Modern Global Engine Oil Standards

Dr. Raj Shah, Dr. Hind Abi-Akar, Mr. Stanley Zhang

Introduction

Engine oils are used for the lubrication of internal combustion engines, which power a wide range of vehicles and machinery that in turn power economies globally. Engine oils play critical roles supporting engine performance including protecting moving parts from friction and wear, transferring heat, and sealing of piston rings. Typically, lubricating oils contain additives like dispersants and detergents, which help suspend contaminants within the fluid and clean the engine from sludge and varnish. Oxidation and corrosion inhibitors are also common additives in lubricants to combat against chemical and thermal degradation of the oil as well as rust and corrosion of components. Further, modern engine oils have taken on additional roles, such as supporting emissions reduction devices in engines that must meet strict emissions reduction regulations.

As a product derived from crude oil, engine oils have varying hydrocarbon compositions, which combined with a range of additives result in a wide spectrum of properties. One of the most important properties of an engine oil is its viscosity. The ability of an oil to retain a high enough viscosity to maintain a lubricating film between moving components, while still having a viscosity low enough to flow around engine parts with minimal drag is vital to identifying its applications. The Society of Automotive Engineers (SAE) has established the SAEJ300 standard, which grades motor oils by their viscometric properties. A combination of an engine oil's kinematic viscosity, high temperature-high shear (HTHS) viscosity, and low temperature performance determines its viscosity grade.

Along with the SAE viscosity grades, organisations around the world have developed engine oil standards to set minimum performance benchmarks and meet original equipment manufacturer (OEM) requirements. The most prominent standards are set by the American Petroleum Institute (API), International Lubricant Standardization and Approval Committee (ILSAC), and European Automobile Manufacturers Association (ACEA). Although these standards were developed based on the markets in their respective markets in North America and Europe, other countries like China and India have adopted and modified these standards to fit their own markets. In this paper, we will explore the development, adoption, and modification of engine oil standards in the United States, Europe, China, India, and Canada.

The United States Upgrades to ILSAC GF-6 to Combat LSPI

In 2020, the American Petroleum Institute (API) announced the approval of new performance standards for passenger car engine oils with improved protection and fuel efficiency for automotive gasoline engines. Two of the new standards, GF-6A and GF-6B are ILSAC specifications that fulfil the performance requirements set by the International Lubricant Specification Advisory Committee (ILSAC). The ILSAC GF-6 standards were implemented to primarily combat low-speed pre-ignition (LSPI) and timing chain wear. The prevalence of turbocharged gasoline direct-injection (TGDI) engines in today's vehicles to increase fuel economy has also increased automobile susceptibility to LSPI. LSPI is an abnormal combustion event that occurs in TGDI engines when the air-fuel mixture ignites before the spark plug fires, which can cause permanent internal engine damage or catastrophic engine failure.

Figure 1. *Two examples of piston damage due to LSPI.*

In response to this phenomenon, API introduced a new supplemental service category, API SP, to reduce the occurrence of LSPI, along with the ILSAC GF-6 standards. API SP is backwards-compatible and includes the performance properties of earlier API service categories, such as API SN PLUS, SN, SM, SL, and SJ. The ILSAC standards are split into two categories, GF-6A and GF-6B. GF-6A is backwards-compatible to previous performance standards, while GF-6B is not backwards-compatible and is only used for SAE 0W-16 oils.

API Certification Mark "Starburst" for meeting ILSAC GF-6A standard.

API Certification Mark "Shield" for meeting ILSAC GF-6B standard.

AP Service Symbol "Donut" for meeting SP standard with SAE viscosity grade.

