# Dealer Training Series

## Engine Lubrication

A Technical Introduction to Engine Lubrication | Presented by AMSOIL INC.

# Table of Contents

# Engine Lubrication: Section 1

This course has been designed as a technical introduction to engine lubrication for two- and four-stroke, gasoline and diesel engines. It is ideal for those who service or maintain mechanical equipment, and those who market AMSOIL lubricants. Topics covered in this course include oil formulation and additive content for various equipment designs and operating environments, as well as major industry standards and the influence operating conditions have on final product formulations.

## Objectives

After studying this course, you should understand and be able to explain the following terms and concepts:

1. Performance properties of base oil
2. Performance properties of additives
3. Implications of SAPS
4. Operating conditions that affect oil selection
5. Oil performance standards
6. SAE viscosity grades
7. Oil requirements for two- and four-stroke engines
8. Oil requirements by fuel type
9. Oil requirements of specialty applications

## Keywords

The following keywords are defined in this section. Pay particular attention to their explanations as these concepts will serve as building blocks for future lessons.

Ashless
Blow-by
Chemically Active
Chemically Inert
Corrosion
Lubricity
Nitration
Phosphorus
Pour Point Depressant
Rust
Sulfated Ash
Sulfur
Viscosity Modifier

## Introduction & History

The Engine Operation manual described the fundamental components of an engine and how they interact to produce power. Topics included the differences between gasoline and diesel engines, as well as two- and four-stroke engine operation.

The AMSOIL Engine Lubrication manual expands on those topics and covers the importance of engine lubrication and how it affects engine performance. Current engine oil specifications governed by the American Petroleum Institute (API) and the International Lubricant Standardization and Approval Committee (ILSAC) are also examined.

### The Evolution of Modern Engine Designs

Modern engines have undergone design changes meant to improve engine performance, increase fuel economy and help reduce emissions. Some of these design changes include direct injection systems, superchargers and advanced aftertreatment systems such as exhaust gas recirculation and diesel particulate filters.

These design changes have made the engine operating environment more severe than previous designs, and engine oil formulations have had to evolve in order to perform in the harsher conditions.

Large diesel vehicles for on-road operation have had to make significant changes to emissions handling in order to meet strict government limits imposed for model year (MY) 2007 heavy-duty diesel engines. The new emissions systems place further stress on oil and require formulations that can withstand the harsh conditions and remain compatible with emissions system components. New heavy-duty diesel trucks generate higher operating temperatures and increased levels of soot and acid, adding to the challenges faced by diesel oils.

## Engine Oil Performance Requirements

The basic functions of an engine oil include:

1. Reduce friction and wear by providing a barrier between moving parts
2. Cool engine components
3. Clean the engine by minimizing the effects of contamination (environmental or combustion by-products) and preventing them from settling on engine surfaces
4. Seal
5. Protect against rust and corrosion by preventing or inhibiting corrosive reactions
6. Dampen shock in critical components such as main engine bearings
7. Enhance fuel economy by improving oil lubricity and reducing friction
8. Provide emissions system compatibility
9. Improve life expectancy

## Engine Oil Formulation

Engine operating environments vary according to the engine's design. Two- and four-stroke engines, air- and water-cooled, diesel, gasoline and natural gas engines all have different operating characteristics because of varying designs and fuel sources.

Oils designed for specific applications are formulated for different levels of protection and their performance properties can range from general to specialized.

Many of the components inside the engine rely on engine oil for protection and to help reach, or even exceed, expected operating life. To properly protect equipment, engine oils must minimize wear, cool parts, resist oxidation and help prevent deposits and corrosion.

While a majority of the quick-lube industry would like motorists to believe engine performance relies on frequent (3,000-mile) oil changes, the truth is that engine oil does not automatically go bad once it's accumulated a certain number of miles. Rather, engine oil quality and its ability to protect and lubricate the engine depends on a number of performance properties that are engineered by the oil manufacturer.

## Base Stock

An engine oil's formulation begins with the base stock that provides a number of key performance properties required by the engine.

### Oxidative Stability

The base stock(s) of engine oil provides most of the finished oil's oxidation performance; higher quality base oils provide better oxidative stability. High-quality base oils contain saturated hydrocarbons, which are more resistant to chemical breakdown because there are less sites for oxygen molecules to attach. Oxidative stability slows the rate of oxidation in the presence of high temperatures and helps prolong the oil's life.

---

### AMSOIL Advantage

AMSOIL engine oils are inherently better at resisting oxidation and create less sludge and varnish because they are engineered with synthetic base oils. Synthetic oil molecules are fully saturated with hydrogen molecules, which helps prevent oxygen molecules from attaching and initiating the oxidation process. Synthetic base oils are also contaminant-free, which further improves their inherent antioxidant properties.

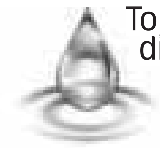
The increased stability of AMSOIL synthetic base oils helps antioxidant additives last longer and increases the oxidation stability of AMSOIL synthetic motor oils.

---

### Soot-Handling

Base stocks provide some soot-handling properties; the degree of viscosity increase due to soot contamination is largely due to the quality of base oil. Lower-quality base oils are susceptible to viscosity increase with less soot contamination, while higher-quality base oils can manage higher concentrations of soot contamination before experiencing a viscosity increase.

## AMSOIL Advantage



To reinforce the soot-handling properties of the base oil, AMSOIL diesel oils are formulated with a sophisticated soot-management additive package that nearly doubles API CJ-4 requirements.

Soot management is an important oil property because oil contaminated with soot can cause excessive friction and wear to engine surfaces.

The Mack T-12 test is designed to evaluate an oil's ability to minimize engine wear in EGR-fitted engines with soot-contaminated oil. The test provides an initial 100-hour interval to allow soot to accumulate in the oil. Another 250-hour interval allows the engine to operate at maximum torque to increase cylinder-liner and piston-ring wear rates.

The wear protection illustrated in the Mack T-12 test results demonstrates AMSOIL diesel oil's soot dispersant abilities, which directly relate to critical engine protection in the cylinder liner and piston rings. Protecting these important components helps extend the engine's service life and keeps the oil suitable for extended service operation.

