The future of heavy duty diesel engine oils

Base oil selection and compliance with new additives are some of the challenges facing end-users and the industry.

The landscape for heavy duty diesel engine oils (HDDEO) is going to change quite a bit in the next few years. The HDDEO market will see demand shift away from the traditional SAE 15W-40 viscosity grade to lower, more fuel-efficient grades like SAE 10W-30 and SAE 5W-30. This shift in demand is being driven by the implementation of PC-11 (Proposed Category), which goes into effect April 1, 2016.

The origins of PC-11 started in August 2011 when the U.S. Environmental Protection Agency (EPA) set the standards for greenhouse gas (GHG) emissions and the National Highway Traffic Safety Administration (NHTSA) set the first U.S. standards for fuel consumption for medium and heavy duty vehicles. These standards are being phased in 2014 and must be fully complied by 2018. In order to be fully compliant, medium and heavy duty vehicles must deliver a 10-20 percent reduction in CO₂ emissions compared to the 2010 baseline, depending on vehicle classification. The goal for 2018 model year Class 7 and 8 rigs is to save four gallons of fuel for every 100 miles traveled compared to 2010.¹ Class 7 and 8 rigs are vehicles with a GVWR (Gross Vehicle Weight Rating) of 26,001 lbs and up. The national and global goal beyond that is for heavy duty trucks to average as much as 20 miles per gallon over the next 10-35 years.

PC-11 was created to help engine manufacturers meet the EPA and NHTSA standards. PC-11 was initially requested by the Engine Manufacturers Association (EMA). The EMA asked the American Petroleum Institute’s (API) Diesel Engine Oil Advisory Panel (DEOAP) to develop a new category for heavy duty engine oils and PC-11 was born. PC-11 must address numerous issues with heavy duty engines. The DEOAP addressed the proposed regulation by defining performance of low viscosity oils, which improves fuel economy. They also addressed biodiesel compatibility (though this requirement has recently been dropped), engine oil shear down, the need for greater protection from higher engine operating temperatures, an increase in adhesive wear protection, as well as the need to reduce engine oil aeration.²

KEY CONCEPTS

- Manufacturers must comply with new PC-11 regulations for fuel consumption of medium and heavy duty vehicles by April 1, 2016.
- A challenge for formulators is creating lower viscosity oils resulting in fuel economy savings without the expense of reduced engine protection.
- The HDDEO market has begun tests using PC-11 technology and transitioning to lighter viscosity oils.

¹ Did you know? Two-thirds of STLE members are lubricant manufacturers, additive

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manufacturers/suppliers or end-users of lubricants and lubricant-related products.
There will not be a specific fuel economy test for PC-11, so the fuel economy benefits will come from using lower viscosity oils. Viscosity reduction, therefore, is going to be the most important change that will allow formulators to achieve the targeted fuel economy gains. The technical challenge with these lower viscosity oils will be in providing wear protection and engine durability. This means that the oils must maintain an oil film and proper surface protection to prevent premature engine wear. In addition, the oil must be more thermally stable to prevent oxidation, which leads to deposit formation, as well as thickens the oil and degrades fuel economy.

Since the fuel economy gains will be coming from lower viscosity oils, while at the same time PC-11 must serve the needs of the older engines, the result will be that for the first time the industry will have to deal with two PC-11 categories. The second category, PC-11B will deal with new engines that will require low viscosity engine oils such as SAE 10W-30 and SAE 5W-30, with a tentative 2.9-3.2 cP HTHS viscosity. The HTHS viscosity of oil is a critical property that relates to both fuel economy and durability. These thin oils will be fine for the newer engines that are designed for them, but the HTHS viscosity is going to be so low that it may not provide the necessary wear protection for older vehicles—therefore it will have limited or no backward compatibility.

The first category, PC-11A will offer full backward compatibility. The engines that fall in this category will use traditional oils like SAE 15W-40. In contrast to the newer oils that will have a 2.9-3.2 cP HTHS viscosity, the oils in this category will have a ≥3.5 cP HTHS viscosity. These oils will still have the performance improvements of PC-11 such as increased shear stability, reduced adhesive wear, resistance to oxidation and resistance to aeration. The one drawback is that there will not be any fuel economy benefits from using an SAE 15W-40 in this category.