Figure 2. *API Certification symbols.*

The necessity of the advent of these new performance standards stems from environmental, market, and technological influences. Due to rising environmental concerns, new EPA regulations under the Clean Air Act limit the maximum greenhouse gas emissions allowed for vehicles. In addition, the National Highway Traffic Safety Administration (NHTSA) implemented Corporate Average Fuel Economy (CAFE) standards that regulate the minimum miles a vehicle must travel per gallon of fuel. In the developed economy of the United States, the average consumer is also looking to reduce their carbon footprint and tend to favour vehicles with higher fuel economy. OEMs in North America must strive to reduce emissions and boost fuel economy in order to meet environmental regulations and fulfill consumer demands. In addition to the aforementioned use of TGDI engines, OEMs have turned to adopt strategies to further reduce emissions and improve fuel economy. Those strategies include start-stop engines and utilisation of low viscosity oils. The ILSAC GF-6 and API SP standards protect against the LSPI of TGDI engines, while also reducing the sludge formation and varnish deposits for start-stop engines. The GF-6B standard yields higher fuel efficiency with the use of lubricants with HTHS low viscosity oils like 0W-16 grade engine oils.

For diesel engines, API CK-4 and FA-4 are the current specifications for oils used in high-speed four-stroke engines. Introduced into the market in December of 2016 as upgrades to CJ-4 generation oils, this is the first time two heavy-duty diesel engine oil categories were developed at the same time. Both CK-4 and FA-4 engine oils were designed to maintain engine durability, protect emissions reduction devices, and provide improvements to shear stability, oxidation resistance, and aeration control. Both categories have the same limited levels of sulphated ash, phosphorus, and sulphur (SAPS). API CK-4 oils retain traditional HTHS viscosity, while API FA-4 oils feature a lower HTHS viscosity with a focus on greenhouse gas emissions reduction through enhanced fuel efficiency for the latest on-highway engines models without sacrificing engine protection. The backwards compatibility of the API CK-4 oil category allows for its utilisation in older engines, while OEMs and owners of the latest on-road modern engines can benefit from a flexible oil selection and improved fuel economy.

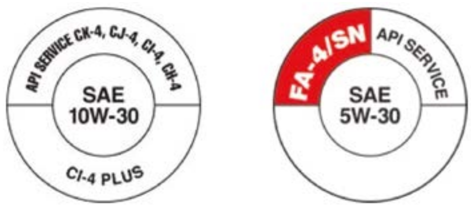

Figure 3. *API symbols for CK-4 and FA-4 diesel engine oil categories. Clear distinction between CK-4 and FA-4 is necessary to avoid miss-filling the engines with not intended oils.*

Europe Introduces new ACEA E8, E11, F8, and F11 Oils

In Europe, engine oil standards are set by the European Automobile Manufacturers Association or Association des Constructeurs Européens d'Automobiles (ACEA) in French. ACEA specifications are divided into classifications for passenger motor oils (A/B class), catalyst compatible motor oils (C class), and heavy-duty diesel engine oils (E class). These classifications are further split into subcategories based on HTHS viscosities and sulphated ash, phosphorus, and sulphur content (SAPS). The A/B class consists of high SAPS oils designed for older gasoline and light-duty diesel engines that do not have emissions reduction-aftertreatment devices. ACEA A3/B3 and A3/B4 require oils with higher HTHS viscosity that provide improved engine protection, while A5/B5 oils have lower HTHS viscosities, possibly sacrificing some wear protection for better fuel economy. The C class is comprised of catalyst compatible oils for gasoline and light-duty diesel engines with aftertreatment devices. C1 and C4 oils have low SAPS content, while C2 and C3 are mid SAPS oils. Additionally, C1 and C2 oils have a minimum HTHS viscosity of 2.9 centipoise, while C3 and C4 have a higher requirement of 3.5 centipoise. ACEA C5 was a new addition in 2016, containing mid SAPS oils with increased fuel efficiency and HTHS viscosities of at least 2.6 centipoise. All of these oils under the C class are designed to increase the lifespan of gasoline particulate filters (GPF), diesel particulate filters (DPF), and three-way catalytic converters (TWC), while maintaining a vehicle's fuel economy and protecting the engines. The heavy-duty engine oils that constitute the E class are differentiated from one another by drain interval. Longer drain intervals can be achieved using E4 and E6 oils when recommended, while E7 and E9 oils target medium drain applications.

