By Dr. Neil Canter
Contributing Editor

Special Report: Additive challenges in meeting new automotive engine specifications

Formulation of engine oil additive packages for passenger car (PCMO) and heavy-duty diesel (HDD) applications is a complicated process because formulators need to incorporate a number of different additive types such as detergents, dispersants, antiwear additives, antioxidants and friction modifiers. All of these components need to be properly balanced to meet the required performance criteria (engine oil specifications) and to be stable.

A more detailed description of the types of additives used in automotive engine oils is provided in an article published in a recent issue of TLT.[1] Author Alan Eachus points out that there are other basestock options available to facilitate the development of more environmentally friendly engine oils.

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Representatives from the four main suppliers of engine oil additives and additive packages—Afton Chemical, Infineum USA LP, The Lubrizol Corp. and Chevron Oronite LLC—are interviewed in this article to provide a good overall examination of the current challenges they face in developing their products to meet current lubricant industry needs. They also provide an assessment of how engine oil additive packages will look in the future as the industry turns more toward gas-to-liquid (GTL) basestocks and how the popularity of flex fuel vehicles continues to increase with consumers worldwide.

Three of the key additive challenges are developing products that will help the industry meet lower emissions standards, higher fuel economy goals and longer drain intervals. Each of these topics is covered below.

Emissions

Much of the traditional additive chemistry utilized in engine oil packages is based on sulfur and phosphorus. Dean Anderson, global manager-automotive for Chevron Oronite LLC, says, "There is a general trend towards low SAPS (sulfated ash, phosphorus and sulfur) formulations throughout the world. Lubricants are not only being asked to play their traditional role of protecting the engine, they are being formulated to minimize any impact they may have on the exhaust aftertreatment devices (e.g. catalytic converters, diesel particulate filters, etc.)"

James Puckace, worldwide marketing manager of engine oils for The Lubrizol Corp., says, "The changing environmental regulatory landscape often impacts the technical requirements for our products. As emission control technologies evolve further to meet more stringent environmental requirements, it is likely that additive technologies will have additional limitations in the amounts of SAPS to minimize the potential of aftertreatment device poisoning."

Joan Evans, industrial liaison advisor for Infineum USA LP, adds, "The formulation of additive systems for motor oils continues to get more complex as engines and emission systems evolve to meet more stringent requirements. The crucial factor in formulating is balance, maintaining engine durability while enabling better fuel economy, engine efficiency and emission system compatibility."

Tom Cousineau, director of engine oils customer technical services for Afton Chemical, says, "Progressively more stringent air quality regulations will increase the need for exhaust aftertreatment units for diesel- and gasoline-powered vehicles and will place greater emphasis on the compatibility of lubricant additive technology with catalysts. Engine combustion-system-design changes resulting in lower emissions and enhanced fuel economy will place greater stress on lubricant formulations. These changes will drive additive companies to develop new and/or alternative molecules while optimizing today's field-proven chemistry."

Evans points out that the lubricant industry has developed reduced SAPS automotive lubricants in response to industry specifications, particularly in Europe. ACEA, the Association des Constructeurs Europiens de l'Automobile (or the Association of European Automotive Manufacturers) has introduced the C-category of specifications that details low SAPS (ACEA C1 Specification) and medium SAPS (ACEA C2 and C3 Specifications) engine oils.

The specific requirements for sulfated ash, sulfur and phosphorus levels are shown in the following table:

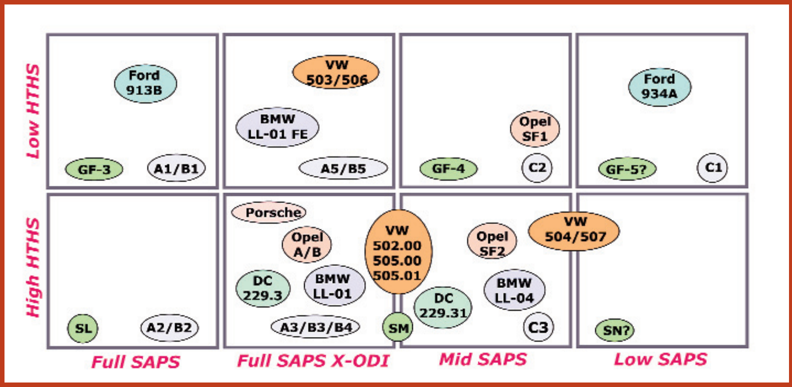
ACEA C Specifications

Parameter	Low SAPS – C1	Mid SAPS – C2/C3
Sulfated Ash	0.5 m% maximum	0.8 m% maximum
Phosphorus	0.05 m% maximum	0.07–0.09 m% maximum
Sulfur	0.2 m% maximum	0.3 m% maximum

Figure 1 shows OEM specifications for a full range of SAPS content for high and low HTHS (high temperature high shear) automotive lubricants. Infineum's Evans says, "Although there is some interest in 'Low SAPS,' actual market uptake is low. Growth of 'Mid SAPS' products has been steady, particularly in Europe."