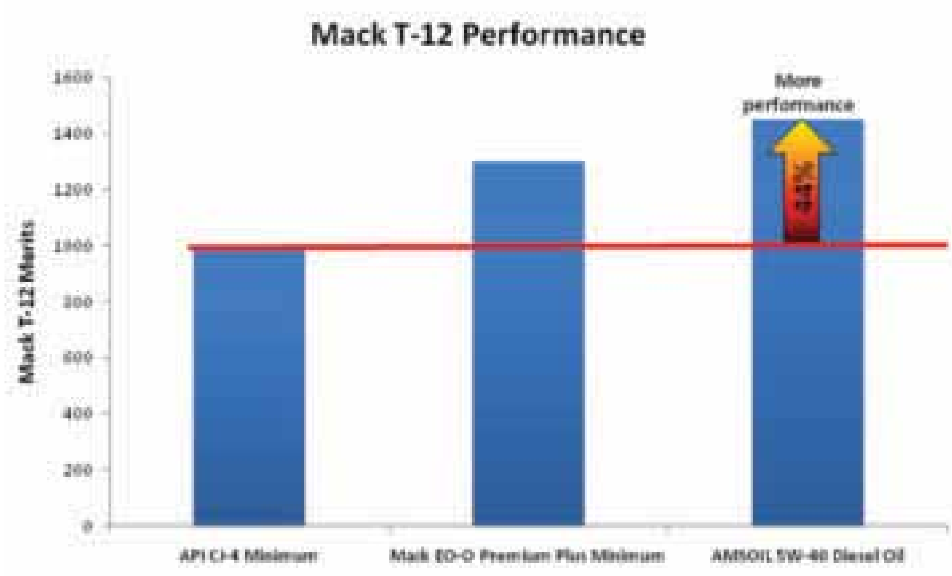
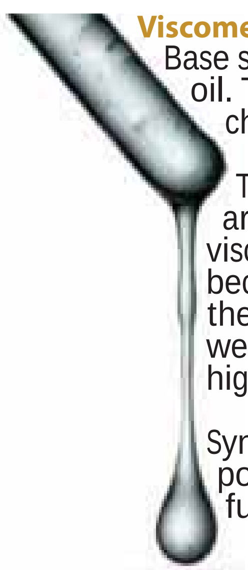



Figure 1.1
AMSOIL Premium 5W-40 Synthetic Oil nearly doubles API CJ-4 requirements for soot-dispersant abilities.



## Viscometrics

Base stocks provide the viscosity characteristics of engine oil. The oil's pour point and low-temperature performance characteristics are dependent upon base oil viscometrics.

To some degree, fuel economy and wear protection are also dependent upon base oil viscometrics. Lower-viscosity engine oils provide increased fuel economy because they impart less drag to internal components. On the other hand, higher-viscosity base oils provide better wear protection to internal components because they have higher film strength.

Synthetic oils inherently have better lubricity and lower pour points than mineral-based oils and can provide better fuel economy and cold-start performance.

**AMSOIL Advantage**

Test results from a field study AMSOIL conducted with a severe-service refuse-hauler fleet show that AMSOIL Premium API CJ-4 5W-40 Diesel Oil (DEO) has better viscosity retention and overall performance than competitive brands.

Figure 1.2 shows that AMSOIL Premium 5W-40 Diesel Oil experiences a gradual viscosity decline over the duration of the 371-hour field trial, rather than a sharp, irregular loss of viscosity as demonstrated by competing products. Unlike the competitive oils, AMSOIL Premium 5W-40 Diesel Oil remains in its intended viscosity grade (SAE 40) for the duration of the test. In contrast, the competitive oils began shearing out of grade before accumulating 100 hours of service. Furthermore, all of the competitive oils had sheared completely out of grade by 168 hours, which is significantly less than typical oil-change intervals for this type of equipment.

When a competitive oil shears out of grade, critical components like cam lobes and the valvetrain are subjected to excessive friction and wear, which ultimately leads to premature failure.

The stable viscosity performance of AMSOIL Premium 5W-40 Synthetic Diesel Oil ensures it will maintain a lubricating barrier during severe-service operation.

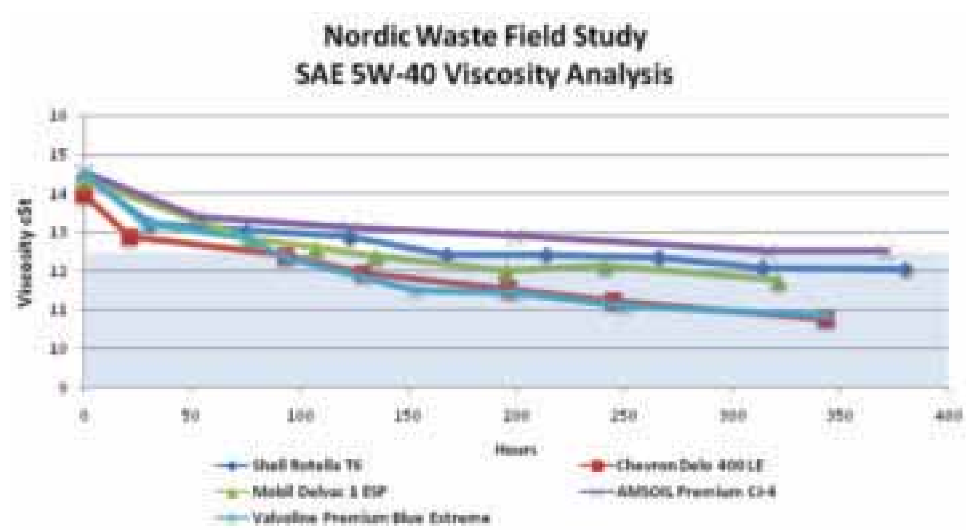



Figure 1.2
AMSOIL Premium API CJ-4 5W-40 Synthetic Diesel Oil viscosity retention under high-shear conditions

## Dispersancy and Solvency

An oil's ability to manage sludge and deposits is somewhat dependent upon the quality of the base stocks used.

High-quality base oils have better dispersant abilities and are better at preventing contaminants from settling on surfaces. However, due to the harsh operating environments inside modern engines, engine oils are typically fortified with dispersant additives to enhance dispersant properties.

### Volatility

The oil's tendency to burn off at high temperatures is controlled by the base oil's chemical makeup. Base oils that contain volatile light fractions of oils will evaporate more readily when exposed to high temperatures. Base oils with less light fractions, or light fractions that are not as volatile, will not be as susceptible to burn off.

Low-quality engine oils that contain high concentrations of volatile light fractions can contribute to a vehicle 'using' a lot of oil as it evaporates during operation. The oil's flash point, the point at which it will spontaneously ignite when subjected to high heat, is also dependent upon the base oil's volatility characteristics.