The ACEA's 2018 engine oil sequences were delayed until 2020 due to adequacy of oils in the current European market. The ACEA plans to introduce and replace several new classes in their upcoming sequence in response to an evolving market. Due to rising concerns in regards to LSPI in TGDI engines, ACEA C6 will be proposed as an improvement to ACEA C5, as it includes performance tests for LSPI, chain wear, and turbocharger deposits. ACEA A7/B7 will replace ACEA A5/B5 as an upgrade with similar performance tests. Also, ACEA A3/B3 will be removed because it is only used for older vehicles and ACEA A3/B4 can be recommended instead. In regards to heavy-duty engine oils, ACEA has proposed upgrades for the E6 and E9 specifications using established ASTM engines tests developed for API's CK-4 and FA-4 standards. More specifically, the Volvo T13 Engine Oil Oxidation Test (ATSM 8048) and the Caterpillar Oil Aeration Test (ATSM 8047) will be utilised to improve extended oil drain capability and compatibility with modern engines. ACEA E4 and E7 should remain unchanged, while ACEA E6 and E9 are anticipated to be replaced by ACEA E8 and E11 respectively. In addition, ACEA proposed to introduce a new F sequence, containing F8 and F11, which will require lubricants to have a HTHS viscosity between 2.9 to 3.2 centipoise. These additional classifications should provide a boost in fuel economy and lower greenhouse gas emissions without compromising engine protection.

Although sharing some similarities, such as most performance targets and some tests with the United States, Europe's engine oil standards differ because of differences in oil change intervals and emissions regulations. Due to higher oil costs and differing OEM recommendations in Europe, longer drain intervals of 16,000 km (10,000 miles) are much more common for European cars compared to the 5,000 mile benchmark commonly used in the United States. This necessitates the use of drain intervals as a primary factor to categorise European engine oils. Additionally, the European Union's (EU) stricter regulations on carbon dioxide (CO_2) and carbon monoxide (CO) emissions caused a shift in the European market towards diesel-powered vehicles that emit less CO_2. However, diesel engines produce higher levels of nitrogen oxides (NO_x) and particulate matter (PM), necessitating the use of DPFs and TWCs to minimise emissions. These emissions countermeasures are sensitive to an oil's composition, especially to its SAPS content, which can drastically reduce these devices' effectiveness and longevity. For that reason, the ACEA's specifications include oil classifications for engines using aftertreatment devices (C class) and tend to contain oils that have mid to low SAPS content.

China Progresses Towards Its Own Domestic D1 Standard

For the past 30 years, China has adopted the API engine oil specifications. China's diesel engine specification (GB11122) is referred to as "National Standards" and aligns with API CD to CI-4. In addition, China adopts their vehicle emissions requirements from the EU's Euro standards. As China's automotive industry continues to experience

Figure 4. *Changes to ACEA Heavy-Duty Sequences.*

expedited growth, the needs of the market consequently evolved as well. Concerns surfaced surrounding the inadequacy of the current US and EU standards to comprehensively cover the latest Chinese OEM requirements. Additionally, issues of consistency emerge when the use of a mix of foreign standards fails to match the demands of the domestic market.

In response to the glaring problems with utilising standards targeted at a foreign market, China began development for a domestic heavy-duty diesel engine oil specification, D1, that was scheduled for release in 2019. The Chinese Lubricant Specification Development Alliance, which consisted of the five leading heavy-duty diesel truck manufacturers (FAW, DongFeng, WeiChai, Foton Daimler and JAC), led discussions for a domestic lubricant standard. Representatives from local lubricant companies, additive companies, independent organisations, and independent test labs also took part in the development process. The new D1 standard adopts the same viscosity classifications and bench tests as the API oil categories, but includes four additional Chinese diesel engine test methods. The first test integrated in the D1 standard is the FAW engine test, which focuses on low oil consumption and high temperature detergency. The next test is the DongFeng engine test, which determines an oil's resistance to viscosity increase and anti-wear performance from soot contamination. The demand for longer drain intervals from Chinese OEMs resulted in the inclusion of the WeiChai WP13L engine test that measures an oil's total base number (TBN) retention and performance up to 100,000 kilometers. Rounding out the D1 standard is the Foton Daimler ISGe4 engine test that was designed to assess an oil's ability to maintain normal lubricating conditions for off-road engine use. These tests allow for the assurance of high performance diesel engine oils that are tailored to the vehicles in China and eliminates the need for oils to undergo engine tests required by API oil specifications but may be unnecessary for the Chinese market.

