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HDEO – More or Less Phosphorus?

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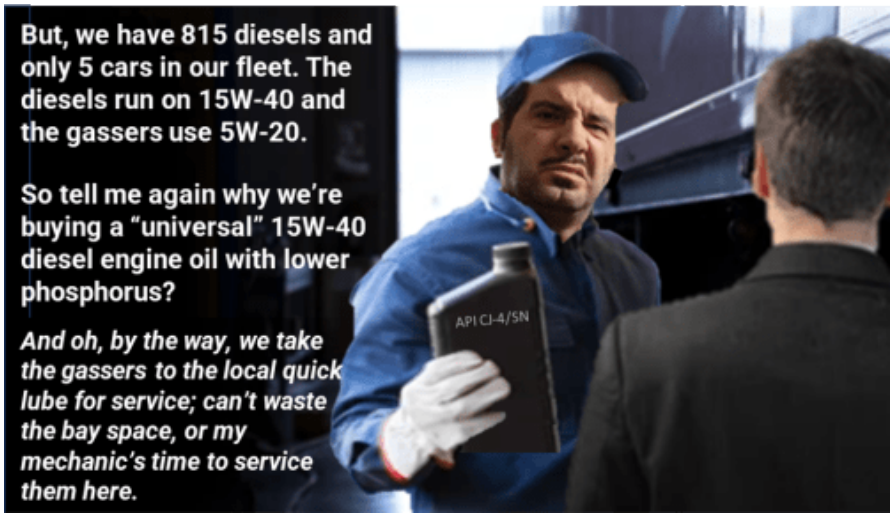
Considering the diversity of makes, models, the age of equipment in operation, and the alphabet soup of performance specifications and OEM approvals, there is little wonder why it can be confusing for buyers of engine oil to know what's right for their vehicles. A case in point, and the subject of this article, is Heavy Duty Engine Oil (HDEO).



Although it's fairly well known in the industry that API CK-4 and FA-4 are the most recent specifications for HDEO, marketers are asking questions about lower phosphorus levels seen in some CK-4 products. And the reason they are is because some say they are seeing invitation for bids that specify the HDEO must be an SAE 15W-40, API CK-4 approved product with less than or equal to 800 parts per million (ppm) phosphorus. This is despite that fact that CK-4 specifies less than or equal to 0.12% (1,200 ppm) phosphorus. While it's understood that lowering the phosphorus levels was necessary to prolong the life of catalytic converters in gas-fired automobiles, some marketers are scratching their heads trying to understand why a fleet comprising predominately heavy-duty diesels would specify a lower phosphorus oil and why they are including chemical limits for phosphorus, calcium and others in RFPs for HDEO. And even if the answer is because the customer also operates gas powered vehicles and want a one-barrel solution, are such fleets well served by using an HDEO with lower levels of phosphorus and calcium?

To help answer this question, starts with a general understanding about the HDEO and PCMO specifications and how they have changed.

Prior to API CJ-4 (2006-2007), HDEOs had no restrictions on sulfated ash (SASH), sulfur, or phosphorus. High total base number (TBN) oils were common, Zinc levels were typically 1,200 ppm or higher, and both API Group I and II base stocks were used to formulate HDEOs.

This changed, however, when chemical limits were included in the CJ-4 Service Category. The CJ-4 category (licensing started in 2006), limited SASH to a maximum of 1.0%, sulfur to 4,000 ppm, and phosphorus to a maximum of 1,200 ppm. This all but eliminated Group I base stock from use in HDEO and impacted the types and levels of additive chemistries that can be used. In addition, it indirectly restricted TBN. These limits remained unchanged when the API approved two new diesel engine oil standards in 2016; API Service Categories CK-4 and FA-4.

Importantly, the most common and field proven anti-wear additive, Zinc dialkyldithiophosphate (ZDDP), contains zinc, sulfur, and phosphorus. So, by limiting phosphorus, upper limits were effectively placed on the level of ZDDP that can be used in HDEO. And while there is no minimum for phosphorus in HDEO, a de facto floor exists since the oil must pass the Cummins ISB, ISM, the MACK T-12, and GM roller follower wear tests.

Detergent additives were also affected by the chemical limits in CJ-4. This is because calcium and magnesium sulfonate, the workhorse detergent additives in HDEO, both contribute to SASH. Similar to how low speed pre-ignition (LSPI) was addressed in PCMO, SASH in HDEO was reduced by rebalancing the ratio of calcium and magnesium in the detergent in favor of more magnesium and less calcium. In addition to reducing SASH, the rebalancing resulted in increasing active TBN since the magnesium contributes more TBN than calcium.