## Additives

Additives are used to combat destructive processes and enhance beneficial properties of the base oil. Building an additive package suited for a particular application is a balancing act because some additive components can counteract the effects of other additives. Formulators consider the performance requirements of an application and emphasize the performance properties that will benefit it most. An oil will not necessarily be formulated with every type of additive; it may just have a few that enhance the performance characteristics most beneficial for its intended application.

Additives can be *chemically active*, which means they interact with other compounds, such as metal surfaces or combustion by-products, to make them harmless. Other additives are *chemically inert* and only change the physical properties of the lubricant itself.

### Antioxidants

Antioxidants prevent oil from reacting with oxygen and improve its oxidation resistance.

Oxidation is accelerated by high-temperatures and causes oil to thicken and develop corrosive acids, sludge and varnish. As oil oxidizes, it can form deposits that increase its viscosity and adhere to component surfaces, reducing engine efficiency and increasing wear rates. Oxidation can also deplete the additive content of motor oil, leaving both the oil and the engine susceptible to the effects of degraded oil.

Common antioxidants include sulfur, zinc and hindered phenols.

### Solvents

Solvents are used in two-stroke oils to promote the mixing of fuel and oil for efficient combustion and lubrication. Solvents also help reduce the oil's viscosity to provide pumpability through the lubrication system.

Solvents are added at balanced concentrations; high concentrations of solvents can reduce oil film strength and lubricity.

### Anti-wear Additives

Anti-wear additives help prevent excessive wear to components in close contact. They react chemically with metal surfaces to form a film barrier that helps prevent metal-to-metal contact and wear. Some anti-wear additives can also provide oxidation resistance.

Common anti-wear additives include zinc dialkyldithiophosphates (ZDDP) and sulfur.

### Extreme-Pressure Additives

Extreme-pressure (EP) additives help prevent components in close contact from seizing under extreme pressure and high loads. They are activated by severe high temperature and pressure and react with metal surfaces to form a sacrificial wear layer on components.

Sulfur and phosphorus are common EP additives.

Under high pressure, surfaces in contact experience friction and high temperatures as they rub against each other, which can cause them to weld together. EP additives provide a sacrificial surface that shears easily. The shearing of the EP layer reduces friction and temperatures and decreases the likelihood of the surface welding.

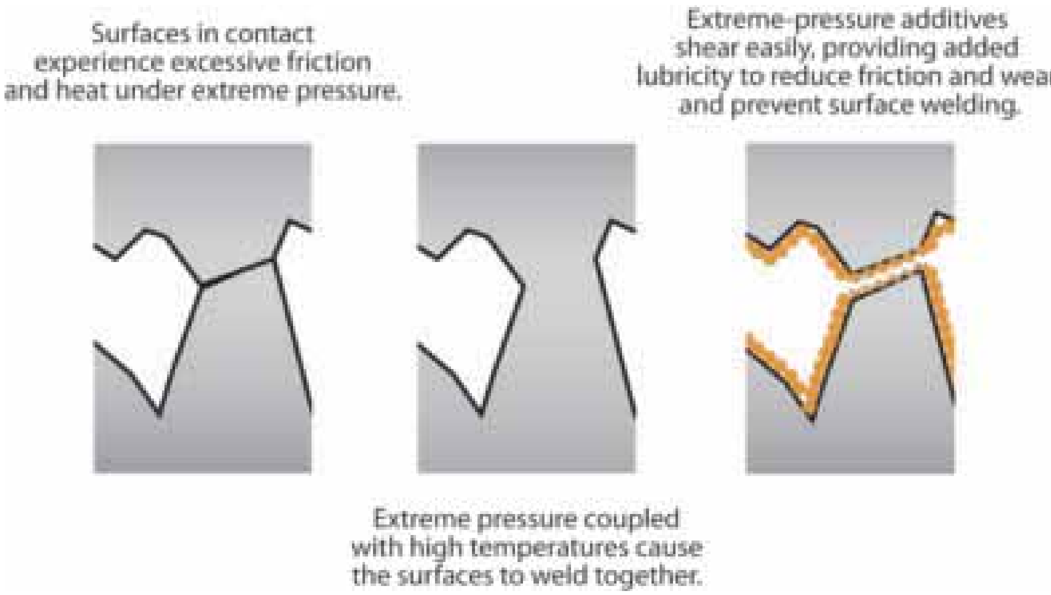



Figure 1.3
Extreme-pressure additives shear easily and reduce the amount of friction and heat created between two moving surfaces.

### Rust & Corrosion Inhibitors

*Corrosion* is a chemical reaction with a metal's surface; it requires the presence of oxygen, electrolytes and an activator. *Rust* is a form of corrosion that develops when iron and iron-derived surfaces are attacked by water and oxygen.

Rust and corrosion inhibitors protect component surfaces by forming a protective barrier to seal out water and contaminants. Some rust inhibitors can also neutralize acids. Barrier rust and corrosion inhibitors are most common in engine oil applications.

Sodium sulfonates are common rust and corrosion inhibitors; they also have detergent properties.

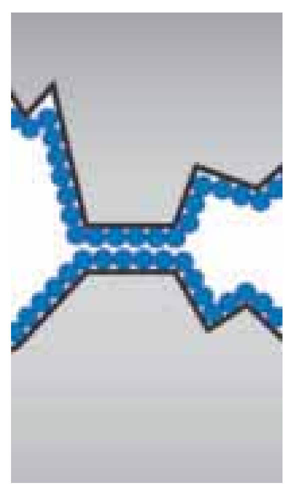


Figure 1.4
Rust and corrosion inhibitors coat the surface of metal parts.

### Seal Conditioners
Seal conditioners help keep seal materials supple to prevent them from becoming brittle and causing leaks. For example, valve seals prevent oil from entering the cylinder during the intake stroke. A dry, brittle seal may allow oil to leak past the seal and be burned during combustion, causing the engine to 'use' more oil than necessary.

### Friction Modifiers
Friction modifiers are used to give the oil either 'slippery' characteristics or 'sticky' characteristics. Friction modifiers used in passenger car motor oils (PCMOs) are typically used to increase the oil's lubricity (slipperiness) for the purpose of improving fuel economy.

Common friction modifiers include esters, fatty acids, graphite and molybdenum.