India Makes a Jump to BS VI in an Effort to Lessen Emissions

The growing vehicle population in India has continually contributed to the country's escalating pollution problem. Consequently, the Indian Ministry of Road Transport and Highways (MoRTH) announced the implementation of the Bharat Stage VI (BS VI) vehicular emission standard over the previous Bharat Stage IV (BS IV) standard. Scheduled for implementation in April 2020, the BS VI standard will restrict vehicle pollution to regulate air quality and bring India's motor vehicle regulations in alignment with the EU's Euro VI standard.

For each vehicle classification and their respective subcategories, proposals were made for mass emission limits, type approval requirements, on-board diagnostic (OBD) systems, and durability levels. In the category of passenger vehicles, stricter limits will be imposed on hydrocarbons, NOx, and PM and a new particulate number (PN) limit will be added. In addition, there will be changes regarding vehicle type procedures for light-duty vehicles through the use of portable emissions measurement systems (PEMS) for in-service conformity testing. BS VI will necessitate the use of World Harmonized Stationary Cycle (WHSC) and World Harmonised Transient Cycle (WHTC) test cycles for commercial vehicles. Also, the durability of pollution control devices for commercial vehicles will adopt the requirements outlined in the

	CO g/km	HC g/km	HC NOx g/km	NOx g/km	PM g/km	PN #/km
Compression ignition	0.50-0.74	–	0.17-0.215	0.08-0.125	0.0045	$6x10^{11}$
Positive ignition	1.0-2.27	0.10-0.16	–	0.060-0.082	0.0045	$6x10^{11}$

Green = new Red = tighter than BS IV

Figure 5. *Passenger Vehicle BS VI Proposed Limits*

Euro VI standards. Unique to the BV VI standard, regulations will be proposed for two-wheeled and three-wheeled vehicles as they comprise over 70% of the vehicle population in India. This includes evaporative emissions limits, OBD specifications, and durability standards to ensure that two-wheelers and three-wheelers will be no more polluting than a gasoline passenger vehicle at a minimum. OEMs will likely have to employ a broader range of aftertreatment technology in order to fulfil the new BS VI requirements. The use of particulate filters and new fuel injection systems may prove necessary for passenger cars, commercial vehicles, and two-wheelers to remain under the new emission limits.

The use of reduced SAPS engine oils for all vehicles is a necessity in order to maintain the performance and integrity of emissions control systems introduced to meet BV VI standards. For passenger car oils, older specifications like API SL will be replaced with newer API SN, ILSAC GF-5, and ACEA C2/C5 quality oils. Specifications like API CK-4 and ACEA E6 plus will experience increased usage as heavy-duty oils for commercial vehicles. API SJ and SL will continue to experience high usage for two-wheeled vehicles, along with API SN, which could be used for enhanced TWC protection due to lower phosphorus content. Despite the use of American and European oil standards, aftertreatment systems in Indian automobiles still suffer from obstacles due to a difference in driving patterns. Low speed, start-stop conditions that predominantly make up the driving conditions in India's cities, cause the excessive accumulation of particles in DPF aftertreatment systems. This hinders the efficiency of DPF regeneration and consequently results in reduced engine performance, increased fuel consumption, and potentially vehicular failure. At this time, there are no indications that a regional Indian oil standard will be developed to target those conditions.