She continues, "Reduced SAPS lubricants are very sophisticated fluids that are costly to develop, and market penetration will take time. We need to recognize that striking the right balance between engine durability and emission system protection is critical and there may not be much further to go from where we are already." Evans believes that widespread SAPS reduction will be achieved more through a change in vehicle selection by consumers rather than any new lubricant or additive developments.

Figure 1. Chemical Limits – Position of OEMs

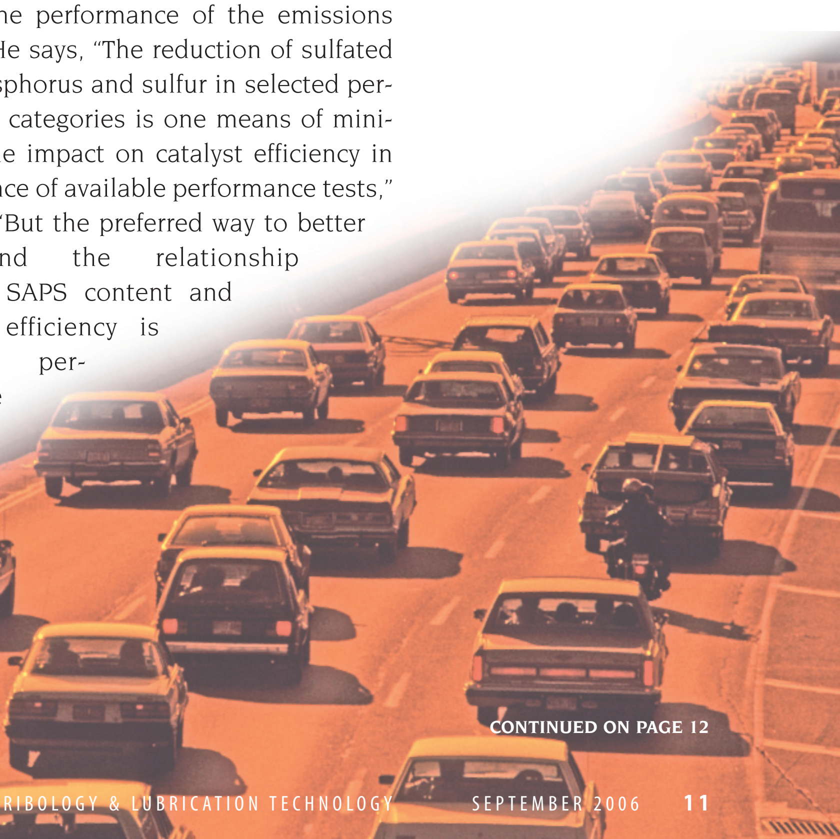


(Chart courtesy of Infineum USA LP)

Shown are OEM specifications for high and low HTHS (high temperature high shear) automotive lubricants at Full SAPS, Full SAPS X-ODI (Extended Oil Drain Interval), Mid SAPS and Low SAPS.

Puckace cites the new heavy-duty diesel engine oil specification, API CJ-4 as the latest example of the push towards lower SAP-containing automotive lubricants. He says, "Typical CI-4 lubricants (the current specification) ranged in sulfated ash content from 1.3%-1.5%. New CJ-4 lubricants will be coming in at 1.0% sulfated ash, representing approximately a 30% reduction in ash content. Additional restrictions were placed on phosphorus (0.12% maximum) and sulfur (0.4% maximum)."

Cousineau sees a direct connection between the reduction in SAPS content in the lubricant and the concern about maintaining the performance of the emissions system. He says, "The reduction of sulfated ash, phosphorus and sulfur in selected performance categories is one means of minimizing the impact on catalyst efficiency in the absence of available performance tests," he says. "But the preferred way to better understand the relationship between SAPS content and catalyst efficiency is through performance



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testing. At present, test methodology has not been developed to properly address this issue."

Gary Parsons, global OEM and industrial liaison manager for Chevron Oronite LLC, indicates that one of the main sources of SAPS is zinc dialkyldithiophosphates (ZDDPs), but there is no direct test that can measure the impact of SAPS on the deterioration of the vehicle's emissions system. He says, "The lubricant industry has tried developing tests and has been largely unsuccessful."