The New Category Development Team (NCDT) met in January 2014 to discuss API naming designations. The API's lubricants group favors the designation of CK-4 for PC-11A, which continues its progression of letters for its heavy duty category. To distinguish the two categories, it was heard that PC-11B be given a new viscosity grade tentatively called SAE 26. The group also heard seven possible API naming designations for PC11A and PC-11B but narrowed it down to two. The first would be CK-4 for both categories and the second, which gathered the most support, would be CK-4 for PC-11A and DK-4 for PC-11B. This issue now goes back to API's lubricants group for review.3

ENGINE TESTS

In addition to viscosity reduction, oils that meet the new PC-11 requirements will have to undergo additional testing compared to oils that are approved for the current CJ-4 spec. There are a multitude of reasons for this. Since 2006, both engine designs and their metallurgy have changed and will continue to evolve. For example, in 2014 the European Union started replacing lead bearings with aluminum bearings. Engine hardware design changes have been brought upon because of the need to improve fuel efficiency and reduce emissions. These changes are some of the reasons why industry experts agree that some of the CJ-4 testing procedures are outdated. Another problem the industry faces is that some parts required to perform some of the CJ-4 tests will be scarce by 2015.

Following are seven CJ-4 tests that will carry over to the PC-11 testing:

1. Cummins ISB (valve train wear)
2. Cummins ISM (valve train wear, sludge, filter plugging)
3. Caterpillar C13 (steel piston deposits and oil consumption)
4. Mack T-11 (soot dispersal)
5. Mack T-12 (ring/liner wear)
6. Caterpillar 1N (aluminum piston deposits)
7. GM 6.5RFWT (valve train wear)

Two new tests (T-13 and C13 aeration) are very likely to be included in PC-11 (T-13 was voted in by the NCDT in January 2014), while the DD13 scuffing and IIIH tests are still being evaluated (though at their January 2014 meeting, the NCDT voted not to include the DD13 test at this time). At this time, there are four new proposed tests for PC-11. They are:

1. Daimler DD13 (scuffing/adhesive wear)
2. Caterpillar C13 Aeration
3. Volvo/Mack T-13 (oxidation and bearing corrosion)
4. Sequence III H (gasoline oxidation)

PC-11 tests will include both engine and lab bench tests to assess engine performance. There are also three new task forces looking at biodiesel, shear stability and oxidation to determine if there is a need for any additional tests.4

BASE OILS AND ADDITIVES

As stated earlier, the biggest challenge that formulators of PC-11 engine oils face is creating lower viscosity oils that result in fuel economy savings but without the expense of reduced engine protection. The areas that they will
look to will be base oil selection and additive formulation changes. Before any oil is developed, an understanding of the wear processes taking place on the different contacting surfaces is critical for success. For heavy duty engines, mechanical losses amount to 13-16 percent of the total energy input from the fuel in which half of that came from frictional losses (including pumping of the oil through the engine). This is the only part that the lubricant can improve. A well-designed lubricant can reduce the frictional losses by as much as one-third, with the end result being fuel economy gains.³

If designed properly for reduced wear and friction, hydrodynamic and mixed lubrication are the most common lubrication regimes in heavy duty diesel engines. In the hydrodynamic fluid regime, the most impact and greatest benefits will come from the oil’s viscosity, base oil and VI improver selection.⁴

Base oil selection will be a critical part to making a finished product that will provide fuel economy gains, as well as the needed engine protection. Base oils make up anywhere from 70-85 percent of a typical HDDEO (see Figure 1). It is expected that the market will see an increase in Group II and III demand. Group IV PAOs might see an increase in demand as well, but it is not expected to be significant due to its high cost and limited availability. Global Group II base oil demand is expected to grow 4 percent annually through 2017, while global Group III base oil demand is expected to grow 10 percent annually during that same time. In 2010, there were 3 million metric tons of Group III oils produced globally, and by 2020 that number is expected to reach 7+ million metric tons. 83 percent of Group III demand is for engine oils. Group III base oils will see its greatest demand for lower viscosity oils like SAE 3W-30 with PC-11.⁷