	CO g/kWh	HC g/kWh	CH4 g/kWh	NOx g/kWh	PM g/kWh	PN #/kWh
WHSC Compression ignition	1.5	0.13	–	0.40	0.01	$8x10^{11}$
WHTC Compression ignition	4.0	0.16	–	0.46	0.01	$6x10^{11}$
WHTC Positive ignition	4.0	0.16	0.5	0.46	0.01	$6x10^{11}$

Green = new Red = tighter than BS IV

Figure 6. *Commercial Vehicle BS VI Proposed Limits.*

		CO g/kWh	HC g/kWh	NOx g/kWh	PM g/kWh
Two wheelers	SI Engine	1.0	0.1	0.06	0.0045
	CI engine	0.5	0.1	0.09	0.0045
Three wheelers	SI Engine	0.44	0.35	0.085	–
	CI engine	0.22	0.1	0.10	0.025

Green = new Red = tighter than BS IV

Figure 7. *Two/Three Wheeler Vehicle BS VI Proposed Limits.*

Canada Embraces API CK-4 and FA-4 Standards

As part of North America, it comes as no surprise that Canada has been utilising API standards for their engine oils as well. With driving forces such as the EPA's new emissions legislation and the occurrence of LSPI in modern engine designs leading to the development of ILSAC GF-6, Canadian lubricant companies had to ensure that their oils could meet the new requirements. Companies like Petro-Canada Lubricants, the biggest oil producer in Canada, began reformulating their repertoire of passenger car motor oils (PCMO) to fulfil the ILSAC GF-6 and API SP category specifications. The changes would spawn a new generation of oils that would provide protection against LSPI, accelerated timing-chain wear, start-stop engines, and enhance fuel economy.

In the field of heavy-duty diesel oils, Canada adapted to the introduction of API CK-4 and FA-4 in 2016. Similar to the United States, Canada's market shifted towards the use of lower HTHS viscosity oil in the latest on-highway engine technologies in favor of the better fuel economy and reduced greenhouse gas emissions. Petro-Canada released oils for the Canadian markets and beyond that are per the API CK-4 and FA-4 categories and appropriate for use in vehicles that are compliant with EPA regulations. Similar to US oils, Canadian CK-4 and FA-4 oils are used in engines with aftertreatment devices such as DPFs with or without Diesel Oxidation Catalysts (DOC), increased rates of Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR).

Conclusion

The engine oil standards developed by API, ILSAC, and ACEA stand at the forefront of the constantly evolving automotive industry around the world. In the United States, the push for smaller, more efficient engines led to the development of TGDI engines, which did boast improved engine performance at the cost of risking LSPI issues. The LSPI phenomenon resulted in the introduction of ILSAC GF-6 standards, which reduced the occurrence of LSPI and utilised lower viscosity oils that provided better fuel efficiency. Also, API introduced the CK-4 and FA-4 standards for diesel engine oils that had enhanced engine performance and for the first time for diesel engine oils reduced greenhouse gas emissions (FA-4 only) to comply with EPA regulations. Standards in Europe similarly evolved with ACEA announcing several updates to their specifications. The new ACEA C6, A7/B7, E8, and E11 standards would address LSPI problems and contain performance boosts, with a greater focus on extending drain intervals, utilising low SAPS oils, and complying with stricter European emissions requirements.

On the other hand, China have adopted API engine oil standards, while using European emission standards for a significant portion of their history. However, with China's vehicle market diverging from the needs of the western market, leading figures in China's automotive industry would come together and begin developing their own domestic heavy-duty diesel oil standard D1. As a developing country, India has been using older API/ACEA standards and has faced a multitude of issues with the low speed, start-stop driving conditions prevalent in urban environments. The implementation of India's BS VI emission standards has pushed the country to adopt updated standards like API CK-4 in an effort to satisfy environmental concerns. Canada's rate of adopting API standards would mirror the United States due to their close proximity and their vehicle markets' sharing similar demands. Likewise, Canadian engine oils reaped analogous performance and protection benefits in both gasoline and diesel categories.

The rapidly developing state of the automotive industry paired with the constant drive for higher performance and efficiency has necessitated continual upgrades to engine oil standards to match OEM demands. Currently, North America and Europe have been paving the way for developing the standards used in modern vehicles. Countries presently trailing behind have begun establishing their own specifications or modifying current ones in order to better represent their domestic market. Although global engine oil standards may differ in certain aspects, they are all designed to provide the highest quality, low viscosity lubricants that yield satisfactory engine protection while maintaining fuel economy and reducing emissions.