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ZDDPs

Tied in with emissions reduction is the concern about the likely incompatibility of ZDDPs with catalytic converters. In last year's TLT, an article detailed the diminishing usage of this additive.[2] The phosphorus level in engine oils has dropped from 0.12% maximum in GF-1 in 1993 to 0.08% maximum in the current GF-4 motor oils. A second article discussed current research describing the mechanism by which ZDDPs function as an antiwear additive.[3]

It is anticipated that automotive OEMs will request that the phosphorus level maximum for the next PCMO specification (GF-5) be closer to 0.05%. ZDDPs are multifunctional and provide not just antiwear characteristics but also function as antioxidants. This makes replacing them very difficult.

Cousineau says, "No single additive provides the same benefit of wear prevention, corrosion protection and oxidation control as cost effectively as ZDDP. ZDDP can be reduced or eliminated but at a cost. Over the last several PCMO category changes, oxidation control requirements have increased while phosphorus limits have been tightened. Formulations have been modified to incorporate higher levels of ashless antioxidants as ZDDP levels have been reduced. If phosphorus requirements of PCMO oils become more restrictive, supplemental wear inhibitors may be required."

He adds, "A better approach is for the lubricant industry to quantify the effect of ZDDPs on emissions, as catalyst fouling may vary based on ZDDP concentration, ZDDP type or formulation style, for instance."

Oronite's Anderson indicates that the impact of ZDDPs in engine oil formulations has been diminishing. He explains, "In many respects, the role ZDDPs plays in oxidation protection has diminished over the years as absolute treat levels of ZDDP have diminished and as higher stability base oils such as Group II and Group III have been introduced. Ashless type oxidation inhibitors have helped to replace the oxidation performance of ZDDPs."

Evans further explains what types of additive chemistries have been used to fill the role of ZDDPs. She says, "Recent additive systems have utilized aminic and phenolic chemistries for antioxidancy. The use of molybdenum chemistry for improved antioxidancy and wear has expanded. There are numerous replacement technologies available. However, the alternatives are all expensive to develop and manufacture and so require acceptable commercial returns to deploy them."

Fuel economy

Past fuel economy testing has been influenced both by the viscosity of the automotive lubricant and by the presence of boundary lubricity additives in the lubricant which are known as friction modifiers. As the industry moves toward the preparation of GF-5, a new fuel economy test known as the Sequence VID is being developed.

Parsons says, "The Sequence VID is in the early stages of development, so it is hard to say how it will drive the formulations and the use of friction modifiers. They tend to have a larger effect when boundary lubrication is involved as opposed to hydrodynam-

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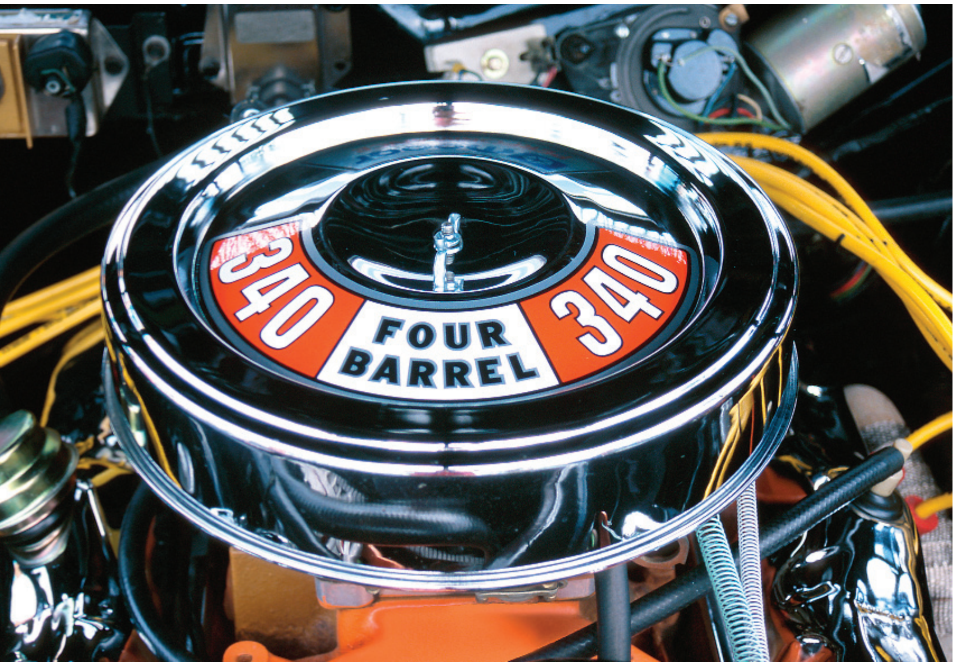


'No single additive provides the same benefit of wear prevention, corrosion protection and oxidation control as cost effectively as ZDDP. ZDDP can be reduced or eliminated but at a cost.'

ic lubrication."