In addition to the changes seen in CJ-4, the European Automobile Manufacturers' Association (ACEA) specification (ACEA E-6) was also developed to improve diesel emissions. But, while this specification ratcheted phosphorus down to a maximum of 800 ppm, it was not required or applicable to North America and only impacts newer diesel engines in Europe. It's important to note that EU consumers are reportedly far less concerned about having a one size fits all lubricant and will use older quality products for older engines and oils formulated for passenger cars for light duty applications.

Heavy Duty Engine Oil (API "C" Service Category)

Year	API Service Category	Phosphorus	Sulfated Ash	Sulfur
Current and older engines	API CK-4 and FA-4	1200 ppm max	1.0% max	0.4% max
For 2016 and older engines	API CJ-4	1200 ppm max	1.0% max	0.4% max
For 2006 and older engines	API CI-4 Plus	-	-	-
For 2002 and older engines	API CI-4	-	-	-
For 2002 and older engines	API CH-4	-	-	-

Note: For all viscosity grades: If API CH-4, CI-4 and/or CJ-4 categories precede the "S" category and there is no API Certification Mark, the "S" category limits for phosphorus, sulfur, and the TEOST MHT do not apply. However, the CJ-4 limits for phosphorus and sulfur do apply for CJ-4 oils, and the limit in the SP-RC column for phosphorus (0.08% mass max) applies when CK-4 with SP or FA-4 with SP is claimed. Note that these "C" category oils have been formulated primarily for diesel engines and may not provide all of the performance requirements consistent with vehicle manufacturers' recommendations for gasoline-fueled engines.

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That helps explain why some RFQs might include chemical limits for HDEO, but not necessarily why one would specify phosphorus levels below 800 ppm when the CK-4 specification limits phosphorus to a maximum of 1,200 PPM, and is silent on a minimum. To address this incongruity moves the discussion to HDEOs that carry both the API "C" and "S" Service Categories.

As with HDEO, phosphorus is also present in passenger car motor oil (PCMO) as an element in the workhorse anti-wear additive (ZDDP). But, while ZDDP is highly effective in reducing wear and has been used for decades in PCMO, it was found that the phosphorus present in the additive can poison catalytic converters and contribute to carbon buildup in engine bores and valvetrains in spark-ignited engines. For these reasons, starting with API SJ in 1996, the level of phosphorus in PCMO was reduced. The SJ classification limited the phosphorus content of PCMO to below 0.1%, (1,000 ppm), down from what was common seen in the range of 1,200 to 1,300 ppm. Phosphorus levels were further reduced to a maximum of 800 ppm with the introduction of API SM in 2004. Understanding that ZDDP remained an important AW additive, the API SP specification also placed a minimum of 600 ppm on phosphorus to ensure low temperature wear protection since the Sequence VE test became obsolete, and a replacement test for that parameter was not established.

Automotive gasoline engines (API "S" Service Category)

Year	API Service Category	Phosphorus	Sulfated Ash	Sulfur
Current and older engines	API SP-RC/ILSAC GF-6A	600 to 800 ppm	-	[c]
For 2020 and older engines	API SN Plus-RC/SN-RC/ILSAC GF-5 Categories	600 to 800 ppm [a]	-	[c]
For 2010 and older engines	API SM	600 to 800 ppm [a]	-	[d]
For 2004 and older engines	API SL	1000 ppm max [b]	-	-
For 2001 and older engines	API SJ	1000 ppm max [b]	-	-

[a] No minimum for API SP or SN Non-ILSAC Viscosity grades

[b] Not required for non ILSAC viscosity grades. There is an implied minimum of 600 ppm phosphorus because the sequence VE engine test is no longer available. The reason it is implied for API SM and later is to insure back serviceability.

[c] SAE 0W and 5W multigrades: 0.5% max, SAE 10W-30 and all other grades: 0.6% max, No maximum for API SP or SN Non-ILSAC viscosity grades.

[d] SAE 0W and 5W multigrades: 0.5% max, SAE 10W-30 and all other grades: 0.7% max, No maximum for API SP or SN Non-ILSAC viscosity grades.

Note:
ILSAC Viscosity grades: 0W-20, 0W-30, 0W-16, 5W-20, 5W-30, and 10W-30
Non ILSAC Viscosity grades: All other viscosity grades

Since the specification for phosphorus in PCMO is 600 to 800 ppm, the phosphorus levels in an HDEO claiming to meet both current "C" and "S" service Categories must also be in the range of 600 to 800 ppm. There is, however, an exception.

