



Global Lubricants



Lubrication[®]

A Technical Publication Devoted to the Selection and Use of Lubricants

Biodiesel and Engine Lubrication

Part 2



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A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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ABSTRACT

There is a global interest in the use of alternative fuels due to the desire for energy independence, the high cost of petroleum-derived fuels, and environmental concerns such as greenhouse gas emissions. Of particular interest is the use of biodiesel (esters of vegetable oil) which can be produced in all regions of the world, and is increasingly used in passenger cars as well as heavy-duty vehicles equipped with diesel engines.

Until now, much of the primary research has focused on process technologies to produce biodiesel from sources such as soy, palm, rapeseed, coconut and jatropha curcas. There have also been studies looking at the impact of biodiesel use on exhaust emissions, vehicle driveability, fuel economy, and fuel system compatibility. There is limited data on the impact of biodiesel use on engine lubrication.

In this two-part series of *Lubrication Magazine*, we first discussed biodiesel composition, feedstocks and production techniques. We also identified the primary benefits of biodiesel, as well as some of the concerns and challenges faced by the biodiesel industry. In addition, we reviewed the existing and emerging regulations that mandate the use of biodiesel in various regions of the world, as well as the Original Equipment Manufacturers' (OEM) positions regarding biodiesel use.

In this issue, we will explore the impact of biodiesel use on engine lubrication through the use of bench tests, laboratory engine tests and real-world experience from fleets. Data will be included based on tests with biodiesel blends derived from soy, rapeseed, palm and coconut. We will also briefly discuss ways in which lubrication additive technology can help fortify the performance of the crankcase oil in order to counteract the effects of biodiesel use, such as increased oil oxidation and piston deposit formation.

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Summary

In Part I, we gave the reader a basic understanding of the nature of biodiesel, current and future biodiesel production techniques, plus some of the social and performance issues related to biodiesel use. In Part II, we will focus on diesel engine lubrication when biodiesel is used. Both laboratory bench tests and laboratory engine tests have been used to evaluate performance.

Impact of Biodiesel Use on Engine Lubrication

Evaluation of Biodiesel Impact Using Bench Tests

Through feedback from Original Equipment Manufacturers (OEMs) and users, fuel dilution of crankcase oil was identified as a primary performance issue. Chevron Oronite then used bench tests that are commonly utilized to predict the performance of lubricants in engines in the real world to evaluate the impact of biodiesel and its fuel dilution effects on lubrication.

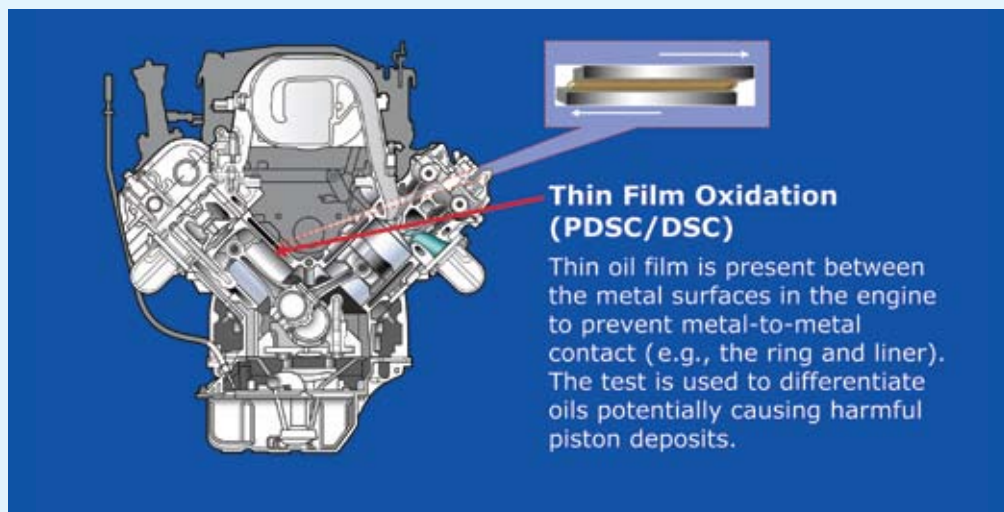
For the evaluation, a mixed-fleet engine oil was selected that is identified as “Oil A” and is a SAE 15W-40 blended in Group I base stocks with a non-dispersant Olefin CoPolymer (OCP) viscosity modifier additive. Oil A is a fleet oil and had undergone a battery of engine tests and fulfilled the performance requirements of API CH-4, ACEA E5, E3, A5, B3. It also met OEM requirements, such as Mercedes Benz MB228.3, MB229.1, Volvo VDS-2, MTU Type 2, Mack EO-M, etc.

For the bench tests, Oil A was artificially diluted with six, ten, and 20 volume percent of biodiesel (B100). As a control mechanism, Oil A was also diluted at one level with six volume percent mineral diesel to closely examine differences between dilution with biodiesel and mineral diesel. Different types of biodiesel were used for the dilution including soy methyl ester (SME), rapeseed methyl ester (RME), palm methyl ester (PME), and coconut methyl ester (CME). This allowed Chevron Oronite to assess the relative impact of various biodiesel feedstocks on engine oil performance.