Cousineau adds, "The contribution of the lubricant viscometric and boundary friction properties will be investigated by the industry's Sequence VID Development Consortium. Should this engine test respond to friction modifiers, additive companies will develop appropriate friction modifier enhanced formulations for improved fuel economy while optimizing overall formulation performance."

Evans believes that the Sequence VID test will respond to both viscometric effects and to friction modifiers. She says, "With respect to friction modifiers, we expect to see a response to inorganic friction modifiers and an increased response to organic friction modifiers. Such chemistries have been widely used in the past, and if the Sequence VID is successful it will be able to recognize this friction modification as is seen in the Federal Testing Procedures (FTP) cycles."

Longer drain intervals

The additive supplier representatives are in agreement that extended drain intervals place more demands on the additives used, increase their treat rates and improve the quality of the basestocks formulated into automotive lubricants. Cousineau says, "Longer drain intervals reduce the safety margin available from today's engine oils and increase the need for greater oil robustness. Longer drain, heavy-duty diesel additive packages require increased dispersant, anti-oxidants and Total Base Number (TBN) reserve."

Evans adds, "Oil drain intervals tend to be lengthening on average while additive treat rates and base fluid qualities are also increasing. Despite lengthening oil drain intervals, we are also seeing some limited growth in additive needs, which is also due in part to the rising global vehicle population. Equally important to note is that the mix of additives is changing as performance demands change, requiring, for example, more dispersancy, more antioxidancy, less ZDDP and less high ash detergents."

Anderson points out that there is a difference in consumer preference for longer drain intervals. European passenger car oils already have drain intervals between 12,000 and 15,000 miles. Consumer preferences in North America are for shorter drain intervals.

New lubricant specifications

The implementation of API's CJ-4, heavy-duty engine oil specification is occurring at a time of confusion for the lubricant industry. Some of the oil marketers have decided to continue to offer the currently available CI-4 Plus oils even after CJ-4 becomes available later in 2006. Several OEMs such as Caterpillar also are including additional testing requirements beyond those in CJ-4.

Puckace says, "With the high costs of heavy-duty diesel equipment for fleets and owner-operators, OEMs want to ensure the best possible lubricant protection. The biggest challenges with CJ-4 include providing superior wear and corrosion protection while maintaining competitive oil drain intervals and not just meeting the elemental restrictions for SAPS."

Evans says, "CJ-4 is designed as a restricted ash, phosphorus and sulfur oil category. It was developed to meet the needs of aftertreatment devices being utilized with new model year 2007 engines. Concerns have been raised that some of the CJ-4 oils may be lower in TBN than their CI-4 and CI-4 Plus predecessors and may not protect a small percentage of older engines when running on higher sulfur (> 15 ppm) diesel fuel."

She adds, "To alleviate these concerns, the Engine Manufacturers Association (EMA) has asked that owner and fleet operators consult directly with OEMs for the recommended drain interval for each engine/fuel/oil combination. As the CJ-4 specification addresses the needs of 2007 model year engines, there remains some uncertainty around how fast the market will convert to this specification despite the very considerable investment made in its development."

Parsons also expressed concern that customers will perceive CJ-4 oils are inferior to CI-4 Plus oils because the former have lower TBN. He says, "TBN has long been used by operators as a broad indicator of an oil's quality." The prospect for the marketplace continuing to offer CI-4 Plus oils prompted Parsons to indicate that additive suppliers will need to keep multiple formulations at different performance levels.

Cousineau adds, "There is uncertainty about the benefit that lower-ash CJ-4 oils will have on diesel particulate maintenance intervals. The biggest source of uncertainty is whether the CJ-4 oils will enable the aftertreatment devices to last for 150,000 miles, as required by the new EPA regulations. We are reasonably sure that CJ-4 oils will do the job, but the data to support this will not be available for at least a year."

The automotive lubricant industry is also beginning to evaluate the testing requirements needed for GF-5, which is due to be launched in 2009. All of the additive industry representatives contacted believe it is too early to tell how much of an upgrade this new category will be as compared to the current GF-4.

