Shell Lubricants

PREPARING FOR PC-11
WHAT THE NEW CATEGORY MEANS FOR YOU AND YOUR HEAVY-DUTY ENGINES

Technical brochure, June 2015
Shell is playing a leading role in this process and has been developing and testing the next generation of low-viscosity oils that will meet the new specifications without compromising oil life or wear protection. This technical brochure explores the drive behind the new categories and what they mean for you and your heavy-duty engines.
ENABLING CHANGE FOR MODERN ENGINES

Selecting the right oil will be critical for heavy-duty-vehicle owners in 2017. For the first time, there will be two new categories of heavy-duty engine oil specification: both categories will reflect improved engine performance and one category is specifically intended to deliver fuel economy benefits for modern diesel engine technology.

The API is completely redesigning heavy-duty engine oil specifications. Shell has a leading role in the new category development and, through more than 20 million miles of real-world testing, has demonstrated the performance of its next-generation, low-viscosity oil formulation technology.

EVOLUTION TO REVOLUTION

Heavy-duty diesel engine designs have evolved substantially over the last 40 years. This evolution has been driven by emission legislation and customers’ requirements for efficiency and reliability. There has been significant progress. For example, high-pressure, common-rail injection systems are now widely used to improve combustion efficiency; advances in turbocharger technology have increased specific power output; and exhaust gas recirculation and aftertreatment devices, such as diesel particulate filters and selective catalytic reduction, have curbed harmful emissions of oxides of nitrogen and particulate matter (i.e., soot).

Despite this progress, there is a long way to go. Recent regulations, coupled with customers’ desires to reduce the total cost of ownership, are making fuel economy the most critical driver for engine manufacturers. Advanced technologies and materials, and new operating conditions such as higher internal temperatures continue to improve engine efficiency.

But oil and engine technology go hand in hand. Engine changes place more stress on the oil, which has to lubricate, cool, clean and protect over extended oil-drain intervals. The vehicle industry is starting to recognize that oil can help to achieve an engine’s full potential for fuel economy without compromising hardware durability. As engine manufacturers create cleaner, more fuel-efficient diesel engines, they will need a new generation of higher-performing diesel engine oils to protect them.

DEFINING THE CATEGORY

Nearly a decade has passed since the last API diesel engine oil category for North America was developed. During this time, engines have changed considerably and have improved fuel consumption and increased power outputs. New EPA and NHTSA emission legislation scheduled for diesel-powered commercial transport vehicles in 2017 requires significant improvements in fuel consumption that will help to reduce carbon dioxide emissions.

These fuel consumption improvements depend on vehicle class, type and size, and include specific improvements for medium- and heavy-duty engines. This has created the need for a new category of lubricant specifications, collectively called Proposed Category 11 (PC-11). These oils, due for licensing in late 2016, will eventually replace the current CJ-4 category.

The API will introduce two types of heavy-duty diesel oil as part of PC-11:

- PC-11A (CK-4) oils will replace today’s CK-4 oils and will be completely backwards compatible with all current vehicles. They will be designed with improved oxidation resistance, shear stability and aeration control.
- PC-11B (FA-4) oils will meet these new requirements and include lower viscosity grades designed for next-generation diesel engines to help maximize fuel economy without sacrificing engine protection. These oils will have limited backwards compatibility because some older engines were not designed to operate with lower viscosity grades.

These new engine oil requirements, especially for PC-11B, are a major change in the industry’s approach to heavy-duty oil specifications. However, the chemical limits used in CJ-4 oils will remain in place for PC-11 oils.

Oil producers will therefore need expertise in formulating oils for the required performance and ensuring that they continue to deliver excellent wear protection and cleanliness—two factors that help to drive down customers’ maintenance costs and prolong engine life.

WHAT IS PC-11?

PC-11A: A VERSUS B

PC-11A oils will have improved oxidation resistance, shear stability and aeration control, and similar viscosity grades to current API CJ-4 products. They are designed to replace oils for current technologies and will have a minimum high-temperature, high-shear (HTHS) viscosity of 3.5 cP.

PC-11B oils will have all the benefits of the PC-11A formulations, but will be formulated to have a lower HTHS viscosity (2.9–3.2 cP), which is known to provide a fuel economy benefit compared with oils having higher HTHS viscosities. As lower-viscosity oils form thinner films, designing products for wear protection will be critical for oil formulators.

