Advancements in Diesel Engine Lubricants: Addressing Biodiesel Challenges and Fluids Performance

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ICONIC Lubrificantes

ABSTRACT

The technical evolution of diesel vehicles in recent years has largely been driven by increasingly strict environmental laws and standards, posing a challenge for the equipment manufacturers to adjust to those requirements. Consequently, new formulations of diesel engine lubricants have been developed focusing on extending oil change intervals, supporting different post-treatment systems to reduce pollutant emissions and compatibility with different fuel scenarios. In Brazil, aligning with global trends, legislation mandates that all commercialized diesel contain a minimum biodiesel content of 14%, with plans to reach 20% by 2030. This presents an additional performance challenge for lubricating oils, particularly in resisting oxidation and degradation.

This study aims to evaluate the impacts of using superior lubricants in the presence of biodiesel, considering the evolution of the API CK-4 specification compared to the API CI-4 and the advantages of a differentiated API CK-4 lubricant to meet the demands of applications with high biodiesel content. For these studies, an assessment of API and ACEA requirements will be conducted, along with a comparative evaluation of data from PDSC and CEC L-109 oxidation analyses between API CI-4, API CK-4 and API CK-4 high-performance products.

RESUMO

A evolução técnica dos veículos a diesel nos últimos anos tem sido impulsionada por leis e padrões ambientais cada vez mais rigorosos, desafiando os fabricantes de equipamentos a se ajustarem a esses requisitos. Consequentemente, novas formulações de lubrificantes para motores diesel têm sido desenvolvidas focando na extensão dos intervalos de troca de óleo, no suporte a diferentes sistemas de pós-tratamento para reduzir emissões de poluentes e na compatibilidade com diversos cenários de combustível. No Brasil, alinhando às tendências globais, a legislação exige que todo o diesel comercializado contenha um mínimo de 14% de biodiesel, com planos para atingir 20% até 2030. Isso apresenta um desafio adicional para os lubrificantes, especialmente na resistência à oxidação e degradação.

Este estudo visa avaliar os impactos do uso de lubrificantes superiores na presença de biodiesel, considerando a evolução da especificação API CK-4 em comparação com a API CI-4 e as vantagens de um lubrificante API CK-4 diferenciado para aplicações com alto teor de biodiesel. Para esses estudos será realizada uma avaliação dos requisitos da API e ACEA, juntamente com uma avaliação comparativa das análises de oxidação PDSC

e CEC L-109 entre produtos API CI-4, API CK-4 and API CK-4 de alto desempenho.

INTRODUCTION

Growing concerns over climate change have driven significant changes in the automotive industry over the last years. The transportation sector in Brazil represents more than 50% of the energy-related CO_2 emissions in the country [1], as seen in figure 1, and road transportation represents more than 70% of the transportations CO_2 emissions worldwide, with a necessary reduction of 30% of its emissions to reach the Net Zero Scenario prediction for 2030 [2], as seen in figure 2. These conditions demonstrate the relevance of those changes to mitigate the impacts of emissions from this sector.

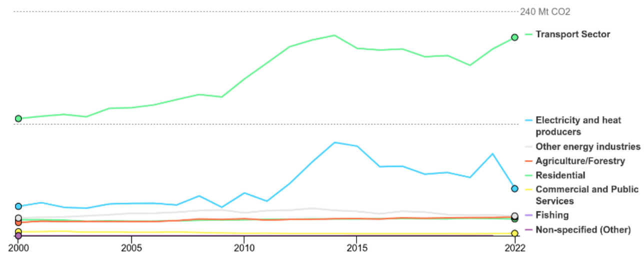

Figure 1. Evolution of CO_2 emissions by sector in Brazil since 2000 [1].

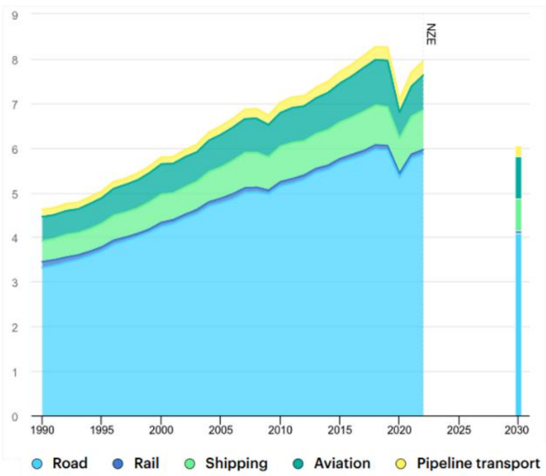

Figure 2. Global CO_2 emissions from transport by sub-sector since 1990 until 2022 and considering the 2030 prediction by the Net Zero Scenario [2].