There are advantages and disadvantages that formulators must look at when selecting either Group II or Group III base oils for their lubricant. The advantages of Group II base oils over Group III base oils are that they have more naphthenic molecules, which give it better solvency. Group II saturates and solvency content is needed as a vital tool for soot dispersancy. Controlling soot wear is critical since it is a major component of the current and future HDDEO spec testing. Soot consists of sub-micrometer-scale particles of primarily elemental carbon. It migrates to crankcase engine oil via blow-by past the piston rings and accumulates in the oil. Soot buildup leads to wear and an increase in viscosity. Low viscosity engine oils will have to be developed to protect against soot induced wear.

Group II oils also have processing advantages over Group III oils, especially for the refiners who do not have access to the best lube crudes. Group III oils consist of 60 percent paraffinic molecules, so they need waxy crudes for refining, and that can be constraining for the refiner. If the crude isn’t as waxy as it needs to be, the refiner can hit the crude harder during the refining process, resulting in high yield losses.⁸

Most HDDEOs are currently formulated with Group II base oils. 80 percent of the U.S. heavy duty market is using an SAE 15W-40 engine oil, so the demand for Group III base oils is low. This is because there can only be limited amounts of Group III base oils in an SAE 15W-40 engine oil. The reason for this is that if there is too much of it, the lubricant will have a cold-cranking viscosity that is too low and it will become an SAE 10W-40 oil.

Group II oils will have a larger market share over Group III oils in the HDDEO market, but both will see an increase in demand. Future oils will need Group II and III base oils to meet the new requirements because of their lower volatility and low sulfur content (see Table 1). Sulfur needs to be minimized because sulfur poisons the catalysts. Additives contain sulfur, so to minimize the lubricant’s sulfur content base oils with lower sulfur levels are desired.

![Figure 1 | Typical engine oil composition. (Source: 2014 Chevron Oronite Co. LLC. All rights reserved.)](image)

### Table 1 | Base Oil Properties
(Source: SAE J300)

<table>
<thead>
<tr>
<th>Base Oil Category</th>
<th>Sulfur %</th>
<th>Viscosity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>&gt; .03</td>
<td>80-119</td>
</tr>
<tr>
<td>Group II</td>
<td>≤ .03</td>
<td>80-119</td>
</tr>
<tr>
<td>Group III</td>
<td>≤ .03</td>
<td>&gt; 120</td>
</tr>
</tbody>
</table>

One benefit of Group III base oils over Group I base oils is their viscosity index (VI) (Table 1). The traditional way to measure VI was to measure the relationship between the viscosity of the oil at temperatures of 40 C and 100 C. Higher VI base oils will be the key in formulating PC-11 oils. These oils experience a limited change in viscosity with temperature, they thin less at higher temperatures and resist thickening at lower temperatures. There are other benefits with higher VI base oils as well. They have a higher boiling point, reduced volatile components, are more resistant to oxidation and are more durable. A typical SAE 15W-40
has a VI of 140, while a typical SAE 5W-30 synthetic diesel engine oil has a VI of 170.

Besides the base oil selection, the selection of additives will be critical for formulators in meeting the performance demands of PC-11. Two additives that could see a greater role in the engine oil formulations are VI improvers and friction modifiers. The most important additive selected may be the VI improver or also known as viscosity modifier. The use of VI improvers has made the traditional way of measuring an oil’s VI into an artificial number. VI improvers make up 23 percent of global additives sales, according to Kline & Co. Viscosity modifier (VM) polymers are chain-like molecules that readily dissolve in mineral and synthetic base oils. The polymer coils expand at higher temperatures and increase the oil’s viscosity. At lower temperatures, the coils contract and thus the viscosity is reduced (see Figure 2).

VM polymers will play a crucial role in providing engine protection at both low temperature starting and high temperature operation. Frictional and pumping losses in diesel engines occur in hydrodynamic lubrication, so VMs can minimize these losses at low temperatures. VM polymers must also have shear stability, which is the ability of the polymer to resist shearing as measured by the Shear Stability Index (SSI). They can shear from increased cylinder temperatures and firing pressures in the engine.