“The current CJ-4 standard has lasted well beyond the life of the typical engine category. Some of the engine tests required to qualify an oil are no longer available or no longer relevant to next-generation engines.”

Dan Arcy, Chair, New Category Development Team, API, and Global OEM Technical Manager, Shell Lubricants
NEW AND UPDATED TESTS
A major part of designing an oil specification is defining a set of rigorous tests that each oil formulation must pass before it goes on sale. PC-11 specifications will continue to use many of the current tests, but some of these tests, such as shear stability, will have more stringent limits to reflect the needs of future engine hardware. Two new tests will be introduced to ensure that next-generation oils can cope with the oxidation stability and aeration control needs of modern technology.

MODIFIED LIMITS FOR OIL SHEAR STABILITY
Shear stability is a measure of an oil's ability to resist being sheared (mechanically degraded) under severe stress (Figure 1). Shearing the polymer used in multigrade oils into smaller parts can reduce oil viscosity, which may result in failure to protect vital engine parts.

PC-11 oils will have to meet more stringent shear stability limits.

AERATION CONTROL FOR MODERN TECHNOLOGY
Aeration is the inclusion of tiny air bubbles, or foam, in the oil, which can impede its ability to cool and protect an engine (Figure 2). The higher operating temperatures, pressures, and oil flow in modern engines can increase the amount of air entrained in lubricants. Oils are also used more frequently as hydraulic fluids for valve-train actuation, a task that may be compromised by aerated oil. Consequently, it is increasingly important for oils to have excellent aeration control.

PC-11 oils will have to pass a new Caterpillar engine oil aeration test.

IMPROVED OXIDATION STABILITY TO PROTECT HOTTER ENGINES
Oxidation is the reaction of oil molecules with oxygen. It can cause oil to degrade, thereby decreasing its life and causing potentially damaging sludge and varnish, viscosity increase and corrosive wear.

Next-generation engines are designed to operate at higher temperatures, which can greatly accelerate oxidation rates.

Selecting the right base oils and antioxidant additives can disrupt oxidation reactions and prevent the formation of harmful byproducts (Figure 3).

PC-11 oils will have to pass a new oxidation stability test.

ON- AND OFF-HIGHWAY
On-highway diesel emission legislation generally leads off-highway emission requirements by several years. On-highway engines are used to develop engine tests because they are typically more advanced and use less fuel than off-highway engines. However, API licensed oils are used for on- and off-highway applications, and PC-11 oils will be valid for transport, agriculture, construction, mining and even diesel pickup applications. Engine manufacturers will determine whether off-highway applications will use PC-11B oils.
VISCOSITY AND FUEL ECONOMY

PC-11B oils will have lower viscosities for enhanced fuel economy. Even small increases in fuel economy can result in significant reductions in fuel consumption and carbon dioxide emissions. For example, every US truck increasing its fuel economy by just 1% would see an annual reduction of over 4 million tons of carbon dioxide emissions, which is equivalent to removing 23,000 trucks from the road. This would save fleet and owner operators combined an estimated $3 million a day.

Lower-viscosity oils pump more easily and help to reduce engine friction, which can improve fuel economy. However, there are different types of viscosity measurements that contribute to an engine oil’s viscosity grade. Critically, it is the HTHS viscosity (defined as an oil’s resistance to flow under high stress conditions at operating temperatures) that will distinguish backwards compatible PC-11A oils from the fuel-economy PC-11B oils for modern engines.

WHAT IS HTHS VISCOSITY?

Society of Automotive Engineers (SAE) oil viscosity grades are defined by four different tests (Figure 4). Low-temperature pumping and cranking viscosities define the wintertime grade (for example, the 15 in 15W-40). HTHS dynamic viscosity contributes to the SAE viscosity grade definition (for example, the 40 in 15W-40). Low shear-rate kinematic viscosity (KV100) contributes to the definition of both the winter and high-temperature viscosity grades.

Switching to a lower viscosity grade SAE oil, for example, from a 10W-40 to 10W-30 oil, will provide modest fuel economy benefits. Even within a viscosity grade, differences in HTHS viscosity could affect fuel economy. The minimum HTHS viscosity for current XXW-30 CJ-4 and future PC-11A oils is 3.5 cP.

PC-11B XXW-30 oils will have HTHS viscosities between 2.9 and 3.2 cP, which will help to enhance fuel efficiency further. Oil companies and engine manufacturers are currently testing these products, which are designed to provide fuel economy without sacrificing engine protection, in a range of applications.