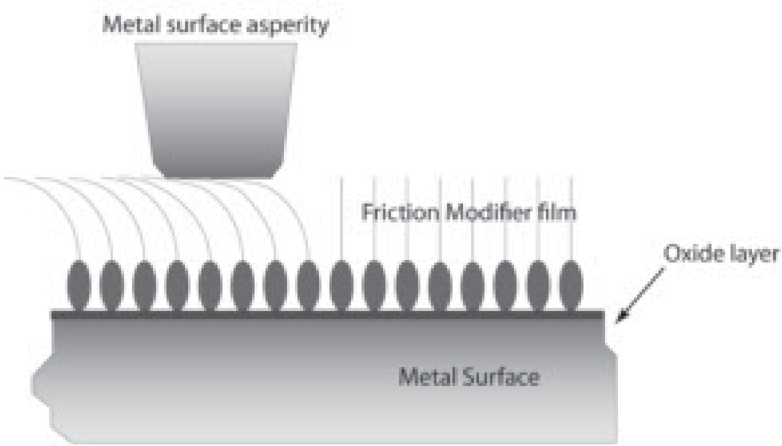



Figure 1.5
The polar end of the friction modifier attaches to the metal surface; this layer reduces the friction coefficient between the two surfaces.

### Anti-foam Additives
Anti-foam additives are relatively insoluble compounds that reduce the surface tension of foam bubbles, which causes them to collapse. Anti-foam additives are added at balanced concentrations; too much anti-foam additive can actually create foam.

Silicone is a common anti-foam additive.

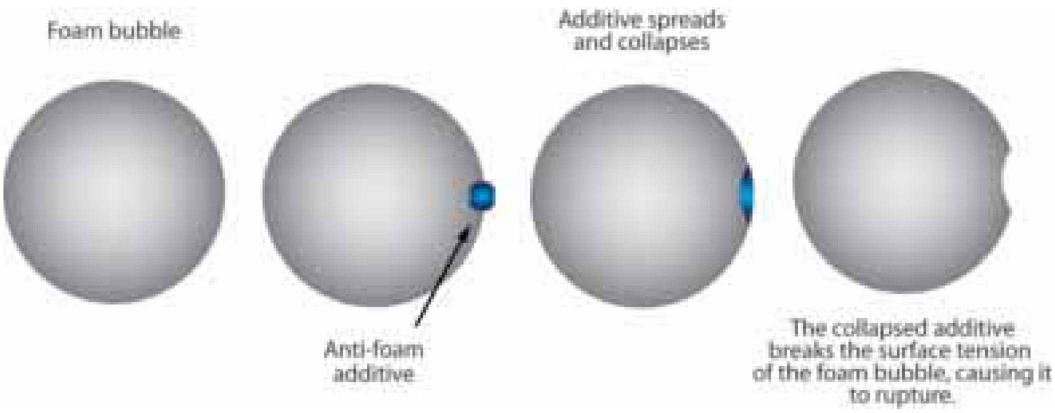



Figure 1.6
Anti-foam additives attach to the surface of a bubble where they spread and collapse, breaking the surface tension of the bubble and causing it to break.

## Detergents

Detergents help suspend and disperse contaminants in the oil to keep engine surfaces free of sludge and deposits. They are most efficient at controlling high-temperature deposits.

Detergents consist of a polar head and soluble tail. The polar head is attracted to other polar surfaces, like soot contaminants, and the soluble tail remains dissolved in the oil, preventing the contaminants from agglomerating into larger particles that increase wear and damage.

Detergents also have neutralizing properties and add to the oil's total base number (TBN) reserve, which can help neutralize acids and combustion by-products.

Common detergents include calcium, magnesium and sodium-based metallic soaps such as sulfonates, phenates and salycilates.

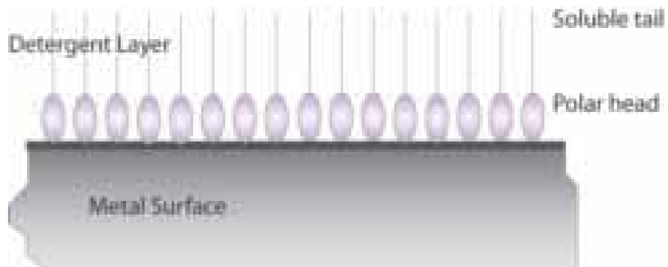



Figure 1.7
The polar end of the detergent additives attach to the metal surface; the soluble tail end of the detergent prevents contaminants from settling on the surface.

## Dispersants

Dispersants help suspend and disperse contaminants in the oil to keep engine surfaces free of sludge and deposits. They are most efficient at controlling low-temperature deposits. Like detergents, they consist of a polar head and soluble tail.

Dispersants and detergents perform similar functions; however, dispersants are non-metallic.

Common dispersants include *ashless*, non-metallic compounds such as succinimides, succinate esters and mannich-type compounds.

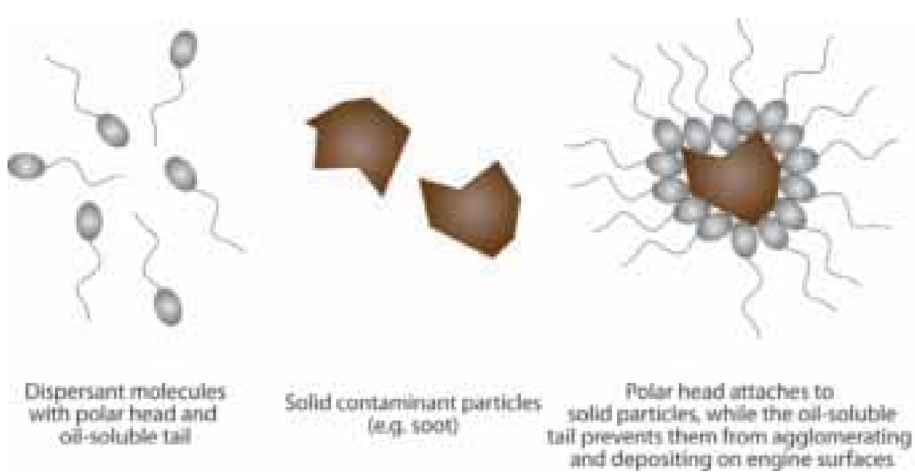



Figure 1.8
The polar head of the dispersant molecules attach to solid particles and prevent them from agglomerating into larger, more harmful contaminants.

## Formulation Limitations: Sulphated Ash, Phosphorus and Sulfur (SAPS)

Sulphated ash, phosphorus and sulfur (SAPS) make up a significant part of engine oil's additive content. Some emissions systems and aftertreatment devices, such as diesel particulate filters (DPFs), are very sensitive to the SAPS content of oil and require low-SAPS formulations.

A major source of SAPS in engine oil is zinc dialkyldithiophosphates (ZDDP), which are common anti-wear compounds. When the SAPS content of oil is too high for a given emissions or aftertreatment system, it can cause catalyst poisoning or filter plugging and negatively impact engine performance.