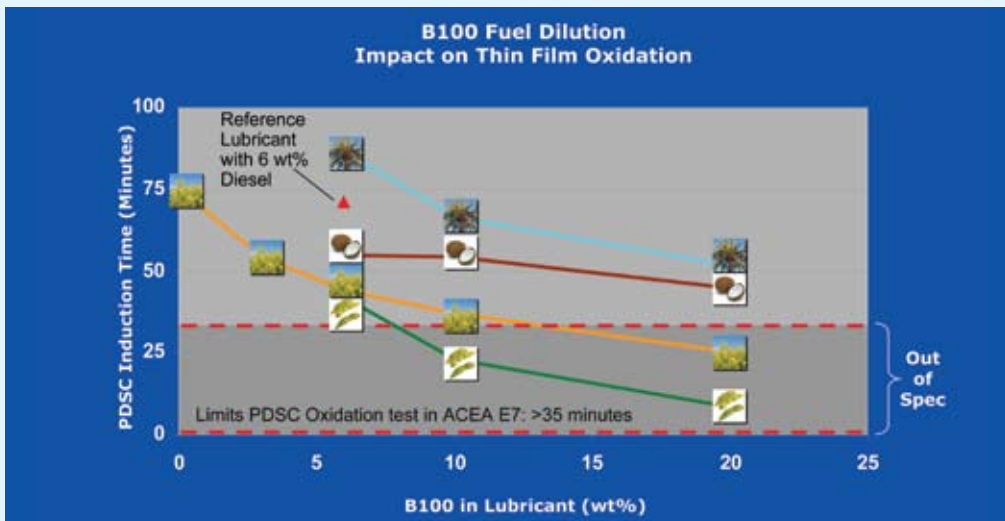
Engine Oil Oxidation Stability Tests

PDSC Thin Film Oxidation Test

Only a thin oil film is present between metal surfaces in many parts of the engine but it is an important film in preventing metal-to-metal contact. Between the piston ring and liner, this oil is exposed to high heat conditions and is subject to thin film oxidation. The Pressure Differential Scanning Calorimeter (PDSC) is an oxidation test that is commonly used to evaluate the thin film oxidation stability of lubricants and base oils. PDSC test results have been correlated with piston deposit performance by some OEMs. In Europe, the Coordinating European Council (CEC) has developed a standardized PDSC procedure, CEC L-85-T-99. This procedure is also used as part of the ACEA E7 engine oil qualification criteria. Due to the relative instability of biodiesel, a modified version of the PDSC was used in this evaluation.



PDSC Test-Engine Oil Oxidation Stability



PDSC Test Results

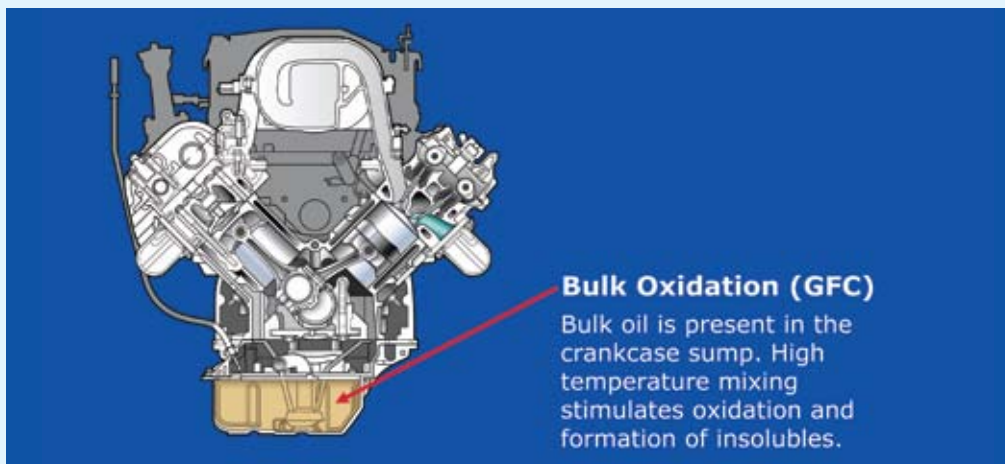
The PDSC results show that dilution with biodiesel can have a major impact on the oxidation stability of engine oil. The PDSC Induction Time is shown on the Y axis and the dilution level is shown on the X axis. The longer the induction time, the greater the stability of the engine lubricant. SME has the greatest impact on stability, followed by RME, CME, and PME, respectively. The minimum induction time required to meet ACEA E-7 requirements is 35 minutes, and engine oil dilution with 20 volume percent SME or RME results in a test-failing oil by this criteria. Engine oil dilution with six volume percent of mineral diesel has a marginal impact on the induction time, as shown.