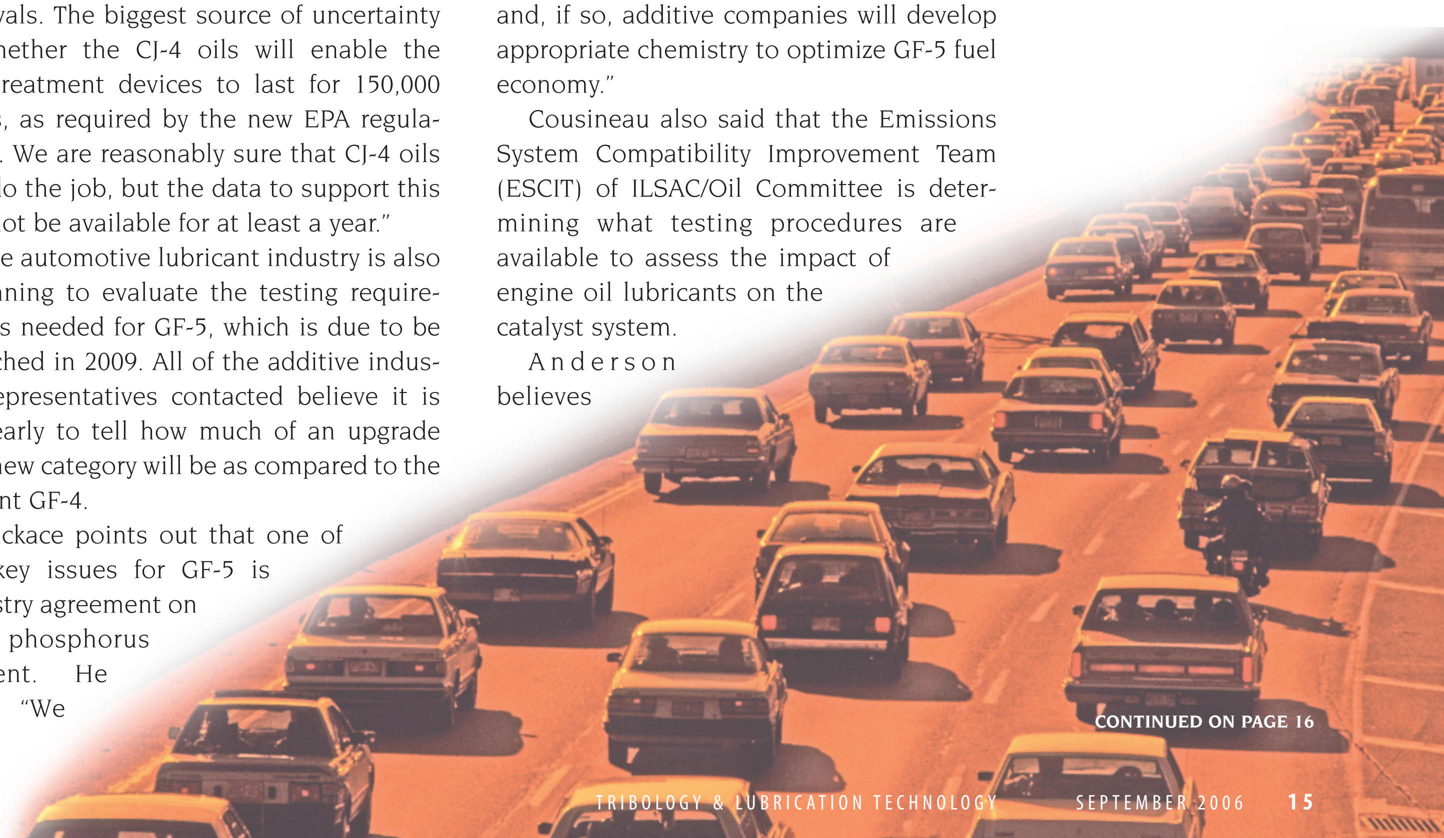
Puckace points out that one of the key issues for GF-5 is industry agreement on the phosphorus content. He says, "We are concerned for the environment and supportive of lower emissions. We are in favor of a lower phosphorus content in finished oils. We would support additional elemental restrictions on phosphorus in GF-5 and, in addition, support a performance test based on a GF-5 sequence test."

Evans says, "As passenger car motor oils are mature technologies, we are realistically looking for incremental benefits. As new engine and emission technologies are introduced to meet higher fuel economy and lower emission regulations, these engines may have diverging appetites requiring specific additive technologies. GF-5 will have to balance the needs of higher fuel economy, lower emissions and improved high temperature oil stability, as was done for GF-4."

Cousineau indicated that the automotive and lubricant industries are combining resources to deal with the challenges of developing better test methodologies for fuel economy and emissions. He says, "The industry has formed a Sequence VID (Fuel Economy) Test Development Consortium to which the major additive companies are members. The purpose of the Consortium is to develop a new fuel economy engine test based on real-world fuel economy data developed by GM and Ford. This test may offer a different response to additive technology than the current Sequence VIB test and, if so, additive companies will develop appropriate chemistry to optimize GF-5 fuel economy."

Cousineau also said that the Emissions System Compatibility Improvement Team (ESCIT) of ILSAC/Oil Committee is determining what testing procedures are available to assess the impact of engine oil lubricants on the catalyst system.