Diesel engine vehicles have a very large participation in the automotive sector, especially in Brazil, considering its goods transportation system is highly dependent on the road network. Brazil's government implemented in 2013 the legislation defining the obligatory use of diesel with maximum of 10 ppm of sulfur for urban areas and maximum of 500 ppm of sulfur for diesel for other applications, in order to reduce the emissions of pollutants derived from the presence of sulfur in the fuel, mainly sulfur oxides [3]. Equipment manufacturers have also been implementing significant changes in the engine structure and design to reduce the systems emissions, such as EGRs, exhaust gas recirculation, to reduce nitrogen oxide emissions, and DPFs, diesel particulate filters, to reduce the emissions of particulate matter [4].

Biofuels represent a relevant alternative in reducing the emissions of internal combustion engines. Biodiesel is a biofuel produced from animal fat or vegetable oils, making it renewable and having a much smaller impact on emissions, since the carbon its combustion releases are derived from the current carbon life cycle. Biodiesel is produced in large scale in Brazil and has a large participation in these initiatives, especially mixed in different percentages in the diesel. There have been different countries using the mix of biodiesel in diesel, as most of Europe with 7% of biodiesel in diesel, but Brazil shows one of the most relevant cases for this endeavor, with a growing share of biodiesel in diesel, currently being at 14% of biodiesel in diesel and a projection of reaching 20% by 2030, defined by the Fuel of the Future program [5,6].

The presence of biodiesel in the heavy-duty engines presents a couple of challenges given the differences it presents when compared to traditional diesel. Notably biodiesel presents a difference in viscosity, worst cold weather performance, higher surface tension, lower volatility, higher specific gravity and worst thermal stability. The lower volatility and higher surface tension can lead to a higher dilution of fuel in the lubricant, the higher rate of unsaturated molecules (compared to diesel) can accelerate the oxidation process, beyond other potential issues [7].

The different characteristics and different performance of biodiesel presents different demands for the lubricating oil used in heavy-duty diesel engines. This works aims to evaluate lubricants capacity to handle these unique needs, specifically on regards to thermal oxidative stability, a key factor of biodiesel performance.

HEAVY-DUTY ENGINE OILS CHALLENGES

Over the last years diesel engine lubricants have been evolving to better support the demands of the heavy-duty engines. Considering this work focuses on biodiesel influence and the significant impact biodiesel has on thermal stability, it will be evaluated the evolution of the different institutional specifications regarding the growing severity of the oxidation analysis.

API, the American Petroleum Institute, publishes since before the 1950's standard specifications to classify lubricating oils, with the heavy-duty engine oils being classified in the C category. The most recent specification in this category is the API CK-4, launched in 2016 and established as a backwards compatible specification with the previous API C specifications, while evolving in the level of requirements [8]. The previous versions to API CK-4, API CI-4 and API CJ-4, had an evaluation of oxidation stability through the test Sequence IIIF (ASTM D6984), Sequence IIIG (ASTM D7320) or Sequence IIIH (ASTM D8111), assessing the increase in the oils viscosity at 40°C after a aging process at around 150°C for about 100 hours. With the rise to API CK-4 the oxidation evaluation became through the Volvo T-13 test (ASTM D8048), which reduced the maximum viscosity change allowed, introduced a maximum for oxidation peak, evaluated through FTIR (Fourier-Transform Infrared Spectroscopy), while also changing the test to 360 hours [9,10,11,12].

ACEA, the European Automobile Manufacturers Association, published its first edition in 1996, with the heavy-duty engine oils being classified in the E category. The most recent update is from 2024, with E8 and E11 being lower ash content categories and E4 and E7 being the higher ash content categories [13]. Both E8 and E11 present the Volvo T-13 (ASTM D8048) oxidation test as a criterion, with the same limits as established in the API CK-4 specification. Oxidation stability is also evaluated through the PDSC (Pressure Differential Scanning Calorimetry) test (CEC L-85-99), which evaluates the peak of the exothermic oxidation reaction to determine the induction time of the lubricant. This test applies to all 4 E categories. Finally the oxidation stability it is also evaluated in the 4 E ACEA categories (with different limits) through the oil oxidation with biodiesel test (CEC L-109-14), which ages the oil samples at 150°C for 168 hours and establishes a maximum 100°C viscosity increase and a maximum for oxidation peak evaluated through FTIR [14].

The evolution of the API and ACEA categories have allowed a better performance to be established for the heavy-duty engine oils, which assists in the lubricants to support variations in application as those introduced but the use of biodiesel. But there is still a possibility to improve in this performance with higher performing oils, especially considering the Brazilian scenario and its higher requirements regarding thermal and oxidative stability because of high biodiesel usage. Higher performing products aim to achieve better results beyond the minimum requirements established by the API and ACEA specifications, focusing on better oxidative stability, longer oil exchange intervals, better engine cleanliness and other factors.

Considering that, this study aimed to evaluated the different performance between API CI-4 SAE 15W40 product, API CK-4 SAE 15W40 product and API CK-4 SAE 15W40 high performance product in supporting biodiesel usage through the ACEA tests of PDSC (CEC L-85-99) and oil oxidation with biodiesel (CEC L-109-14) to show the different performance between API CI-4 and API CK-4 standards and the potential benefits a higher performing fluid than the latest specification.