While PME and CME appear to be more thermally stable than RME and SME (as

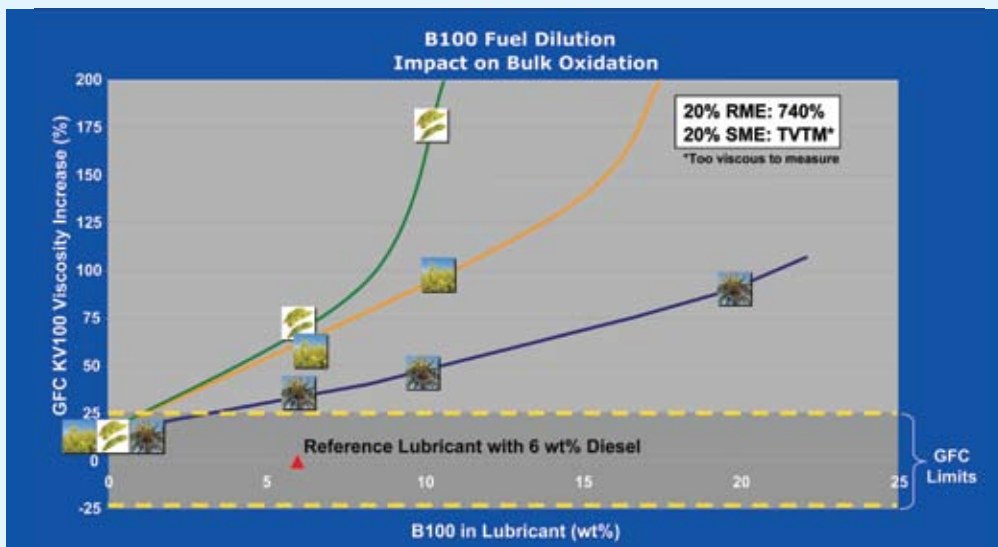
shown in the plot), their low temperature properties are comparatively inferior. The key factor is levels of unsaturation. Fatty Acid Methyl Esters (FAMES) with higher levels of unsaturation levels tend to be less thermally stable, but have better low temperature performance and cetane number.

GFC Bulk Oxidation Test

Since oil is churned in the crankcase at elevated temperatures in an air environment, it is also subject to oxidation. In this case, it is in bulk rather than in a thin film condition. The Bulk Oxidation GFC (Groupement Francais de Coordination) test simulates conditions in which bulk engine oil is mixed with air at elevated temperatures. Oil samples are collected during the procedure to determine



Bulk Oxidation (GFC) Test



Bulk Oxidation (GFC) Test Results

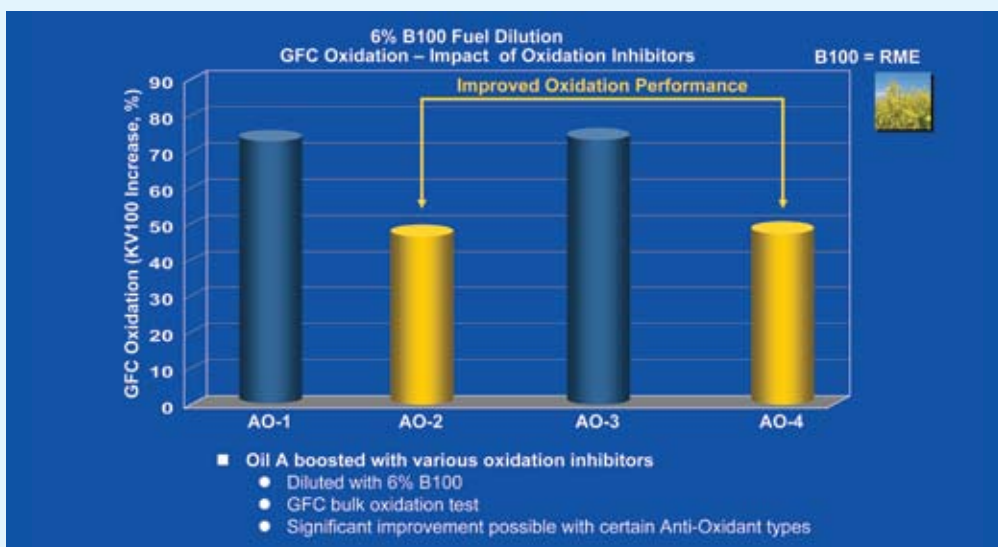
the amount of degradation. Some OEMs have correlated performance in this bench test with performance in their engines.

The Y axis shows the kinematic viscosity (at 100°C) increase after 144 hours. Viscosity increase is an indication of oil oxidation. SME, RME, and PME all had a dramatic effect on worsening the oil's oxidation stability. In fact, at the six percent dilution level, they all resulted in the oil's failing the GFC limit of +/-25 cSt. As noted, when the oil was diluted with six percent mineral diesel, the viscosity of

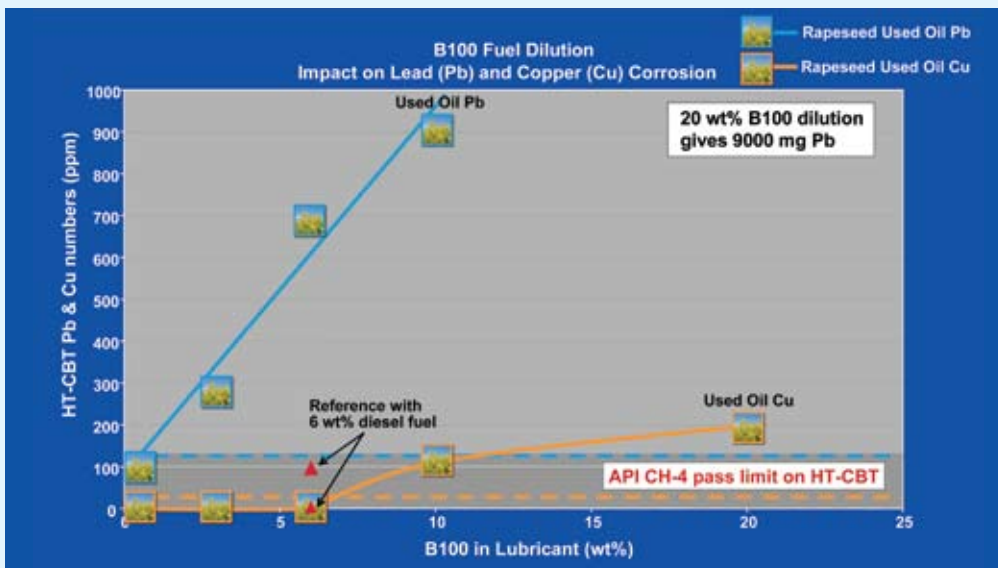
the oil actually thinned slightly. Excessive thickening or thinning can both lead to engine lubrication problems.