Anderson believes



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that the new requirements demanded by the OEMs will lead to the development of new additives for GF-5. He says, "We are faced with a whole new set of requirements for GF-5. In many cases, these requirements are not independent variables from a formulating standpoint, and they are often conflicting. The more stringent emission requirements have led to an increase in the level of development of new chemistries. It is not just a matter of mixing the same components together to pass engine tests. New chemistries are needed to provide performance at a reasonable cost while meeting all of the new requirements."

Testing costs

The impending introduction of CJ-4 and the work being conducted to develop test methodology for GF-5 raises the concern about the cost of carrying out the large number of engine tests needed to approve a specific automotive lubricant formulation. Engine oils ultimately need to include the proper balance of additives to meet the test requirements.

Parsons says, "Engine testing for CJ-4 is so expensive because this category includes nine engine tests and six bench tests. It is the most robust category ever from a test requirement perspective. Whether each of these individual tests is actually required to assure performance is a matter of debate. In some cases, there is a degree of redundancy in the tests."

Cousineau acknowledges that the automotive industry realizes that good bench test procedures will help reduce new category engine test costs. He says, "Consideration has been given in GF-5 for replacement of the Sequence VIII test (evaluates bearing weight loss) with the High Temperature Corrosion Bench Test (HTCBT), the Sequence IIIGA test (measures used-oil viscosity increase at low temperatures) with the Romaszewski Oil Bench Oxidation Test (ROBO) and possibly, developing a new emission compatibility test. Unfortunately, no correlation was found between the Sequence VIII and the HTCBT. However, the ROBO procedure looks promising and the industry is working together to validate this procedure for use in the category."

Puckace focuses on the need for lowering test costs. He says, "Given the reluctance to potentially sacrifice any assurance of engine protection, bench testing has not made significant inroads in replacing heavy-duty diesel engine tests. As test costs continue to escalate, pressure to find more cost-effective alternatives will increase."

Evans indicates that the cost of a one-test pass scenario for a CJ-4 oil is $600,000. The lubricant industry has made some progress in developing new tests but in other cases faces redundancy. She says, "The introduction of new tests for CJ-4 (Caterpillar C13, Mack T-12 and Cummins ISB) was a good example of industry collaboration to maximize the use of base oil interchange and viscosity grade read-across. Yet, the industry fell short of the goal on test redundancy, as we currently have three wear tests in CJ-4 [Roller Follower Wear Test (RFWT), Cummins ISB and the Cummins ISM]. This is very difficult to justify given the significant testing costs associated with this redundancy."

Backward compatibility

The development of new engine technology to meet emissions requirements and the reduction in the use of traditional engine oil additives such as ZDDPs means that modern engines may have performance features that differ from those of older engines. Automotive lubricants prepared for modern as compared to older engines may require different engine oil additive formulations. But current engine oil specifications such as GF-4 and the impending CJ-4 need to cover all engines currently used in the marketplace. This issue of backwards compatibility is a difficult one that the industry currently has to deal with.

Puckace indicates that the best way to address the concern about backward compatibility is to do field testing. He says, "We have taken steps to ensure the backward compatibility of CJ-4 additives by conducting more than 12 million miles of field testing to demonstrate real-world engine protection with the lower SAPS products."

Cousineau adds, "Additive companies must balance the performance needs desired by the consumer (wear control, oil drain interval, etc.) with the OEM needs driven by governmental compliance. Proof of performance for passenger car engine backward compatibility is hampered by the unavailability of historic test engines used to evaluate wear protection. A suitable replacement test for wear protection has not been developed and, while newer engine designs are more robust in terms of wear, emphasis is being placed on the reduction of select anti-wear components to increase emission catalyst compatibility."

Evans adds, "Protecting engine durability of older vehicles as newer engine designs emerge is always a key element of product design. New emission requirements have imposed chemical restrictions that result in formulation changes that must be technically evaluated for backward compatibility."

Anderson is in agreement that the needs of new engine and emission systems technologies must be balanced with the needs of existing equipment. He says, "In a typical market, backward compatibility is a major concern because the fleet turnover is typically less than 10%. As a result, there is a large existing population that a newly formulated lubricant must be capable of serving the day it is introduced."

Into the future

The representatives of the additive companies were asked for their thoughts on such future issues as the impending commercialization of GTL base oils, the impact that the European Union (EU) Eco-Label system, REACH and flexible fuel vehicles might have on automotive engine oil lubricants and how will differences in global specifications affect the types of additive packages offered in specific markets.