To measure the effect of lubricant viscosity on fuel economy, Shell has used a proprietary in-house driveline test rig. The experiments have shown that fuel economy benefits vary with engine speed and load, and, therefore, driving conditions. For example, for a specific heavy-duty engine, switching from a 15W-40 CJ-4 oil with a 3.9 cP HTHS viscosity to a 10W-30 oil with a PC-11B (2.9 cP) HTHS viscosity provides a fuel economy improvement of about 1% in high-speed, high-load driving conditions and up to 4% at low-speed, low-load driving conditions (Figure 5). Manufacturers are also using this information to design modern engines, for example, downsizing the engine to improve fuel economy.

FIGURE 5: The fuel economy benefit of a 10W-30 oil with a PC-11B (2.9 cP) HTHS viscosity compared with a 15W-40 CJ-4 oil with a 3.9 cP HTHS viscosity in a heavy-duty diesel engine, as measured using a Shell proprietary driveline test rig.

FIGURE 4: Viscosity grade tests.

1. Resistance to pumping in cold conditions: determines an oil’s ability to circulate through the engine
2. Oil viscosity in crankshaft bearings during cold start up: determines performance of oils at low temperature
3. Internal resistance to flow: Minimum value sets the SAE winter grade; the range determines the SAE viscosity grade
4. Resistance to flow between narrow moving parts; mimics crankshaft and connecting rod bearing lubrication. The SAE viscosity grade specifies a minimum HTHS viscosity value.

*EIA – US Energy Information Administration – 2012 On-highway fuel sales. Calculation based on 1% of 36.34 billion gallons of fuel consumed annually at $3.00/gallon.
DEVELOPING A NEW ENGINE OIL SPECIFICATION

THE ROAD MAP TO PC-11

The road to a new engine oil category is long and complex. A three-phase process is defined in API 1509 for the development of the new category.

In Phase 1, the New Category Evaluation Team (NCET) is formed, which consists of manufacturers (EMA), oil marketers (API) and additive companies (ACC, American Chemistry Council). The focus of the NCET, through a consensus process, is to review the request and evaluate the need for a new specification.

Phase 2 consists of the formation of a category development team (NCDT) to oversee the specification and test method development, and to agree any additional guidelines (Figure 6). The NCDT is structured with four functional work groups that report to the NCDT. Each of the four groups, consisting of API, ASTM, ACC and EMA, have specific responsibilities. In addition, ad hoc work groups from SAE and engine test laboratories are asked to participate. The NCDT works through a consensus process to develop the category.

Once the category and the tests are defined, the first license for PC-11 will be issued. This is currently scheduled for late 2016.

Shell is playing a leading role in the development of the new engine oil category: Dan Arcy, NCDT Chair, is a member of the Shell heavy-duty engine oil team.

Phase 3 of the development is the category implementation.

SHELL

Dan Arcy elected NCDT chair
Shell initiates field testing of low HTHS viscosity oils to evaluate durability
Shell conducts and publishes first teardown of PC-11 oils
Shell completes an extensive component screening program involving more than 20 engine tests

If all US trucks increased their fuel economy by 1%, fleet and owner operators would save an estimated $3 million a day and reduce carbon dioxide emissions by over 4 million tons/yr, which is equivalent to removing 23,000 trucks from the road.

GENERAL

2011
NHTSA and EPA agree new regulations for medium and heavy-duty engines
NCET proposes new oil category to API lubricants committee

2012
NCDT begins to oversee development of new test methods for PC-11 oils

2013
Shell begins an extensive laboratory and engine test additives screening program to deliver a high standard of performance for PC-11 oils

2014
PC-11 final specifications issued

2015
PC-11A (CK-4) and PC-11B (FA-4) oils licensed

2016
New greenhouse gas legislation comes into effect

2017
New engine technology launched

API
language
licensing
Base oil interchange (BOI) and viscosity grade read across (VGRA) guidelines

EMA
Proposes tests
Provides hardware
Reference oils
Category targets

NEW CATEGORY DEVELOPMENT TEAM (NCDT)

API, ACC, EMA and liaison members (EMA, SAE, ASTM) manage development of new category by a consensus process

ASTM
Co-ordinates test development
Establishes performance limits

ACC
Template guideline
Code of practice

FIGURE 6: Structure of the NCDT

FIGURE 7: Road map of the development of PC-11
LABORATORY TO ROAD: MAKING PC-11 A REALITY

In addition to helping to lead the PC-11 category development, the Shell heavy-duty engine oil team has already been creating new oils targeted to meet the PC-11 specifications. The main challenges are to satisfy the stringent new performance requirements and to ensure that engine cleanliness and wear protection are maintained in future engine hardware. All this must be achieved within strict chemical limits for exhaust aftertreatment compatibility.