Based on the PDSC and GFC oxidation tests, it appears that oxidation improvement is a performance area that requires modification in order to improve lubricant performance when fuel dilution occurs with biodiesel use.

As shown in the attached GFC tests at six percent biodiesel dilution, although it is possible to improve the oxidation performance through the use of additives,



Oxidation Inhibitors Can Impact Performance



High Temperature Bench Corrosion Test (HTCBT)

not all oxidation inhibitor additives are equally effective. Real-world engine tests are necessary to confirm the bench tests results.

High Temperature Bench Corrosion Test (HTCBT)

The High Temperature Bench Corrosion Test (HTCBT) was originally developed by Cummins Engine Company and is now widely used in the industry. It is part of the bench test sequence that is required to qualify oil as API CH-4, API CI-4, or API CJ-4. In the HTCBT procedure, metal coupons are immersed in a flask of oil at an evaluated temperature with air bubbles. The oil is analyzed for metals content after 168 hours.

HTCBT results are presented for both lead and copper. While all the HTCBT tests were conducted with RME, similar results would be expected for biodiesel produced from other feedstocks. The HTCBT results demonstrate that lead corrosion is potentially a big issue with RME. Peroxides and other organic acids are formed when FAME oxidizes, and these compounds cause lead corrosion. Even small amounts of dilution result in lead levels climbing above the 120 ppm limits established for CH-4 oils.

The impact on copper corrosion is not as dramatic. However, at RME dilution levels between six and ten volume percent, copper

levels climb above the 20 ppm maximum limit for CH-4 oil. In contrast to biodiesel, dilution with six volume percent mineral diesel appears to have a limited impact on both copper and lead corrosion in this test.

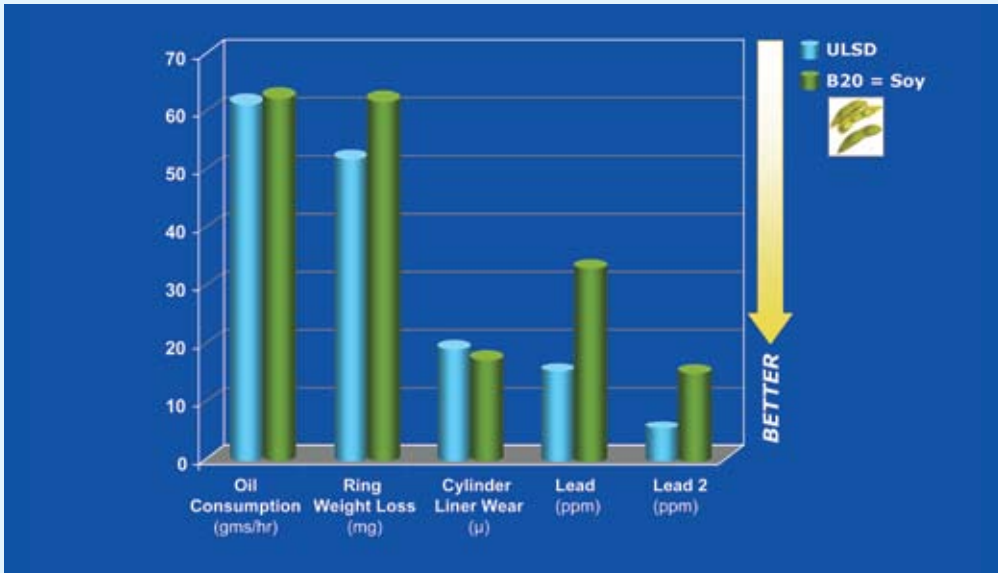
Engine Performance Tests

Based on the results from the PDSC, GFC and HTCBT bench tests, additional laboratory engine tests were conducted to further investigate the impact of biodiesel on engine lubrication.

Mack T-12 Standard Engine Test

The Mack T-12 engine test is a 300-hour test run in a Mack E-7E-Tech 460 horsepower engine with high rates of exhaust gas recirculation (EGR). The Mack test is an ASTM standard test that is used to qualify oils as part of the API CJ-4 performance criteria. Its primary purpose is to evaluate the oxidation, lead corrosion, and liner and ring wear performance of heavy-duty engine oils under severe operating conditions.