As a group, the engine oil additive representatives do not know enough about the properties of GTL base oils to comment on the types of additives and chemistries that will be required. Parsons says, "GTL basestocks have a higher viscosity index (VI) than mineral oils and

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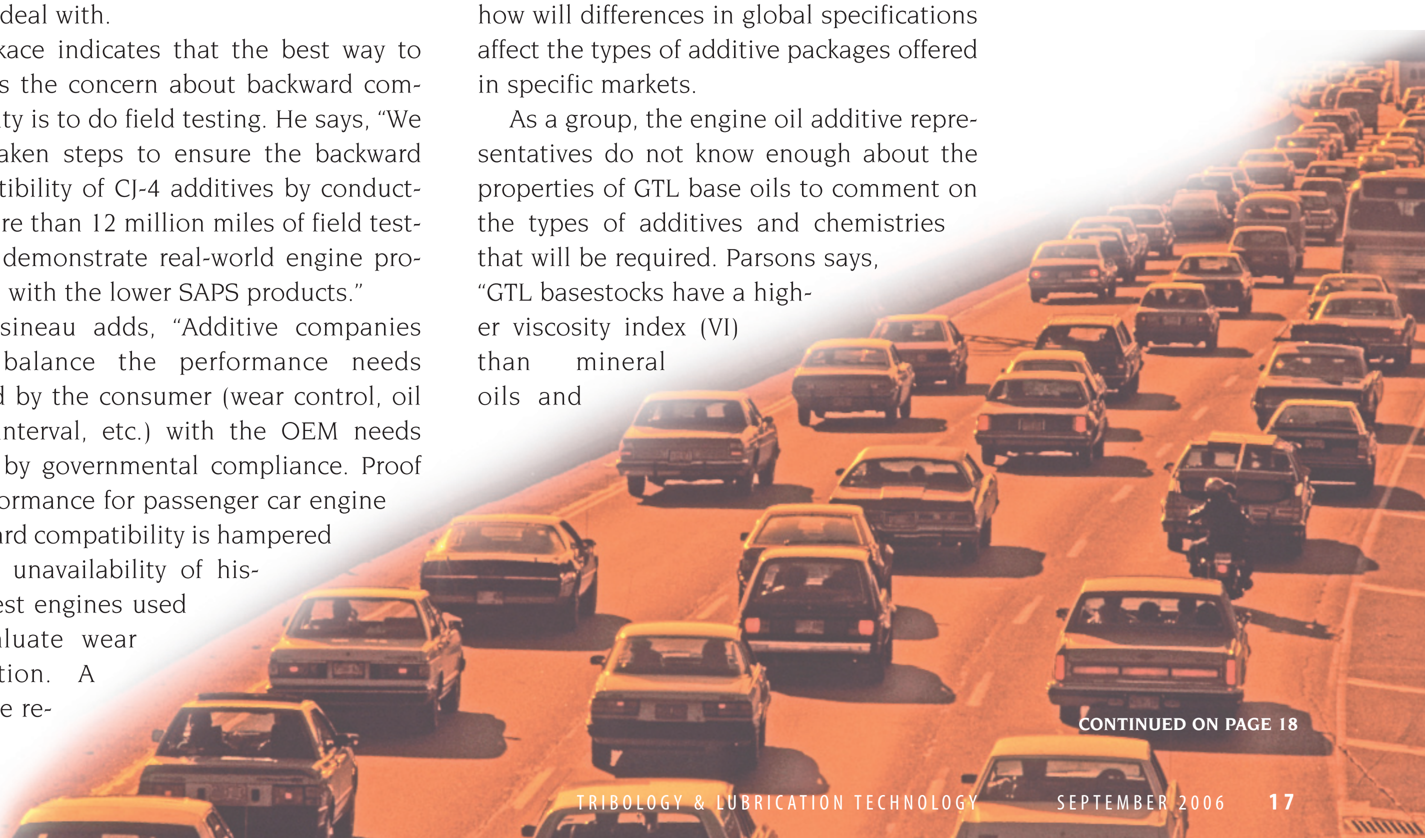

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will require less polymer thickener and less viscosity index modifier in general."

Evans comments, "GTL basestock is clearly the next generation of basestock for our industry to contend with. It is not certain exactly when this technology will be available, in what volume and in what regions. GTL does bring enhanced capability in lower viscosity grades such as 0W-20/30 and will enable greater fuel economy performance."

The EU's Eco-Label system has not impacted the way that the engine oil additive companies are developing their products. Anderson maintains that this development along with REACH is prompting additive companies to stress the importance of toxicity testing earlier in the development process. He says, "In general, toxicity testing has moved up in the development process to earlier stages of development, and testing has become more sophisticated. Aquatic toxicity and biodegradability are two of the aspects that are evaluated. Used oil recycling is also being encouraged in most regions to avoid aquatic toxicity and biodegradability issues associated with improper used oil disposal."