For PC-11A oils, optimizing the oil composition for antioxidant and viscosity modifier chemistry combinations that will meet shear stability requirements is critical for success. An additional challenge for the low-viscosity PC-11B oils is to balance these requirements with the right anti-wear components for wear protection with thinner oil films.

The Shell team has many decades of experience of developing high-quality products that have been tested and fielded in the laboratory. By the time PC-11 is introduced, Shell will have invested millions of dollars in testing and development. To date, the team has performed more than 9,000 tests using proprietary test rigs and external engine test rigs in collaboration with engine manufacturers in order to understand the PC-11 formulation requirements.

Lubricants are complex mixtures of base oils and additives, and getting the balance of components requires significant expertise and extensive screening in the laboratory and on the road. Shell scientists have designed and screened prototype oils to optimize additive chemistry in combination with high-quality base oils (Figure 9). They recognize that selecting the right additive chemistry is about finding the right component combinations that will help next-generation Shell Rotella engine oils to meet and exceed the demanding targets of the PC-11 category.

WEAR PERFORMANCE OF PROTOTYPE CHEMISTRIES

<table>
<thead>
<tr>
<th>PC-11 Limit</th>
<th>Legacy product</th>
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<tbody>
<tr>
<td>Chemistry A</td>
<td>Chemistry B+C</td>
</tr>
<tr>
<td>Chemistry B</td>
<td>Chemistry B+D</td>
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<tr>
<td>Chemistry C</td>
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<td>Chemistry D</td>
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<td>Chemistry B</td>
<td>Chemistry A</td>
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▲ BETTER PERFORMANCE

FIGURE 9: PC-11 engine screening tests show that combinations of prototype anti-wear additives could exceed PC-11 requirements and the performance standard of a legacy product.

It is not enough to evaluate prototype oils in the laboratory: the real test is how they work in on- and off-road vehicles in the real world. Field trials are an integral part of the Shell engine oil technology development process. They are extensive programs run in collaboration with customers and require scientific rigor, experience and expertise.

Shell performs millions of miles of real-world testing with customers (Figure 12). Between 2006 and 2014, Shell provided more than 60,000 gallons of lubricants for use in customer field tests. A special focus has been placed on a subset of more than 37 engines, which have been thoroughly inspected. These engines received additional attention and were part of a teardown program to inspect parts following significant mileage accumulation.

A heavy-duty vehicle on the road is expected to meet a million miles of life without engine failure. Although some wear is normal, higher levels can indicate durability issues.

During each trial, samples of oil during service are analyzed to evaluate the oil’s wear protection and viscosity performance. Used oil analysis can also provide information, for example, about coolant leaks, which can be used for preventive maintenance.

PC-11B oils have lower viscosities, and therefore form thinner oil films, than any products currently on the market, so ensuring that they provide good wear protection is critical. Shell has assessed the wear protection performance of low-viscosity oils in the field for several years and demonstrated that low HTHS viscosity oils can deliver effective wear protection and long oil life. By the beginning of 2015, Shell had performed more than 20 million miles of testing on low HTHS viscosity oils. An additional 10–15 million miles of testing will occur during 2015. The field trials cover all the major manufacturer’s on-highway engines and in different vehicles with diverse duty cycles. Positive wear protection results have been recorded.

In addition to used oil analysis during field trials, Shell engineers teardown field trial engines, sometimes in collaboration with manufacturers and customers, to inspect and quantitatively rate engine component wear and thus evaluate the oil’s ability to protect critical hardware. For trucks running on low HTHS viscosity oils, 13 engine teardowns have been performed, including one in front of the media.

GOING THE DISTANCE: 20 MILLION MILES AND COUNTING

FIGURE 12: Shell real-world testing with customers.
PC-11B VERSUS CURRENT TECHNOLOGY: A HALF-MILLION-MILE EXAMPLE

As part of the extensive field program, a fleet of vehicles with 2011 Detroit DD15 engines was tested over multiple oil-drain intervals and more than 500,000 miles to compare current 15W-40 and 10W-30 CJ-4 oils with a prototype (PC-11B) low HTHS viscosity 10W-30 oil. In addition, in June 2015, a Detroit DD15 engine running a low HTHS oil with more than 800,000 miles was inspected and compared with a similar engine running a 15W-40 viscosity oil.

