimum requirement levels of lubricant performance and are always updating these specifications. The normative organizations play a crucial role in the industry, providing guidelines and standards to ensure the quality, performance and compatibility of lubricants used in different applications. These organizations develop technical specifications and test methods to evaluate the physical, chemical and performance properties of lubricating oils, establishing criteria to determine the necessary characteristics that products need to have to guarantee that they will be able to withstand all the extreme conditions to which they will be submitted.

The specifications created provide guidance for oil manufacturers, allowing them to develop products that meet the minimum requirements demanded by their applications. In addition, equipment manufacturers also use this information to size their vehicles, aware that the lubricants industry will make products compatible with their technologies available on the market to enable the final consumer to purchase products with the same level of performance in different locations.

The standard-setting organizations are also responsible for carrying out certifications to verify that the products already developed are following the established specifications. These certifications guarantee the quality and performance of products in accordance with established standards and help consumers when choosing the ideal lubricating for their vehicle.

It is also possible to mention that normative organizations are co-responsible for directing the industry towards meeting the increasingly strict policies of environmental preservation and sustainability. This is done, for example, through stricter requirements regarding fuel economy levels and the reduction of harmful emissions into the environment.

Among the most well-known and influential associations in the lubricating oil industry are the Society of Automotive Engineers (SAE), the American Petroleum Institute (API), the International Lubricant Specification Advisory Committee (ILSAC), the European Automobile Manufacturers' Association (ACEA), and the American Society for Testing and Materials (ASTM).

HOW SPECIFICATIONS ARE ARRANGED TODAY

When establishing standardized specifications for a particular certification, normative organizations follow a systematic process. This involves identifying and isolating the characteristics that will be evaluated, identifying application factors that have the greatest influence on product behavior, and developing tests that simulate these conditions, typically in an isolated manner. The objective is to analyze and compare the products that will be considered for certification in order to determine their compliance with the established criteria.

This approach aims to ensure a fair and impartial evaluation process, where products undergo tests that replicate parts of real application conditions. By isolating and separately analyzing the most significant factors, normative organizations can obtain more precise and comparable results.

For example, for a lubricant to be classified under the API SL specification, currently the minimum performance level authorized for commerce in Brazil by ANP (Brazilian National Petroleum Agency) [2], it is necessary that, in addition to meeting the requirements of chemical and physical properties, it passes the following ASTM performance tests:

1. Sequence III F/G - This test method was developed to evaluate automotive engine oils for protection against oil thickening and engine wear during moderately high-speed, high-temperature service [3, 4].

2. Sequence III H - Developed to evaluate automotive engine oils for protection against oil thickening and piston deposits during moderately high-speed, high-temperature service [5].

3. Sequence IV A - Developed to evaluate automotive lubricant's effect on controlling cam lobe wear for overhead valve-train equipped engines with sliding cam followers [6].

4. Sequence V E - This test method has been correlated with vehicles used in stop-and-go service prior to 1988, particularly with regard to sludge and varnish formation and valve train wear [7].

5. Sequence V G - Used to evaluate an automotive engine oil's control of engine deposits under operating conditions deliberately selected to accelerate deposit formation [8].

6. Sequence V H - Evaluates an automotive engine oil's control of engine deposits under operating conditions deliberately selected to accelerate deposit formation. This VH test method was correlated with the previous VG test method, which was correlated with field service data, determined from side-by-side comparisons of two or more oils in police, taxi fleets, and delivery van services [9].

7. Sequence VIII - This test evaluates automotive engine oils for protection of engines against bearing weight loss. This test method is also used to evaluate the "stay-in-grade" capabilities of multiviscosity-graded oils [10].

As we can see, all the sequences were developed to individually measure certain aspects of lubricant performance, and in order to ensure the fair comparability of results between different products produced globally, it was necessary to standardize some parameters of the test, like the type of equipment and the fuel used in each method. For example, Sequence III H utilizes a 2014 Chrysler Pentastar port fuel-injected engine [5], while Sequence IV A utilizes a 1994 Nissan KA24E 2.4 L fuel-injected four-cylinder engine [6], and Sequence V H utilizes a 2013 Ford 4.6 L fuel-injected eight-cylinder engine [7]. All of them uses gasoline as fuel and the gasoline itself must also have specific standard parameters.

Due to the need for specific engines and the standardization of other inputs, such as the fuel used in the tests, they can be very costly and their availability very limited. Also, considering the global demand for them, lubricant companies often need to schedule and wait their turn to submit their products for these tests. This can result in extended timelines for obtaining test results, affecting the time required to develop and launch new products in the market.