METHODOLOGY

To perform the oil oxidation with biodiesel test (CEC L-109-14) the samples were prepared by mixing each product with 7% of biodiesel and adding and iron catalyst. The samples are settled in a heated bath at 150°C with a constant synthetic air flow of 10 L/min for 168 hours. After the 168 hours the samples are ran through the FTIR to evaluate the oxidation peak in the infrared spectrum, measured in absorbance per centimeter, and the kinematic viscosity at 100°C test is performed and compared with the kinematic viscosity at 100°C of the samples previous to the aging process of the test to determine the percentage increase.

To perform the PDSC test (CEC L-85-99) the samples were ran through the calorimetry equipment with a pressure of 100 psi of synthetic air and heated to 210°C. The equipment will provide the oxidation induction time of each analysis through the evaluation of the peak of the exothermic oxidation reaction.

RESULTS

The oil oxidation with biodiesel test (CEC L-109-14) presented a better performance for the API CK-4 products, as seen in Table 1.

Table 1. Results of viscosity increase and oxidation increase of the oil oxidation with biodiesel test (CEC L-109-14).

	Oxidation increase (A/cm)	Viscosity at 100°C increase (%)

API CI-4 SAE 15W40	55	47
API CK-4 SAE 15W40	31	45
API CK-4 SAE 15W40 high performance	33	50

All 3 products presented results in compliance with the stricter ACEA standard of maximum of 80 A/cm of oxidation increase and a maximum of 130% of viscosity increase. No significant difference was noted in the viscosity increase between the 3 products, but on the oxidation increase both API CK-4 products demonstrated a better performance. The high-performance API CK-4 SAE 15W40 product did not show significant differentiation when compared to the API CK-4 SAE 15W40 product.

The PDSC results also showed a better performance for the API CK-4 products, as seen in Table 2.

Table 2. Results of induction time of the PDSC test (CEC L-85-99).

	Induction Time (min)
API CI-4 SAE 15W40	78
API CK-4 SAE 15W40	104
API CK-4 SAE 15W40 high performance	150

The specification for all the ACEA E categories for the PDSC test is a minimum of 65 minutes of induction time, which all the 3 products meet. The API CK-4 SAE 15W40 product showed an approximately 33% higher induction time than the API CI-4 product, while the high-performance API CK-4 SAE 15W40 presented an induction time 92% higher than the API CI-4 SAE 15W40 and 44% higher than the regular API CK-4 SAE 15W40.

CONCLUSION

The growing concern with greenhouse gas emissions has impacted on the demands for the heavy-duty diesel engines industry, entailing in new designs and usage of new fuels. As a consequence, those new developments have also impacted the technical demands for the lubricant oils used in these engines, resulting in the rise of new lubricant specifications to better encompass those needs. Particular scenarios as the Brazil's fuel market with its significant usage of biodiesel mixed with diesel require more performance from the lubricants and the projection of further adding higher amounts of biodiesel in the future poses an even bigger challenge. The new API's and ACEA's updates present an improvement in the performance standard for lubricating oils but there is also space for higher performing products, especially with challenges such as those presented by biodiesel.

The evaluation performed in this study showed the difference in performance in thermal oxidation stability between products of new API specification, API CK-4, and older specification, API CI-4, which is still largely used in Brazil. Through the oil oxidation with biodiesel test (CEC L-109-14) it was possible to perceive an improvement in the oxidation increase in the API CK-4 products, with at least 40% reduction in the results, although in the viscosity increase there was no significant alteration. In the PDSC test (CEC L-85-99) it was noticed an improvement in the induction time for the API CK-4 products, when compared to the API CI-4 product, with at least a 33% increase in induction time, demonstrating a better capacity to deal with the oxidation process the oils are subjected to in the engine.

Comparing the API CK-4 SAE 15W40 regular and high-performance products, no difference was perceived in the oil oxidation with biodiesel test (CEC L-109-14), neither in oxidation increase, nor in viscosity increase. In the PDSC test (CEC L-85-99) the induction time of the high-performance product was 44% higher than the regular API CK-4 product. It is possible to conclude that even though in the oxidation test with biodiesel both API CK-4 product were not distinguishable, the difference in the induction times showed a better oxidative stability of the high-performance product.

It is relevant to point out that the oil oxidation with biodiesel test (CEC L-109-14) is carried out with a mix of 7% of biodiesel in the oil. While 7% of biodiesel in the diesel is the maximum stablished in the European Union today, Brazil's fuel already uses 14% of biodiesel, presenting a scenario with a chance of higher amounts of biodiesel contaminating the lubricating oil in the engines operation than in most other places, so in possible future works might be beneficial to evaluate an adaptation of the test for a higher treat rate of biodiesel mixed in the oil, to better illustrated the local challenges and investigate possible performance differentiations in the oils performances in this condition.

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