There are five main functions of a VM, they are:

1. Reduce viscosity changes with temperature.
2. Enable the engine to start at low temperatures.
3. Ensure engine durability during boundary layer lubrication regimes of valve trains and rings/liner, as measured by HTHS viscosity.
4. Provide non-viscometric performance benefits such as improved piston cleanliness and deposit control, reduced soot mediated viscosity increase and wear and durability of seals and friction materials.
5. Provide protection and better operation for a secondary usage of engine oil.

Not all viscosity modifiers perform the same though. Some VI improvers can maintain HTHS viscosity but at the expense of low temperature viscosity. This is critical because the control of engine oil viscosity at low temperatures improves the engine operation and longevity. When the engine starts, it is critical for the oil to be pumped throughout the entire engine as quickly as possible to avoid metal-to-metal contact. If the oil is not pumped to all the moving parts quickly enough, it could result in an engine failure. This means that selecting the correct VI improver will be critical.

Another additive that could play an important role with PC-11 formulations is the friction modifier (FM). FMs are crucial during boundary lubrication. The parts of an engine that are vulnerable to boundary lubrication are cams and followers, cylinder liners and piston rings. The function of the friction modifier is to reduce the effect of friction on the metal surface. The FM molecules afford a cushioning when one of the coated surfaces connects with another coated surface.

There are two major types of friction modifiers that formulators can select: organic friction modifiers (OFM) and metal-containing friction modifiers (MFM). They each have two segments—a polar group that attaches to metal surfaces and an oleophilic group that provides both oil solubility and a slippery organic layer to reduce friction. The reduction in friction will improve the overall fuel economy of the oil. It is important to note that friction modifiers will need to be compatible with dispersants. If they are not, soot levels could increase, resulting in oil thickening and premature wear. Friction modifiers are an effective perf-
formance additive, but not all formulators agree on the importance of friction modifiers in regards to PC-11 formulations.

Optimizing fuel efficiency for PC-11 will not just come from lowering the oil viscosity, but, rather, a combination of lower base oil viscosity, base oil type and additive selection. Formulators will choose the best VI improvers, friction modifiers, dispersants and detergents, antiwear and extreme pressure additives to maximize engine protection and obtaining fuel economy gains. If the right additive combination is not used, it could result in friction losses, premature wear and eventually catastrophic engine failure.

MARKET CHALLENGES
There are many challenges for the heavy duty industry when it comes to PC-11. Most important is getting the industry to feel confident in using lower viscosity oils. Changing the minds of fleet maintenance managers who have used SAE 15W-40 oils for many years and have seen its success in their engines is going to take a while. Chris Damiano, fleet maintenance manager with Diesel Direct in Stoughton Mass., says, “I have torn apart engines that have had 500,000 miles on them, using nothing but 15W-40, and their components have been flawless. Why would I want to switch to a lower viscosity oil? Maybe I can save a little bit on fuel economy but at what cost? If I can’t get the same life out of my engines, then any fuel economy cost savings I might have gotten was just thrown out the window.”

Dustin Emerson, fleet maintenance manager with Narragansett Improvement Co. in Providence, R.I., feels the same way. He says, “I’d prefer to stick with 15W-40 because I know how it performs. If I was in a colder climate, then I would use a lighter viscosity grade. If a lighter oil could provide the same protection as a 15W-40, then we would consider using it.” It could take years of real world results before Damiano and Emerson feel comfortable using lighter viscosity oils in their fleets.

Though the majority of end-users are currently using SAE 15W-40 oils, there has been a shift in the marketplace towards SAE 10W-30 diesel oils. Chris Graffeo, equipment manager with J. Derenzo Co. in Brockton Mass., has been using SAE 10W-30 in his fleet of over 300 pieces of equipment for years. The majority of his equipment is provided by Caterpillar and ranges in age from 16 years to brand new 2014 units and uses SAE 10W-30 for everything. When asked why he uses SAE 10W-30 over SAE 15W-40, he says, “CAT recommends using 10W-30, and we wanted to go with a lighter oil to help with cold starts. We also wanted the fuel cost savings with the lighter oil.” Graffeo has not seen any slip in engine performance or durability since his fleet has been using SAE 10W-30. Successful transitions such as this will go a long way in giving the rest of the
heavy duty industry confidence when it comes to using lower viscosity oils.