A comparison of the various performance parameters is shown for a passing API CJ-4 oil run on Ultra Low Sulfur Diesel (ULSD - 15ppm sulfur maximum) and also a run in which 80 volume percent ULSD was blended with 20 volume percent SME (i.e. B20). As may be noted, lead levels were elevated in those tests in which SME

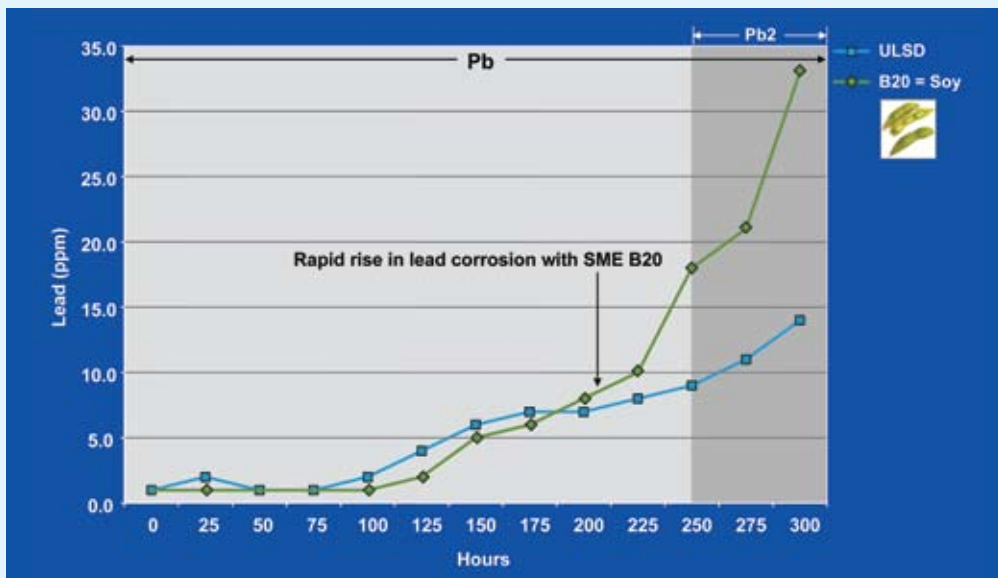


Mack T-12 Parameter Comparison

was used. These results are consistent with those found in the HTCBT bench test. Oil consumption, ring weight loss, and cylinder liner wear all appeared to be similar in the cases of both ULSD and biodiesel.

The plot of hourly lead level readings in ppm shows a typical increase in lead levels as oil oxidizes during the test procedure. With B20, the lead level increases rapidly after about 180 hours, and by the end of

the 300-hour test, the used oil lead level is more than double that with ULSD. Consequently, the outcome of operating the engine with B20 was that an oil that passed the API CJ-4 and Mack EO-O Premium Plus ultimately failed the Mack T-12 test. Also, based on the point of inflection in the B20 lead levels, one could argue that drain intervals in the T-12 should be reduced by at least 40 percent (1-180/300) if operated on B20.



Mack T-12 Used Oil Lead (Pb) Comparison

- Cummins ISB is a 350-hour test run in Cummins 5.9 liter 300-HP engine with EGR
- Test is part of API CJ-4, as well as Cummins CES 20081 specification
 - First 100 hours are at retarded timing to generate 3-3.5% soot in oil
 - Last 250 hours are cycles every 27 seconds from low-speed idle to rated load and speed to peak-torque (32,000 cycles total)
- Primary purpose is evaluation of wear on cam and tappet