### Sulfated Ash

*Sulfated ash* is the by-product of metallic compounds as they are burned. It can improve an oil's antioxidancy, anti-wear properties, TBN, corrosion resistance, engine cleanliness properties and soot-handling ability. Ash can plug DPFs used on diesel engine aftertreatment systems, causing back-pressure in the engine, which can result in increased fuel consumption and reduced power.

### Phosphorus

*Phosphorus* is present in motor oil for its antioxidant properties. ZDDP is present for its anti-wear properties. Phosphorus can deposit on the catalyst (noble metal) sites and deactivate them, which can permanently poison them.

There are different types of ZDDP used for anti-wear properties, which range from high to low volatility. Oils engineered with volatile ZDDP components release extra phosphorus after initial oil changes and expose catalytic converters to phosphorus poisoning. If these oils are changed at frequent intervals, they expose emissions systems to phosphorus much more frequently than oils engineered for extended drain intervals.

### Sulfur

*Sulfur* is present in motor oil for one or more of the following functions: antioxidancy, anti-wear and engine cleanliness.

Catalyst sites absorb sulfur preferentially to other compounds, causing the sites to become blocked and inefficient. Sulfur also reacts with oxidation catalysts and causes increased emissions of sulfates.

## Operating Conditions

The performance abilities of engine oil are dependent upon the operating conditions in which it is used. The following operating conditions influence engine oil performance and formulation.

### Temperature

The viscosity of engine oil is susceptible to change under varying temperatures. Cold temperatures cause oil to thicken; warm temperatures cause it to thin.

For proper performance and protection, oil must be formulated for the temperatures in which it will be used, which is mainly a property of the base stock. Generally, multi-grade oils are used to provide performance over a wide temperature range and can provide superior performance over a broader temperature range than single-grade oils.

### Operating Environment

Operating environment is an important factor when determining the appropriate engine oil. Dirty environments, such as construction or mining sites, increase the amount of contamination the lubricant is exposed to. Contamination shortens the life of lubricants and exposes the engine to excessive wear.

### Load

Heavy loads stress lubricants and can also increase the operating temperature of the engine. These conditions can accelerate oxidation in motor oil and shorten its life.

### Speed

The stress on engine oil changes with varying speeds. Soot contamination can be especially problematic during low-speed or idle conditions where combustion is not as efficient. Water contamination can also be a problem during low-speed operation because the engine may not get hot enough to evaporate it completely. This can expose the engine to excessive moisture and put it at risk for rust and corrosion.

### Engine Design

Engine design is a critical factor for oil formulation because two- and four-stroke engines use oil in different ways and require different performance attributes.

Because two-stroke engines burn engine oil during combustion, they require a more specialized oil formulation that will not harm the engine during the combustion process. Because oil is burned along with the fuel, two-stroke oils usually have more detergent and dispersant additives to prevent the accumulation of combustion by-products on engine parts.

Four-stroke engines hold motor oil in the engine for longer periods of time and have to maintain performance abilities for their entire service life. Thus, four-stroke oils are formulated to endure the conditions inside the engine for an extended time.

### Fuel Type

The operating environments inside gasoline and diesel engines differ greatly and each requires oils formulated for specific conditions. For example, diesel engines run hotter and create more soot and nitrogen oxides during combustion. Diesel oils must have high-temperature performance properties like oxidation stability, as well as detergency and dispersancy properties to properly manage soot contamination.

### Fuel Delivery System
The fuel and air mixture required for combustion can be mixed before the cylinder or inside the cylinder. The location of the fuel injectors can affect the required oil performance properties.

Fuel injectors placed in the cylinder are exposed to high temperatures, high pressure from combustion and combustion by-products.

Due to the high temperatures and combustion by-products produced, in-cylinder injectors require engine oils that inhibit deposit and varnish formation.

### Service Duty
Service duty can vary depending on the environment and type of use a vehicle is exposed to. Vehicles that operate under lightly loaded conditions and mainly stay on paved surfaces may have different lubrication requirements than vehicles that operate under heavily loaded conditions on dirty roadways.

Service duty is especially critical when considering the necessary oil performance properties for small recreational engines. These types of vehicles operate in a wide range of operating environments that place very different demands on the engine oil.

### Cooling System
Liquid-cooled and air-cooled engines have different maximum operating temperatures. Engine oil is formulated to work in a particular temperature range and will provide inadequate protection and performance if used in temperatures it was not designed for.

### Emissions System
It is important that engine oil be compatible with emissions systems or it could deactivate the catalysts or block filters. Most gasoline passenger and light-truck vehicles use three-way catalytic converters that can be sensitive to the phosphorus content of motor oil.

Modern diesel vehicles incorporate different emissions systems that are sensitive to the SAPS additive content and even the fuel used (low-sulfur or ultra-low-sulfur fuel). Modern diesel engines require specialized oils with low SAPS content and good soot-handling properties.

## Governing Bodies & Specifications

### Engine Oil Performance Standards in the U.S.
The creation and management of engine oil performance standards in the U.S. is conducted by the American Petroleum Institute (API) and the International Lubricant Standardization and Approval Committee (ILSAC).

The API and ILSAC establish minimum performance requirements for gasoline and diesel engines. Consumers can use these service categories to select oils that are compatible with their vehicle technology.

Over time, technologies and materials change, requiring engine oil technology to also change in order to be compatible with current technologies and materials and achieve certain performance limits. In addition to technology changes, federal and local legislation may enforce certain performance standards, such as emissions, that are impacted by the use of engine oil. For example, Congress has mandated that by the year 2020, corporate average fuel economy (CAFE) must be 35 mpg at minimum. Engine oil can be engineered to provide fuel economy gains and help vehicles meet those requirements; the new ILSAC GF-5 service category includes benchmark tests for the fuel economy parameter.

## API Service Categories

The API service categories are divided into separate classifications for gasoline and diesel engines. Gasoline engine oils fall under the *Service* (S) category, while diesel engine oils fall under the *Commercial* (C) category. Each category represents a minimum level of engine oil performance, which can be demonstrated by certain laboratory and engine tests. Most vehicle manufacturers will recommend an API service category oil to be used in their engines. Oils that satisfy the requirements of the recommended service category will provide adequate protection and performance for the engine. New service categories are developed as needed and are often a result of changes to federal legislation, manufacturing materials, fuel economy improvements or all of the above.