Other market challenges include adding extra inventory and guarding against the misapplication of the two different oils. As fleets bring in new equipment and integrate them in with their older equipment, they will have to deal with carrying two different oils in their inventory. Many end-users will be forced to add an additional bulk tank or keep additional drums of oil on hand. This means that they will have to sit on their inventory a bit longer. Graffeo believes that this will be a major inconvenience for his fleet. He says, “This is going to be an added expense for us. We are going to have to add storage in our garage, as well as adding storage on our lube truck.”

The chances for misapplication between the two oils will be a major concern as well, especially since the newer oils may not be backwards compatible. Different naming conventions are being explored to try and reduce the likelihood of misapplication. Larger fleets who have multiple people adding oil to their trucks or equipment may have the greatest challenge, making sure that the right oil goes to the right piece of equipment. “I have a hard enough time making sure people do not put hydraulic oil in the engines. Now I’ll have to worry about them putting the right engine oil in the right engine. The way it works now is we can leave oil at the job sites and the oil can be added by the mechanics or foreman,” Graffeo says. “When PC-11 comes around, we will have to limit the amount of people who can add the oil to the equipment to minimize the possibility that the wrong oil will be added by accident. For a fleet as large as ours that has equipment scattered at different job sites, it is very difficult to watch over everything all of the time.”

Companies that do all of their services in their garage or by a limited amount of people may have an easier time making sure the correct oil is added. Roy Morse, fleet maintenance manager for the Town of Bourne Integrated Solid Waste Management (ISWM) in Buzzards Bay, Mass., doesn’t see a major problem carrying two oils. He says, “As we add newer equipment that calls for the lighter oil, we will just add a drum of it in inventory. There are only two mechanics who handle the oil and we do our top offs before any of the operators come in, so we’ll be able to monitor it closely.” Emerson also feels that this isn’t a major issue for his company. He says, “It will be like the old days when we had some trucks on straight oils and the newer ones were using 15W-40, we were able to manage the oils back then and we’ll be able to do it again.”

One important tool that can be used to help fleet managers will be used-oil analysis. There are numerous benefits of having an oil analysis program, but

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European immigrants brought Halloween to North America. They celebrated the
harvest around a bonfire, shared ghost stories, sang, danced and told fortunes.

For us to make sure that our employ-

ers are well trained and educated.” Get-

ting information out ahead of PC-11’s im-
plementation date will help compa-

nies like Kenworth Northeast educate

their employees and customers so that

mistakes and confusion are minimized.

**UNIVERSAL OIL**

The market may also face another
change with PC-11. Gerald Shaw, Amer-
ica’s Region automotive engine oil prod-

uct line manager for Chevron Oronite

Co. in Houston, says, “In addition to

fuel economy and viscosity reduction,
gasoline engine manufacturers will pro-

hibit the use of heavy duty engine oils

in gasoline-powered vehicles unless the

oils are formulated in such a manner

that the finished oil has a maximum

phosphorous content of 0.08 weight

percent (wt-%). Phosphorous is added

to the oil in the form of zinc dithio-

phosphate (ZDDP), which is a very ef-
fective antiwear/antioxidant additive.”

“Until now, marketers of heavy duty

engine oils were able to claim gasoline

engine performance (e.g., API SN) and

formulate with up to 0.12 wt-%, as long

as the heavy duty claim was the primary

performance claim (e.g., API CJ-4/API

SN). The gasoline-engine producers

are concerned about long-term catalyst

durability as a result of phosphorous

poisoning when oils containing higher

levels of phosphorous are (i.e., 0.12

wt-%) used,” Shaw continues. “From

the fleet perspective, there is significant

value in engine oils, which can be used

in both diesel and gasoline engines as

many fleets have both. Modern addi-
tive and formulating technology allows

the formulating of heavy duty engine oils

at the 0.08 wt-% phosphorous level

without sacrificing engine wear and

oxidation stability. While there is the

possibility that PC-11 oils containing

both 0.12 wt-% and 0.08 wt-% will co-
exist in the market, many believe the

added value of universal oils will shift

the market towards PC-11 oils, making

both a diesel and gasoline claim. This

will be especially beneficial to owners

with mixed fleets.”