For most HDEO quality levels through API CJ-4, the specifications allowed marketers to include PCMO API "S" claims (i.e., as API SL, SM or SN) on diesel engine oil even though the oil did not meet PCMO restrictions on phosphorus, provided it passed the engine tests required for the claimed PCMO service category, and the API heavy duty claim came first (i.e., API CJ-4/SN). These diesel oils were marketed as "universal," or dual spec oils. But this changed with API CK-4 and FA-4. For more about this, JobbersWorld turned to Steve Haffner, President of SGH Consulting.

Haffner says it's important to understand that, "While some 15W-40 HDEOs are marketed as "Universal," the vast majority of light-duty gasoline engine OEMs specify lower viscosity oil (0W-20, 5W-20, 5W-30), not 15W-40. The lighter viscosity grades provide improved fuel economy which enables the oils to meet the standards for API Resource Conserving and ILSAC performance claims. In addition, these oils have the lower phosphorus levels necessary to protect the catalyst systems of the light duty gasoline engines."

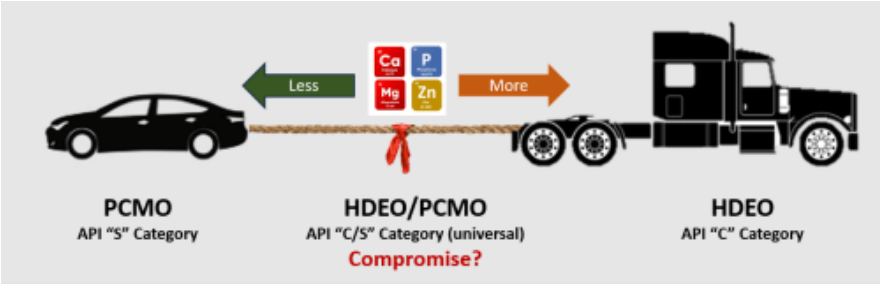
Adding to this, Haffner noted that “The API CK-4 Service Category (2016/17 introduction) restricted phosphorus levels for overlapping viscosity grades that could be specified for both diesel and gasoline engines, primarily SAE 5W-30 and 10W-30. The restriction, however, does not apply to SAE 15W-40 and heavier grades. SAE 0W-20 and 5W-20 are not allowed for diesel engine oils today. This led to some blenders to enter HDEOs into the market when CK-4 was introduced that have lower phosphorus levels (600 to 800 ppm). It was believed that such products would gain traction among buyers looking for an API CK-4 HDEO that meets both “C” and “S” specifications, as well as ACEA E-6. Many marketers in the US, however, dropped the passenger car claim for SAE 10W-30 diesel oil, and few showed interest in making the ACEA claim. As it turned out, few end users likewise expressed interest in such universal claims. Instead, for the most part, they made buying decisions based on brand loyalty and price. The appeal of universal HDEOs was also dismissed by a notable number of on-road fleet operators who felt it was best to stick closer to what they knew worked (higher phosphorus), and had years of field proven performance. And for the most part, universal/lower phosphorus HDEOs proved to be a non-starter for many off-road applications.”

So, what does this mean when choosing a PCMO?

Haffner says, “It means is that if you want the right oil for your vehicles, start by reading the owner’s manual. Heavy duty oils should not be used in your gas engines. So having an “S” claim on an HDEO does not offer any real benefits to an end user servicing gas fired engines. And market research work showed that few end users cared about, or used diesel lubricants in their light duty vehicles, and the ACEA E-6 claim did not drive sales in North America.”

With that said, JobbersWorld had to ask Haffner the question we get.

Does a universal (API C/S) HDEO with a phosphorus level meeting the 600 to 800 ppm range for the API “S” Service Category provide the same level of wear protection as a HDEO meeting only the CK-4 Service Category?



While Haffner says he is not aware of any public data that answers this question, he notes “The latest hardware is designed to operate on lower phosphorus oils, and you can take some comfort in knowing that there has not been reports of widespread issues with its use. But technical sources note that while lower ZDDP performance can still pass today’s engine tests, they do not appear to deliver better performance than higher ZDDP oils. Further, since back serviceability is critical, it’s important to consider how these oils perform in older engines.”

According to Haffner, “We also know that most engines operate at higher CK-4 viscosities (10W-30 and 15W-40) than the lower viscosity FA-4 products where use and history are limited. What we can say is that as viscosity goes down, wear protection may become more challenging, although low temperature start-up protection might be better as significant wear can occur at start-up in very cold climates at higher viscosity until the oil flows.”