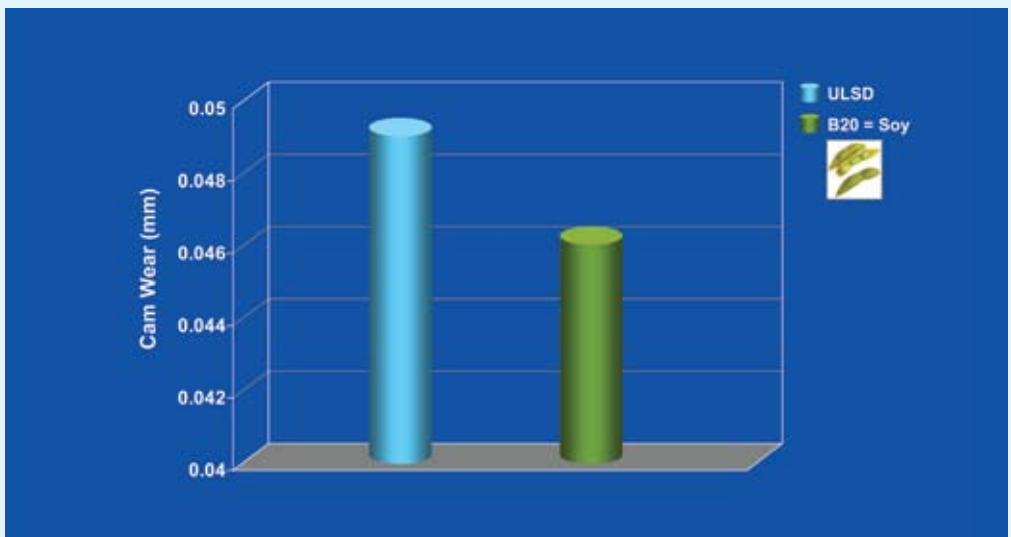
Cummins ISB Standard Engine Test

Cummins ISB Standard Engine Test

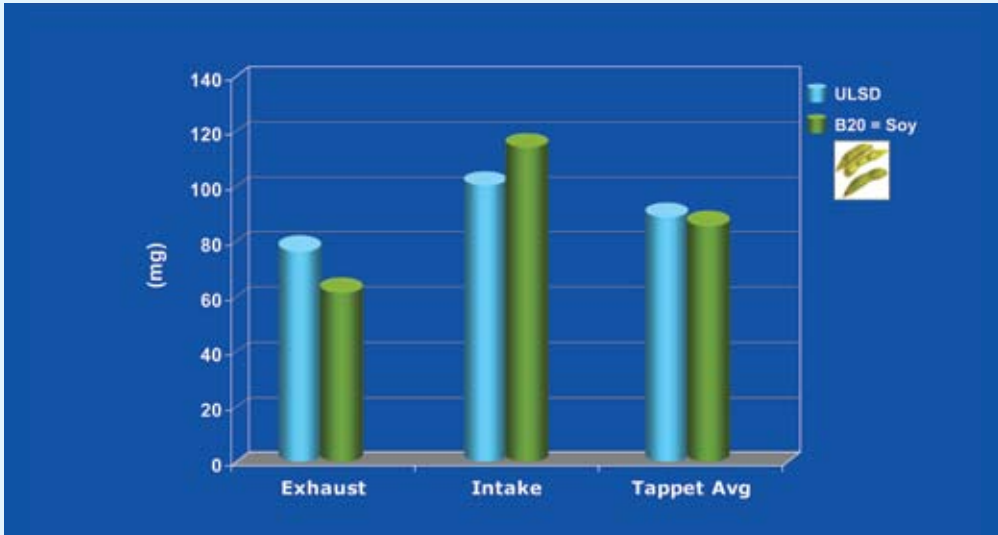
The Cummins ISB test was developed to evaluate the valve train (cam and tappet) wear performance of engine oil with slider/follower type lifters in a severe environment. The ISB is a standard ASTM test that is one of the sequence tests used to qualify oil as meeting the requirements of API CJ-4. It is also part of the Cummins CES 20081 specification. In the test, cam and tappet wear is evaluated after the engine is operated under cyclic conditions with 3-3.5

percent soot in the oil.

API CJ-4 oil was used in this evaluation. The first run was conducted with ULSD fuel. A second run was conducted with B20 containing SME. Although differences were not statistically significant, wear rates were directionally lower when B20 was used. These results are not completely unexpected since esters (primarily synthetic) are often used in the additive industry to formulate lubricants. In addition, FAME is known to improve the lubricity of diesel fuel.



Cummins ISB Camlobe Wear

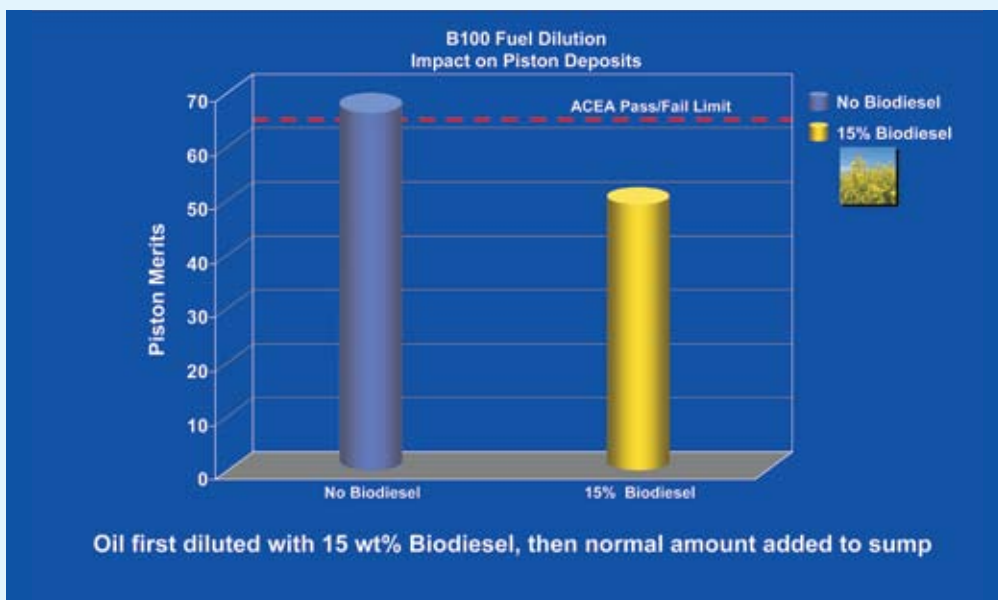


Cummins ISB Tappet Weight Loss

Volkswagen TDI Test

The Volkswagen (VW) TDI (Turbo Direct Injection) test is used to evaluate the performance of engine oils with respect to ring sticking and piston cleanliness (deposit control). It is a severe 54-hour test and is the basis for many of the European passenger car diesel engine oil qualifications. Since it is a short test, we diluted the engine oil with 15 percent

RME prior to the test and ran the engine on regular sulfur diesel fuel (CEC RF-90-A-92, 0.25-0.30% Sulfur). Based on input from passenger car OEMs, we know that levels of 15 percent fuel dilution can be found in the field when biodiesel is used. As a reference, we used oil that passed the VW TDI test at the A3/B4 level. The piston merits and a picture of the piston are shown both for the test with neat engine oil as well as the test with oil



VW TDI Piston Merits (Higher = Cleaner)



VW TDI Pistons After Test With Biodiesel

dilution with 15 percent RME. The inclusion of 15 percent RME in the crankcase oil significantly increased the level of piston and ring groove deposits and resulted in a failing test. These results are consistent with those found in the PDS thin film oxidation bench test discussed previously.