SPECIFIC CONDITIONS

Each region has external variables that influence vehicle behavior and, consequently, lubricant performance. Additionally, different user profiles in specific segments and applications can also impact the severity of engine working conditions and the lubricants used in them. Some examples can be shown in figure 2:

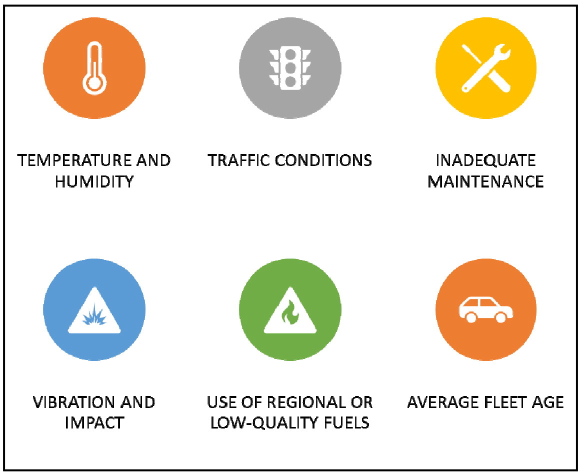

Figure 2. Conditions that can affect engine oils: a) Temperature and humidity; b) Traffic conditions; c) Inadequate maintenance; d) Vibration and impact; e) Use of low quality or regional fuels; f) Average fleet age

a) Temperature and humidity: Environmental conditions such as high temperatures or excessive humidity can affect the vehicle's internal components. Extreme heat can lead to engine overheating, transmission issues, and damage to other systems. Moisture can contaminate the lubricating oil and increase the need for corrosion protection.

b) Traffic conditions: Heavy traffic, especially in large urban areas, can increase wear on the vehicle's internal components. Frequent use of brakes, constant shifting of gears, and aggressive acceleration can negatively affect the performance of braking systems, clutches, and transmissions, as well as cause more frequent operation under boundary lubrication conditions, leading to increased wear.

c) Inadequate maintenance: Lack of proper maintenance, such as not regularly changing oil, filters, spark plugs, and other components, can result in internal damage, accumulation of dirt, excessive wear of parts, and system failures.

d) Vibration and impact: If the vehicle is exposed to uneven roads, bumps, potholes, or aggressive driving conditions, resulting vibrations and impacts can negatively affect internal components, causing premature wear of parts, for example.

e) Use of low-quality or regional fuels: The use of low-quality or adulterated fuel can negatively impact the vehicle's internal components, especially the fuel system, injection system, and engine. Fuel contaminants such as water, solvents, and undesirable chemicals can enter the fuel system and if they are not adequately filtered, they can be carried into the engine's lubricating oil resulting in oil dilution. This may reduce its protective and lubricating capacity, and form a harmful mixture for the engine, potentially leading to premature wear of components such as pistons, rings, valves, and bearings. Low-quality fuels may also contain compounds that accelerate oil oxidation, reducing its lifespan. Regarding regional fuels, depending on their composition they can also cause similar problems if the vehicle system is not prepared to deal with their particularities.

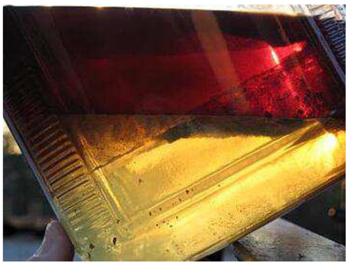

Figure 3. Example of contaminated fuel [11]

f) Average fleet age: Over time, mechanical components of the vehicle, such as the engine, transmission, suspension, and brakes, tend to experience wear. Seals and gaskets may start leaking, moving parts may wear out, and components can lose their original efficiency. This can result in performance loss, increased fuel consumption, and a higher probability of mechanical failures.

OPTIMIZATION OPPORTUNITIES

Considering that the effects of vehicle system operating conditions on lubricants are diverse, that they occur in a combined manner, and that regulatory organizations generally evaluate different lubricant performance properties isolated from each other, while the influencing factors may vary according to regional characteristics, we understand that there are opportunities for performance optimization for lubricants that will be developed with a focus on usage in segments with specific operational profiles.

Instead of only observing the properties measured by specifics standard tests, it would be possible to improve the lubricant performance for a given niche by understanding the niche’s common usage profile and the inherent factors that could affect the operation conditions of the system, as well as the necessities of the average user, considering these data during the process of lubricant development.

To identify the primary factors influencing oil behavior in a particular usage profile, it is necessary to measure representative samples from that specific niche. By gaining a more comprehensive understanding of these operational details, it becomes possible to develop cost-effective and widely accessible tests that represent the combined effects of these factors. This allows for evaluating which lubricant characteristics can be optimized to enhance performance in these specific applications.

Future efforts in this regard will be made in partnerships with research institutes to verify the practical confirmation of the insights obtained in this review of the current scenario regarding lubricant development.

CONCLUSION

When reviewing the current scenario of how the development of new lubricants is carried out, it becomes apparent that the integration of initial tests, offering preliminary insights into product performance before subjecting them to globally standardized tests, can yield notable advantages. These include optimizing product efficacy for specific conditions, process cost reduction and agility.

It is important to note that the intention of this study and future works is not to create a new widely used standard or replace existing specifications. Rather, it aims to provide characteristic data from representative sampling of a specific segment, which may or may not reflect profiles that were not evaluated.

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