Used engine oil analysis showed that the low HTHS viscosity oil compared with the current oil offers:

- the same wear performance (Figure 13)
- similar aging characteristics (Figure 14)
- no discernible difference in wear performance (Figure 15)

Engine teardowns show:

- no discernible difference in wear performance (Figure 15)

Currently, Shell is working on the PC-11B formulation and making sure that the product not only meets but also exceeds the PC-11B specification, which has built in fuel economy wins.

“...in more than 20 million miles of real-world field testing, we are seeing promising performance and durability for low-viscosity PC-11B oils. Customers using Shell Rotella T products can be assured that we are committed to delivering next-generation engine oils that will provide the opportunity to reduce fuel consumption without compromising the products’ excellent wear protection.”

Matt Urbanak, Team Leader for Heavy Duty Engine Oil Development, Shell Lubricants.
BEYOND PC-11: LOOKING TO THE FUTURE

There is a worldwide need to improve heavy-duty engine fuel efficiency. The introduction of PC-11 to the North American market in 2017 is another milestone on the road to greater efficiency. As global fuel economy targets and the associated penalties for failing to meet them become increasingly important for manufacturers, they will turn more and more to engine oil as a critical enabling technology. Getting this right requires out-of-the box thinking and long-term technical partnerships.

STUDYING SOOT

For example, Shell is sponsoring a PhD project at Imperial College London, UK, to further understanding of the mechanisms behind soot-induced engine wear using a range of state-of-art experimental techniques (Figure 16). Soot produced in diesel engines can promote wear, so it is critical to employ the correct lubricant chemistries to mitigate this issue. In addition, selecting the optimum dispersant system plays a significant role in keeping soot particles dispersed in the oil, so it is important to understand how dispersants interact with the anti-wear additives. This project enables Shell to test the newest low-viscosity fuel economy PC-11B oils in a cut Baghdidge vehicle and offers the potential to test oils with even lower viscosities. These experiments will provide the Shell team with valuable information as they work to create low-viscosity engine oils without sacrificing performance for PC-11 and beyond.

THE “STARSHIP” TRUCKING INITIATIVE

Shell is also working with AirFlow Truck Company to co-engineer a new hyper-fuel-mileage Class 8 tractor-trailer nicknamed the StarShip (Figure 17). The project aims to break current fuel efficiency records when the vehicle is launched in 2017 through advances in engine, vehicle and drivetrain technology. A Shell lubricants research and development team is working with others to co-engineer hardware and fluids. This project enables Shell to test the newest low-viscosity fuel economy PC-11B oils in a cut Baghdidge vehicle and offers the potential to test oils with even lower viscosities. These experiments will provide the Shell team with valuable information as they work to create low-viscosity engine oils without sacrificing performance for PC-11 and beyond.

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Bob Silva, President of AirFlow Truck Company

The drive for fuel efficiency comes from greenhouse gas emissions legislation and the ever-present need for successful businesses and customers to cut operating costs. Engine technology continues to evolve and engine manufacturers and regulators recognize that engine oil, along with developments in engine technology, will power the delivery of enhanced fuel efficiency.

A major milestone along the road to ever-greater fuel economy will be the launch of a new specification category currently known as PC-11, which will include a sub-category for low-viscosity, heavy-duty engine oils (PC-11B).

Shell has a leading role in the PC-11 development process. The new specifications set more stringent shear stability limits and new tests for aeration control and oxidation stability. In addition, the new specifications for PC-11B will set low HTHS viscosities for greater fuel efficiency.

A key concern for operators is whether low-viscosity oils can reduce fuel costs and carbon dioxide emissions while providing the long oil-drain intervals and reliable engine protection required to keep down the total cost of ownership.

Extensive laboratory screening has helped Shell to formulate promising PC-11B prototype oils efficiently. Millions of miles of road testing have since demonstrated that engine durability is not significantly compromised through using these low HTHS viscosity oils. Fuel economy demonstrations have come through specific test protocols using highly statistical test methodologies. These oils offer the potential for significant fuel savings while matching the oil life and wear protection performance of today’s leading commercially available oils.

From 2017, Shell Rotella customers will be able to take advantage of the fuel savings offered by PC-11B oils with the peace of mind that their engines are protected.

CONCLUSION: PC-11 WITH PEACE OF MIND

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