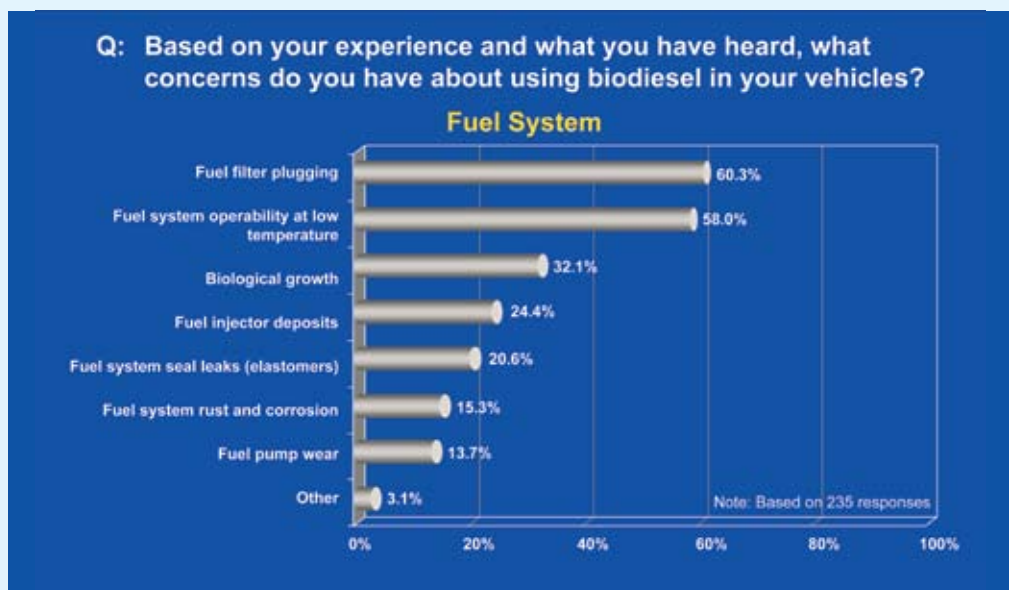
Biodiesel Truck Fleet Survey

In July 2007, a third-party survey was conducted in which fleets that use biodiesel

were asked about their concerns. Survey results show that many fleets have apprehensions about biodiesel use based on real world experience. It is imperative to develop effective and reliable performance additives and new lubricant technologies before biodiesel can be safely and confidently used at elevated levels.

Conclusion

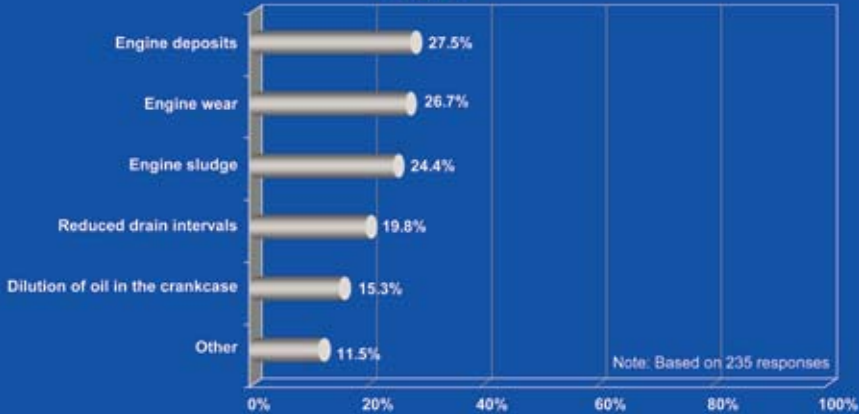
While biodiesel use will continue to increase worldwide, engine builders and fuel system



Biodiesel Truck Fleet Survey-July 2007

Q: Based on your experience and what you have heard, what concerns do you have about using biodiesel in your vehicles?

Engine



Biodiesel Truck Fleet Survey-July 2007

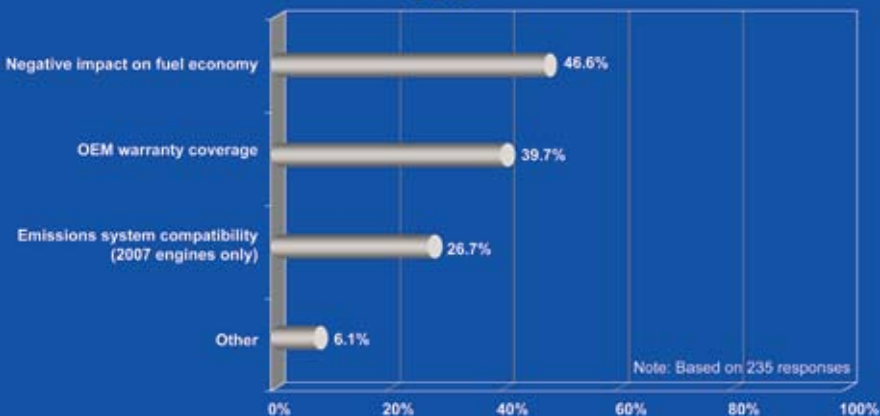
suppliers currently restrict the use of biodiesel during warranty periods due to operational concerns. From a lubrication standpoint, biodiesel's properties render it more likely to enter and remain in the crankcase causing dilution of the lubricating oil. The oxidation of biodiesel in crankcase oil creates increased deposits and lead corrosion. Equipment operators are encouraged to conduct used oil analysis as well as reduce drain intervals

to compensate for the increased severity due to biodiesel use. In addition, the appropriate use of performance additives in conjunction with engine oil formulating technologies can be used to offset some of the impact of biodiesel use.