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Evans cites that REACH may limit the additive options that the industry has for formulating automotive engine oils. She says, "There are costs associated with REACH that may cause a re-evaluation of the use of certain additives—not for environmental reasons but simply that bringing the data on these additives up to REACH standards may not be economically justifiable."

Flexible fuel vehicles are capable of using multiple fuels such as gasoline and ethanol. They have gained in popularity in certain regions of the world such as Brazil. Between 2003 and 2005, the number of flexible fuel vehicles in this country has climbed from 6% to 73%. Cousineau says, "The consumer need for a common engine oil will drive conventional products to meet any special requirements required by flex fuel vehicles. Certain OEMs have identified rust, corrosion and emulsion stability as key parameters for flex fuel vehicles. Sequence engine tests for flex fuel vehicles may have to be developed."

Evans agrees about these parameters for vehicles using alcohol-based fuel. She adds, "Typical gasoline engine additive packages need to be altered to neutralize the negative effects of combustion byproducts associated with bio-fuels. Industry will need to monitor fuel quality and its impact on lubricants. Depending on the fuel, it is not clear that one standard lubricant or standard oil drain interval will be acceptable."

Parsons indicates that most OEMs reduce their recommended drain intervals if alternative fuels are used rather than requiring the use of special engine oils. He says, "Reducing recommended drain intervals is the preferred route to avoid potential problems with misapplication of lubricants for flex fuel vehicles."

Puckace feels that specific additive technology may need to be developed for flex fuel vehicles. He says, "At this point, we know of no significant effect that flex fuel vehicles have on engine oil additive packages. If the use of flexible fuel vehicles increases dramatically, specialized additive packages may need to be developed to address any unique requirements that become known."

Convergence of global specifications is a trend that is starting to take place. Cousineau says, "OEMs are increasingly globalizing through mergers and business activities. The sharing of common designs, hardware and fuel quality are driving global engine oil specifications. As OEMs market vehicles in various regions, local consumer markets will demand that regional engine oils comply with global specifications."

Anderson believes that the trend toward convergence is particularly noteworthy from the standpoint of emissions standards. Transfer of technology to the underdeveloped countries is also facilitating this process. He says, "Most developing countries and regions are using American or European emissions or product standards, rather than creating something new on their own. As a result, technology transfer from more mature regions to developing areas is occurring."

Evans cautions that the trend toward convergence will be slow. "Different markets will continue to have somewhat different needs," she says. "There are also cultural differences and preferences that have an impact upon market technical profiles."

Puckace is concerned that the non-convergence of global specifications is making it more difficult for the additive industry to provide technology that meets worldwide criteria. He says, "Non-harmonization of the performance requirements of worldwide specifications creates significant uncertainty in the program requirements and the ability of these oils to comprehensively meet customer needs. Further, complex programs can restrict the timely and cost-effective development of lubricant additive systems."

The next 25 years

Finally, our additive company representatives were asked about how engine oil packages will change during the next 25 years. Puckace says, "The continued focus on reducing the potential negative effects on aftertreatment devices will continue to reduce or limit key lubricant elements such as SAPS. The further development and enhancement of carbon-, oxygen-, hydrogen- and nitrogen-containing chemistries will continue to be a focus of lubricant research."

Cousineau says, "Engine oil additive packages will evolve to meet the three basic market demands of improved fuel economy, better emission system compatibility and greater oil robustness. These changes will be required to maintain adequate performance safety margins for OEMs and consumers. Certain known and cherished components may be reduced or phased out. Alternative technologies will enhance or replace these components but will need to be proven in the field."

Evans expects that mature, internal combustion engine technologies will continue to be dominant over the next 25 years with changes evolving slowly. She says, "In the medium term, we will have largely reached the limits of what is possible with respect to emissions control, and so we shall see some stability with regard to the demands that additives and lubricants have on compatibility with comprehensive emission systems. The quest for energy efficiency, however, will continue, resulting in more engine downsizing, greater use of turbochargers, better heat management, more sophisticated combustion control, various modes of hybridization and new materials."

Parsons indicates that the continuing challenge for engine oil additives is to do more without significantly altering the chemical fingerprint of the automotive lubricant. He says, "We anticipate continued development of low ash type formulations with even lower levels of sulfur, phosphorus and ash. In addition, a cradle-to-grave approach may develop in which factors such as biodegradability and the ability to recycle may come into play. Lower viscosity engine oils and friction modifiers will be used to improve fuel economy. Drain intervals will be extended in part to reduce the environmental burden by reducing the amount of used waste oil." **<<**

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