All considered, Haffner points out that as ZDDP levels decline in HDEO, it would be tough to prove that wear protection is not impacted, especially in older engines. According to Haffner, “While there is a history of proven field performance for API CK-4 type performance with phosphorus in the range of 800-1,200 ppm in on road applications, there is less history for off-road equipment. For on road, it should also be noted that older engines have significant mileage and are out of warranty, so any impact of lower ZDDP would be hard to determine, but again, I have heard of no issues. This is especially the case for older off-road equipment where it does not appear there is significant use of 800 phosphorus oil.” Haffner adds, “Caution should be taken when considering universal engine oils in light duty applications calling for the latest ILSAC quality oils. Universal oils may be convenient, but they also make compromises in performance and for light duty this may sacrifice fuel efficiency or emission system protection. One should note, that ZDDP is also a powerful anti-oxidant, so reducing it, generally adds to the cost of the additive as it is replaced with more expensive ashless anti-oxidant.”

Haffner says, “The best advice is to follow your owner’s manual and use the oil specified. Where possible, oil analysis can show if the engine is protected, and oil analysis is highly recommended to ensure the health of your vehicle, especially when drains are being extended. Nothing beats field proven performance via oil analysis and engine tear downs over the life of any engine, but this takes a long time, is expensive and consumes a lot of resources and both people, and dollars are not abundantly available.”

So, is it necessarily a compromise to specify a CK-4 with less than 800 ppm of phosphorus in order to have a single barrel solution to service a fleet of both diesel and gas engines?

“While it could be a compromise that results in a less than desirable outcome, the answer resides in a careful analysis of fleet specific variables. These include the number of new and old engines, diesel and gas powered, and makes and models in the fleet, as well as the OEM’s oil recommendations and warranties. In addition, it is also important to take into account the vocation and location of the equipment, oil drain intervals, predictive and preventative maintenance practice and other variables.

But as experience has unfortunately shown, rather than taking all these variables into account and making an informed decision that’s best for a given fleet, buyers sometimes take shortcuts. They write requirements into an invitation to bid simply because they saw the requirement on an invitation to bid from another company, or because that’s that way they did it the last time. And in some cases, specifications show up in invitations to bid because a salesperson talked it up and persuaded the buyer to include the specification in an RFQ.

Important here is that what might work well for one fleet, may not for another. Something to consider when writing an invitation to bid. Because if care is not taken, you will likely get what you ask for, and it may not turn out like you expected.” **— Thomas F. Glenn, JobbersWorld**

Future Perspective

Looking to the future, Haffner says PC-12 engine oils are expected to enter the market in early 2027, or sooner. These oils are projected to meet even lower Chemical limits (0.9% SASH, 800 ppm maximum phosphorus and 3,000 ppm Sulfur), as well as introduce lower viscosity engine oils (SAE 0W-20 and 5W-20). Back serviceability will only be allowed for higher viscosity oils, but not for the lower viscosity ones in diesel engines meeting API F”X-4”. Marketers are also likely to add universal gasoline protection “S” claims to the latter.

But as history has shown, Haffner says, “The market will ultimately decide which are the best oils to use. But with PC-12, it’s unlikely that the market will have the same options they have today with regards to phosphorus for on or off-road use.”

About Steve Haffner

Steve Haffner has 47 years of experience in the petroleum industry which includes over 30 years specific to the lubricants business, with Exxon Chemical Paramins, Infineum, and SGH Consulting since his retirement from Infineum in 2017. Haffner’s experience includes formulation of Heavy Duty and Passenger Car Engine oils, product, and marketing management in North America and globally for engine oils and additive components. Prior to his work in lubricants, Haffner spent over 15 years working in manufacturing for Exxon Chemical Company. Haffner holds a BSME and MBA degrees.

About Thomas F. Glenn

Thomas Glenn is President of Petroleum Trends International, Inc. (PTI). Founded by Glenn in 1999, PTI is an independent consulting firm specializing in market research and consulting in the lubricants space. Glenn also serves as the President of the Petroleum Quality Institute of America (PQIA). Glenn’s 45 years in the lubricants business include 10 years with Kline & Company in key consulting and management positions, and in sales at Texaco Lubricants Company. He started his career in the late 70’s as an analyst and Laboratory Manager at one of the world’s leading used oil testing laboratories. During that time Glenn developed a strong technical background in oil analysis and predictive and preventive maintenance practices, and in working directly with end users of automotive and industrial lubricants.

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