Despite these issues, biodiesel is now the fastest growing alternative fuel in the U.S., with production soaring from 25 million gallons in 2004 to 250 million gallons

Q: Based on your experience and what you have heard, what concerns do you have about using biodiesel in your vehicles?

Other



Biodiesel Truck Fleet Survey-July 2007

(approximately 6 million barrels) in 2006, states the National Biodiesel Board (NBB). However, it is important to place the scale of biodiesel production and usage in a proper perspective. This is a drop in the vast bucket of U.S. on-road diesel demand of approximately 38 billion barrels a year. Although the NBB projects a biodiesel production potential of 3.5 billion gallons a year by 2015, this will still account for only about seven percent of national on-road diesel fuel consumption, according to the Department of Energy (DOE). The use of biodiesel in the U.S. has escalated dramatically since federal and state fleet operators have been allowed to meet the Energy Policy Act Alternative Fuel Vehicles (EPA AFV) targets by using B20 or higher blends. Thousands of government fleets (especially military non-combat), agricultural and construction businesses, truckers and other consumers use biodiesel. However, with respect to potential consumer use of biodiesel, it must be remembered that diesel passenger cars comprise only 3-4 percent of the new car market in the U.S., with fewer than 50,000 new diesel cars sold annually. In Europe, on the other hand, diesel-powered cars comprise 50 percent of annual 15 million new car sales,* and biodiesel is widely used in both passenger cars and heavy-duty trucks.

Biodiesel has strong government support both in the U.S. and internationally, primarily due to concerns about CO₂ emissions and global warming, plus the desire for energy independence. President Bush's Advanced Energy Initiative calls for replacing 75 percent of oil imports from the Middle East by 2025. The U.S. government has mandated that by the year 2012, 7.5 billion gallons of all fuel used in transportation should consist of renewable fuel. The Energy Information Administration (EIA) estimates this will reduce the consumption of crude oil by 80,000 barrels per day. Across the Atlantic, the European Commission wants to increase the proportion of biofuel used in road transport from the level of 2.5 percent in 2008 to 5.75 percent by 2010, and eventually to 10 percent by 2020. In the U.S., renewable fuel mandates can largely be met through the increased use of

ethanol in gasoline (e.g. E10). In Europe, the higher ratio of diesel to gasoline related in part to the high penetration rate of diesel passenger cars make it more likely that biodiesel will play a larger role in Europe to meet renewable fuels mandates.

Critics argue that since biodiesel receives substantial tax incentives and subsidies from limited government budget resources in order for its price to be competitive with that of petroleum diesel, it constitutes a bad investment and is not economically sustainable. Moreover, the degree to which vegetable-based biodiesel can displace petroleum fuels is limited by the availability of cropland and water. As noted above, DOE projections show that even if all existing and future available domestic feedstocks were devoted to U.S. biodiesel production, this would displace no more than about seven percent of on-road diesel demand by 2015. Europe is in a similar position. An EU-sponsored study states that the 5.75 percent biofuels target would consume 14-27 percent of EU agricultural land, and would require approximately 192 percent of EU oilseed production or 14 percent of the forecast world production in 2012. Therefore, it cannot be met by domestically-produced feedstocks alone, necessitating substantial imports. This triggers environmentalists' concerns that the increased demand for these imported feedstocks may be fulfilled by clearing natural habitats of global importance such as Indonesian rainforests and the Brazilian Cerrado. They argue that net greenhouse gas savings will be negligible without ecological safeguards, and the public will ultimately reject biodiesel if it is not perceived to be a credible environmental alternative to fossil fuels.

These resource constraints are at the core of the potential "food versus fuel" debate because vast areas of land are required to grow the crops necessary for biodiesel. Consequently, new non-food based feedstocks are being explored, such as algae and wood and wood-waste biomass. Also, many believe that over the next 10-20 years, current biodiesel feedstocks could be replaced by "second generation" renewable fuels that triple the yield per hectare, offer greater CO₂ efficiency, and unlike first-generation biodiesel, do not compete with

*NBB statistics

food production. While renewable diesel's properties appear to be similar to those of mineral diesel, it will not increase severity on the engine oil as biodiesel does.

However, as discussed earlier, relatively high manufacturing and logistics expenditures mean that these second-generation biofuels cannot yet be economically produced in commercial quantities.

In conclusion, although it is obvious that biodiesel alone currently lacks sufficient capacity to meet the new renewable fuels targets, it is a significant energy resource that may provide part of the solution for complying with worldwide federal mandates

to prevent and reduce pollution, diversify fuel sources and increase energy efficiency and sustainability. And although the macro view shows that biodiesel volume is insignificant compared to mineral diesel, there will still be many regions worldwide where higher concentrations of biodiesel will be used. Therefore, it is imperative that lubricants be formulated for engines operating in these severe conditions. Additionally, as shown by the survey and test results in the previous section, in order for biodiesel to realize its full potential (and to compensate for some of its less desirable properties), it should be used in conjunction with properly formulated lubricant technologies and performance additives.

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