On the horizon, a possible challenge is looming for OEMs and oil marketers: the emergence of regional standards that may challenge the current OEMs strategies of common engine designs for the global market. Another challenge that remains a consideration as oil standards are developed or become obsolete is the variation of fuels (sulphur, lead, octane, etc) globally that necessitates the need for several oil categories co-existing in the global markets.

Dr. Raj Shah *is currently a Director at Koehler Instrument Company, NY (a renowned manufacturer of petroleum testing instruments) and an active ASTM member for the last 25 years. A Ph.D in Chemical Engineering from The Penn State University and a Fellow from The Chartered Management Institute, London, Dr. Shah is an elected Fellow by his peers at STLE, NLGI, IChemE, Energy Institute and the Royal Society of Chemistry. He can be reached at rshah@koehlerinstrument.com*

Dr. Hind Abi-Akar *is a technical fluids expert at Caterpillar in Peoria, IL. She is an expert on Lubricants and is a key contributor at ASTM for the past two decades. Currently part of the fluids engineering group at Caterpillar she is the author of numerous publications.*
Raj and Hind are members of the newly formed ASTM's Global Lubricants test standards team.

Mr. Stanley Zhang *is a chemical engineering student from Stony Brook University, where Dr. Shah is the Chair of the External Advisory Board of directors and he is also a part of a thriving internship program at Koehler instrument Company, Holtsville, NY.*

References

1. "ACEA European Oil Sequences." European Automobile Manufacturers Association. 2016.
2. "ACEA European Oil Sequences Update." Lubrizol 360, Lubrizol. 30 Apr. 2019.
3. Augusteijn, Nick. "ACEA 2018 Delayed Until 2020." Lubes'N'Greases. 9 Apr. 2019.
4. "Bharat Stage VI." Infineum Insight, Infineum International Limited. 21 May. 2019.
5. Fangqing, Wang. "China Drafts Diesel Engine Oil Specifications." Lubes'N'Greases. 8 Jun. 2018.
6. Fujimoto, Kosuke, et al. "Engine Oil Development for Preventing Pre-Ignition in Turbocharged Gasoline Engine." SAE International Journal of Fuels and Lubricants, vol. 7, no. 3, 2014, pp. 869–874. JSTOR.
7. "ILSAC GF-6 is moving forward. It's important to keep up." Petro-Canada Lubricants, Petro-Canada Lubricants.
8. Jin, Yuefu, et al. "Development of Fuel Consumption Standards for Chinese Light-Duty Vehicles." SAE Transactions, vol. 114, 2005, pp. 185–195. JSTOR.
9. Mc Geehan, J. A., et al. "API CI-4: The First Oil Category for Diesel Engines Using Cooled Exhaust Gas Recirculation." SAE Transactions, vol. 111, 2002, pp. 609–636. JSTOR.
10. McGeehan, James A., et al. "Minimizing Diesel Particulate Filter Incombustibles by Using Ultra Low Ash - Zero Phosphorus Oil." SAE International Journal of Fuels and Lubricants, vol. 7, no. 3, 2014, pp. 890–900. JSTOR.
11. Nag, D.S. "Quality of Indian Lubes Rising for BS VI." Lubes'N'Greases. 17 Jan. 2020.
12. "Oil Categories." API, American Petroleum Institute.
13. "SAE Viscosity Grades." Anton Paar, Anton Paar.
14. Stone, Aaron. "Engine oil specifications: China charting its own course." Fuels and Lube, F+L Magazine.
15. "What You Need To Know About ILSAC GF-6." Pennzoil, Pennzoil.
16. Whitacre, Shawn. "Making the decision to switch to API CK-4 engine oils." Chevron Lubricants, Chevron Lubricants. 26 Oct. 2017.

LINK
www.koehlerinstrument.com