In general, gasoline engine oils can be engineered to satisfy more than one service category, and new service categories will generally include the performance properties of earlier categories. For example, if a vehicle calls for SL-category oil, SN-category oil will provide the necessary protection. Diesel oils will usually include the performance properties of earlier categories, but not always; therefore, it is always important to check with manufacturer oil recommendations to ensure the right oil is chosen.

*Service* category oils for gasoline engines are engineered with a focus on the following performance characteristics:

- Engine cleanliness
    - Detergency and dispersancy
- Oil durability
    - Oxidative stability
    - Inhibiting acid (oil TBN)
    - Rust and corrosion protection
- Fuel economy
    - Oil lubricity

**Current API Standards: Four-Stroke Gasoline Engines**

| | |
|---|---|
| **SN** | Appropriate for 2011 and older vehicles.<br><br>Provides increased high-temperature protection for pistons and turbochargers; increased sludge control, fuel economy, emissions system compatibility and seal compatibility.<br><br>Provides protection for engines running on ethanol fuels (up to E85). |
| **SM** | Appropriate for all 2010 and earlier gasoline passenger cars.<br><br>Provides increased oxidation resistance, performance and wear protection and better low-temperature performance than preceeding oils. |
| **SL** | Appropriate for 2004 and older gasoline passenger cars. |
| **SJ** | Appropriate for 2001 and older gasoline passenger cars. |

*Commercial* category oils for diesel engines are engineered with a focus on the following performance characteristics:

- Wear protection
  - Oil viscosity
  - Film strength
  - Anti-wear additives
- Oil durability & soot handling
  - Oil detergency and dispersancy
  - Inhibiting acid (oil TBN)
  - Emissions system compatibility

**Current API Standards: Four-Stroke Diesel Engines**

| | |
|---|---|
| **CJ-4** | Designed for MY 2007 and newer engines with EGR exhaust systems.<br>Designed for more hostile environments than CI-4+.<br>Has less sulfated ash (metal by-products of combustion) than CI-4+ oils. |
| **CI-4+** | Designed for MY 2006 and older diesel engines.<br>Compatible with high- and low-sulfur fuel.<br>Greater soot-handling abilities and shear stability than CI-4 oils.<br>Higher levels of sulfated ash than CJ-4 and is not compatible with aftertreatment systems in emissions-compliant 2007 and newer engines. |
| **CI-4** | Appropriate for MY 2006 and older four-stroke diesel engines that can use high- and low-sulfur fuel.<br>Meets October 2002 exhaust emissions standards.<br>Improved performance properties over preceeding specifications in the following categories: corrosion, soot handling, low- and high-temperature stability, oxidative thickening, foaming and viscosity loss from shear. |
| **CH-4** | For MY 2002 and older four-stroke diesel engines that use fuel with up to 0.5% sulfur (≥ 0.5% sulfur). |

## Japanese Automobile Standards Organization and International Standards Organization Air-Cooled Two-Stroke Performance Categories

The following performance categories for air-cooled two-stroke lubricating oils are managed by the Japanese Automobile Standards Organization (JASO) and International Standards Institute (ISO).

Performance requirements for these oils focus on detergency, lubricity, initial torque, exhaust system blocking and smoke.

**Current JASO and ISO Standards: Two-Stroke Air-Cooled Engines**

| | |
|---|---|
| **JASO FA** | Regulate lubricity, detergency, initial torque, exhaust smoke and exhaust system blocking. |
| **ISO-EGB JASO-FB** | Regulate lubricity, detergency, ash content and pre-ignition.<br>Usually contain metal-based detergents (ash-producing). |
| **ISO-EGC JASO-FC** | Regulate lubricity and initial torque (same as FB).<br>Require higher detergency, exhaust smoke and exhaust system blocking requirements than JASO-FB. |
| **ISO-EGD JASO-FD** | Have same lubricity and initial torque, exhaust smoke and exhaust system blocking requirements as JASO-FC.<br>Have higher requirements for detergency than FC. |

A key performance requirement for air-cooled two-stroke oils is the smoke requirement, which becomes more stringent with JASO FC and FD and ISO EGC and EGD categories.

| Two-Stroke Smoke Performance Standards (ISO & JASO) | | |
|---|---|---|
| ISO **EGB** | ISO **EGC** | ISO **EGD** |
| JASO **FB** | JASO **FC** | JASO **FD** |

→ **less smoke**

## NMMA Engine Oil Specifications

The National Marine Manufacturers Association (NMMA) is a trade organization that represents boat and marine engine and accessory manufacturers. The NMMA also manages the TC-W3 oil standard for two-stroke outboard engines. It was designed to reduce emissions and warranty problems and increase engine life and consumer satisfaction with outboard engine oils.

The TC-W3 standard is a performance-based program where the fluid is tested rigorously for properties such as fluidity, lubricity, rust prevention, smoke production, detergency and ring sticking. The NMMA also manages the FC-W standard for four-stroke outboard motors.

## ILSAC Gasoline Engine Oil Specifications

The ILSAC engine oil standards are developed for gasoline engines and focus on fuel economy and fuel economy retention, engine oil robustness and emissions system protection. The current ILSAC performance level is GF-5; GF-1 – GF-3 are obsolete. GF-4 is licensable through September 20, 2011; after which ILSAC will only license the GF-5 performance level.

GF-5 is considered to be a performance upgrade from GF-4; it is suitable for MY 2011 and older vehicles. It provides improved protection against high-temperature deposits on pistons and turbochargers and for vehicles operating on ethanol-containing fuels. It also provides enhanced performance in the areas of sludge control, fuel economy, and emissions-system and seal compatibility.

**Current ILSAC Standards: Four-Stroke Gasoline Engines**

| | |
|---|---|
| **GF-5 (current)** | Provides improvements to fuel economy, emissions system protection and engine oil robustness over GF-4 oils.<br>Not for diesel engines. |
| **GF-4** | Similar to API SM service category, but requires the sequence VIB Fuel Economy Test (ASTM D-6837). |
| **GF-3** | Oil must meet API SL & EC-II requirements.<br>Has more stringent performance properties for oil's robustness.<br>Has improved fuel economy, volatility, deposit control and viscosity performance over GF-2 oils.<br>Requires less additive degradation and reduced oil consumption over the life of the oil. |

| Current ILSAC Standards: Four-Stroke Gasoline Engines | |
|---|---|
| **GF-2** | For SAE 0W-30, 0W-40, 5W-20, 5W-30, 5W-40, 5W-50, 10W-30 and 10W-40 viscosity grades.<br>Must meet API SJ and EC-II requirements.<br>Has more stringent performance properties for phosphorus content, low-temperature operation, high-temperature deposits and foam control over GF-1. |
| **GF-1** | Oil must meet API SH and EC-II requirements.<br>Created in 1990; updated in 1992 and represented the minimum requirement for oils used in American and Japanese vehicles. |

## Engine Manufacturer Standards

Because heavy-duty equipment needs are often very specialized, these OEMs often develop performance specifications that go beyond API service categories. OEM performance specifications often exceed API standards and provide performance benefits that are superior to API-licensed oils.