**WHAT DOES THE FUTURE HOLD?**

The EPA set the stage back in 2011

with their CO₂ emission targets and it

has been up to the industry to find

ways to meet those goals. Emission reg-

ulations benefit the environment and

the industry. The cost of diesel fuel ac-

counts for 40 percent of the total cost of

operating over-the-road Class 8 trucks

in North America. It is economically

beneficial for truck fleets to find ways
to cut back on their fuel consumption.

Fuel savings from lower viscosity oils

is just one small piece of the fuel effi-
ciency puzzle (see Figure 3). Compared
to SAE 15W-40 Class 8 trucks, using

an SAE 10W-30 oil could realize a 1 percent fuel economy saving. The same
Heavy duty engines are well below show that emissions from modern research council released their ACES on Dec. 4, 2013, the coordinating council was successful in curbing emissions. Gains, but the end result is still an operational cost savings.

The increased cost of these lighter viscosity oils compared to SAE 15W-40 will offset some of these gains, but the end result is still an operational cost savings.

PC-11 fuel economy savings will improve as the industry has already been successful in curbing emissions. On Dec. 4, 2013, the coordinating research council released their ACES (Advanced Collaborative Emissions Study) Phase 2 Report. The results show that emissions from modern heavy duty engines are well below the required levels. Emissions of NO₂, which contribute to ozone smog, were 61 percent below the 2010 EPA standard and 99 percent lower than 2004 engines. Emissions of fine particles were also 92 percent lower than the 2010 standard and 99 percent lower than 2004 emissions. Further results show that carbon monoxide was 97 percent and hydrocarbons 99.9 percent lower than 2010 required levels.

**CONCLUSION**

PC-11 will create major shockwaves to the diesel engine oil market. For the first time, the industry will deal with an oil grade that isn’t backward compatible. It will take hard work from formulators, base oil and engine manufacturers to come up with oils that result in fuel economy savings without compromising engine durability. The market will have to work on the challenges of inventory control and preventing_misapplication of the engine oils. Educating the industry will be extremely important in the success of PC-11.

The market has already begun its transition to lighter viscosity oils. Many engine manufacturers such as Caterpillar, John Deere, Volvo and Cummins already factory fill with SAE 10W-30 diesel engine oils. Many more allow the use of 10W-30 and 5W-30 oils. It is expected that as more of these engines enter the marketplace, the shift in demand will drift away from SAE 15W-40 oils and be replaced primarily by SAE 10W-30 oils and on a smaller scale by SAE 5W-30 oils.

Testing has already been done using PC-11 technology. For example, Infineum tested a 2.1 cP BHTS lubricant with new additive technology in a high soot producing 2007 Cummins ISX 450HP engine and found that there were no significant differences in the performance of these low viscosity oils compared to SAE 15W-40 in terms of oil consumption, used wear metals and parts measurement. Furthermore, Infineum has reported that an SAE 5W-30 diesel engine oil formulation with new additive technology has successfully completed 1,000,000 miles in a Cummins ISX 450 fleet.

Results like these will give OEMs and end-users confidence that these low viscosity oils can provide fuel economy savings without compromising engine durability. The question is how long will it take for the market to accept these oils? The automotive market has already been exposed to low viscosity oils like SAE 0W-20 and the new SAE 0W-16 and has seen the majority of the market shift from grades like SAE 10W-30 to SAE 5W-30 and SAE 5W-20. There has even been some testing on 0W-10 passenger car oils.

How low will HDDEO go in terms of viscosity? Will the market ever see a 5W-20 diesel engine oil? Shaw says, “The industry will need to first adjust to the current shift to low HTHS 5W-30 oils with PC-11. However, with the continuing pressure to find ways to better improve fuel economy through hardware and lubricant technology,
even lower viscosity oils could be in store for the future.”

The question that formulators will face in the future will be how low an HDDEO’s viscosity can be before they pass the point of diminishing returns. The first step to this answer will be determined by how well low-viscosity engine oils are accepted and how they perform in the field after PC-11 is implemented.

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**REFERENCES**