## Japanese Standards

In Japan, JAMA and the Petroleum Association of Japan (PAJ) establish engine oil performance standards. These organizations work with ILSAC and other organizations in the automobile and oil industries to develop Japanese standards. Japanese engine oils are not certified through a particular governing body; instead, they are self-certifying.

## European Standards

The Association des Constructeurs Eurpeens de L'Automobile (ACEA) creates service-fill quality classifications for European automobiles.

ACEA oil specifications consist of two sequences:

| | |
|---|---|
| **A/B Sequences** | For passenger car/light-duty diesel. |
| **C Sequences** | For vehicles with advanced aftertreatments systems. |

ACEA oil sequences represent a minimum performance standard; many European OEMs use them as a starting point and develop standards that go beyond these performance requirements.

| Passenger-Car, Light-Duty Diesel Standards | |
|---|---|
| **ACEA A1/B1** | Gasoline/light-duty diesel engines designed for low-viscosity oil. Do not provide the minimum performance required for most new OEM specifications. |
| **ACEA A3/B3** | For a  wide range of gasoline/light-duty diesel engines. Do not provide the minimum performance requirements for most new OEM specifications. |
| **ACEA A3/B4** | For high-performance gasoline and light-duty diesel engines. Do provide minimum performance demanded for many OEM specifications. |
| **ACEA A5/B5** | For high-performance gasoline and light-duty diesel engines designed for low-viscosity oil. |
| **Heavy-Duty Diesel Standards** | |
| **ACEA E4** | Ultra-high-performance-diesel (UHPD) lubricants designed for severe-duty, long-drain applications. |

| | |
|---|---|
| **ACEA E9** | Mid-SAPS oil, super-high-performance diesel (SHPD) lubricants for mid-drain applications. Recommended for vehicles with advanced exhaust aftertreatment systems (DPFs, EGR, SCR). |
| **ACEA E6** | Low-SAPS UHPD lubricants for long-drain applications. Recommended for vehicles with aftertreatment systems (DPFs, EGR, SCR). |
| **ACEA E7** | SHPD lubricants for mid-drain applications. |
| | **Catalyst-Compatible Standards** |
| **ACEA C2** | Top tier, lower SAPS oils. High-performance gasoline and light-duty diesel engines with advanced aftertreatment systems (DPFs, three-way catalysts). |
| **ACEA C4** | Top tier, lower SAPS oils. High-performance gasoline and light-duty diesel engines with advanced aftertreatment systems (DPFs, three-way catalysts). |
| **ACEA C1** | Top tier, lower SAPS oils. High-performance gasoline and light-duty diesel engines with advanced aftertreatment systems (DPFs, three-way catalysts). |
| **ACEA C3** | Top tier, lower SAPS oils. High-performance gasoline and light-duty diesel engines with advanced aftertreatment systems (DPFs, three-way catalysts). |

## Engine Oil Viscosity

Oil viscosity is the single most important property in terms of adequate protection and performance offered by engine oil. Viscosity is a measure of a fluid's internal friction, or its resistance to flow.

| Common Fluid | Viscosity (cSt) |
|---|---|
| Peanut Butter | 250,000 |
| Ketchup | 100,000 |
| SAE 40 engine oil | 350 |
| SAE 30 engine oil | 200 |
| Olive oil | 80 |
| Water | 1 |
| Gasoline | 0.5 |

Viscosity index (VI) refers to the degree to which a fluid's viscosity is affected by temperature changes. A high VI indicates a fluid that undergoes little viscosity change due to temperature fluctuations, while a low-VI fluid will experience greater viscosity variance as temperatures fluctuate.

The viscosity of an engine oil is closely related to temperature; fluids tend to become thicker at lower temperatures and thinner at high temperatures. However, in an engine oil, this temperature-viscosity relationship can be managed by the use of viscosity modifiers such as viscosity index improvers or pour point depressants.

Low-viscosity oils have good low-temperature properties, but aren't able to provide high-temperature protection. High-viscosity oils have good high-temperature properties but aren't able to provide low-temperature pumpability. Viscosity modifiers are added to low-viscosity oil to raise its viscosity at both low and high temperatures.

Low-viscosity oils provide:
- lower fluid friction
- better cooling
- less load-carrying ability

Low-viscosity oils are suited for cold-weather conditions because they maintain fluidity in low temperatures. Low-viscosity oils provide good performance for high-speed, low-pressure applications because they can circulate faster than high-viscosity oils. They also provide better fuel economy than thicker oils because they provide less fluid friction to engine components.

High-viscosity oils provide:
- higher fluid friction
- less cooling ability
- better load-carrying ability

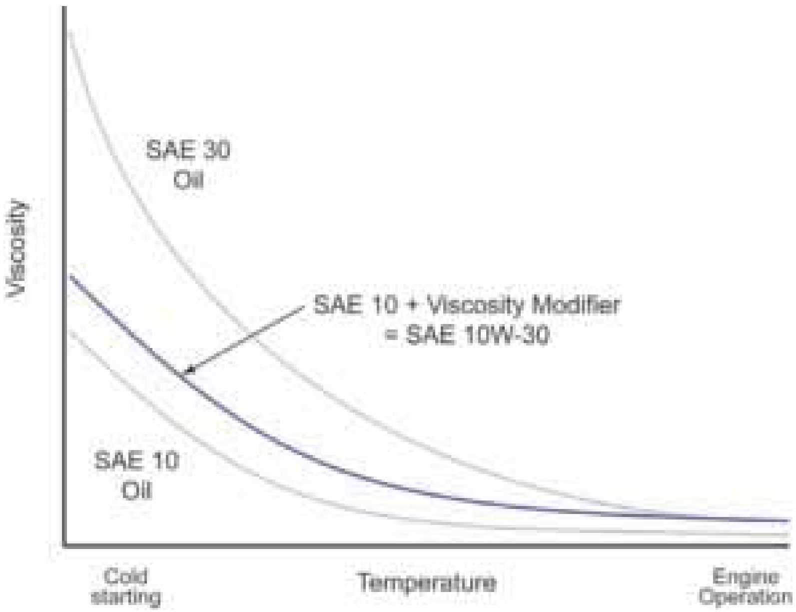



Figure 1.9
When viscosity modifiers are added to an SAE 40 viscosity grade oil, its temperature performance properties change. It is less susceptible to viscosity increase at low temperatures; however, its high-temperature performance is not affected.

High-viscosity oils are better suited for hot conditions and operating at low speeds and high pressure. High-viscosity oils provide good performance for extreme-duty equipment subjected to heavy loads. These oils are not suited for cold-weather operation as the oil will thicken and lose its ability to be pumped through lubrication systems; subsequently, it will not provide optimal lubrication to parts.

Viscosity modifiers function by decreasing the temperature-viscosity relationship of a fluid. When oil temperature is low, the viscosity modifiers contract and have little impact on oil's viscosity. However, when the oil temperature is high, the viscosity modifier's polymer chains expand, causing the oil's viscosity to increase.

Oil temperature affects polymer size, and the polymer size affects the oil's viscosity. The further the polymer expands, the greater the thickening effect it has on engine oil.

*Viscosity modifiers* are temperature dependent; they expand and contract as temperatures rise and fall. This action helps maintain the oil's viscosity as its temperature increases.

*Pour point depressants* are formulated to give high-viscosity oils good low-temperature properties. Pour point depressant polymers inhibit the formation of crystals by coating them and help minimize low-temperature viscosity increase.

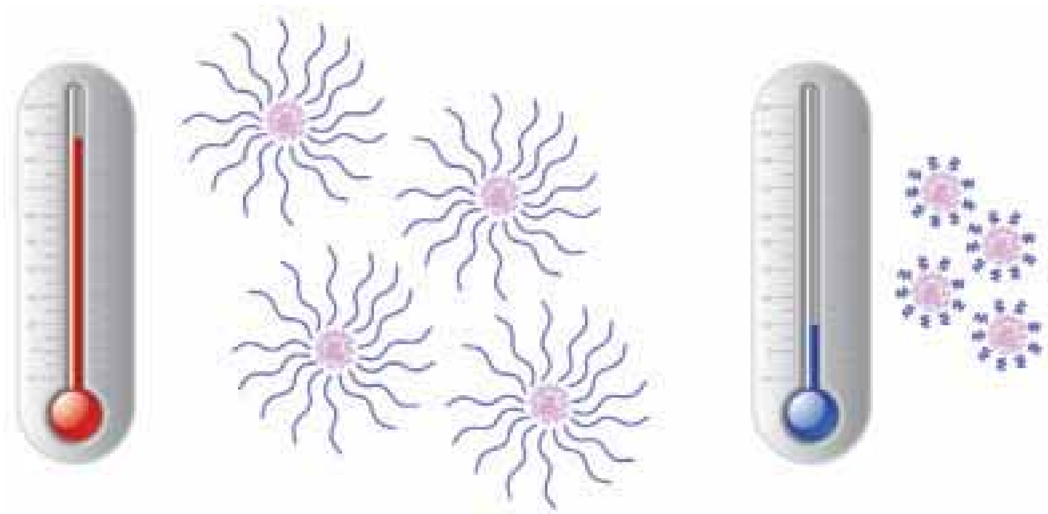


Figure 1.10
In warm temperatures (left), viscosity modifier polymers expand, raising the viscosity of the oil. When temperatures are cooler (right), viscosity modifier polymers contract, imparting no viscosity effect on the fluid.

## SAE Viscosity Grades

Engine oil viscosity grades are defined by the SAE J300 standard. SAE oil grade is based on the kinematic viscosity performance of the oil. Kinematic viscosity is determined by timing how long it takes the oil to completely flow out of a viscometer device when heated to typical operating temperatures for passenger car and truck applications (100°C/212°F). The elapsed time, in seconds, it takes for the oil to drain is converted to

**SAE J-300 Engine Oil Viscosity Classification (1)(2)**
January 2009

| SAE Viscosity Grade | Low-Temperature Viscosities | | High-Temperature Viscosities | | |
|---|---|---|---|---|---|
| | Cranking (cP) max at temp °C | Pumping (cP) max with no yield stress at temp °C | Kinematic (cSt) at 100°C min | Kinematic (cSt) at 100°C max | High Shear (cP) at 150°C and $10^6$ s$^{-1}$ min |
| 0W | 6200 @ -35 | 60,000 @ -40 | 3.8 | — | — |
| 5W | 6600 @ -30 | 60,000 @ -35 | 3.8 | — | — |
| 10W | 7000 @ -25 | 60,000 @ -30 | 4.1 | — | — |
| 15W | 7000 @ -20 | 60,000 @ -25 | 5.6 | — | — |
| 20W | 9500 @ -15 | 60,000 @ -20 | 5.6 | — | — |
| 25W | 13000 @ -10 | 60,000 @ -15 | 9.3 | — | — |
| 20 | — | — | 5.6 | < 9.3 | 2.6 |
| 30 | — | — | 9.3 | < 12.5 | 2.9 |
| 40 | — | — | 12.5 | < 16.3 | 2.9 (0W-40, 5W-40, and 10W-40) |
| 40 | — | — | 12.5 | < 16.3 | 3.7 (15W-40, 20W-40, 25W-40, and 40) |
| 50 | — | — | 16.3 | < 21.9 | 3.7 |
| 60 | — | — | 21.9 | < 26.1 | 3.7 |

Figure 1.11
The SAE J300 engine oil viscosity classification defines the limits for classifying engine oils by SAE viscosity grade. Reprinted with permission from SAE J300 Nov2007 © 2007 SAE International

a viscosity measurement called centistokes (cSt). SAE viscosity grades are based on this measurement. For example, to obtain an SAE 30 viscosity designation, an oil's Kinematic viscosity at 100°C must be a least 9.3 cSt and no more than 12.5 cSt. To obtain an SAE 40 viscosity designation, an oil's Kinematic viscosity at 100°C must be at least 12.5 cSt and no more than 16.3 cSt.

In addition to the Kinematic viscosity requirement, each viscosity classification (SAE 20, 30, 40, etc.) has a high-temperature/high-shear (HTHS) requirement. The HTHS test simulates an engine operating at high temperatures and load, to measure how well the oil maintains a lubricating film in severe service. The higher the viscosity grade, the higher the HTHS viscosity value.

Winter ("W") viscosity grades are determined using the Brookfield Cranking viscosity and Brookfield Pumping viscosity tests. The Brookfield Cranking viscosity test evaluates the amount of energy it takes to start an engine at a specified cold temperature; the lower the winter grade, the lower the temperature at which the Cranking test is performed.

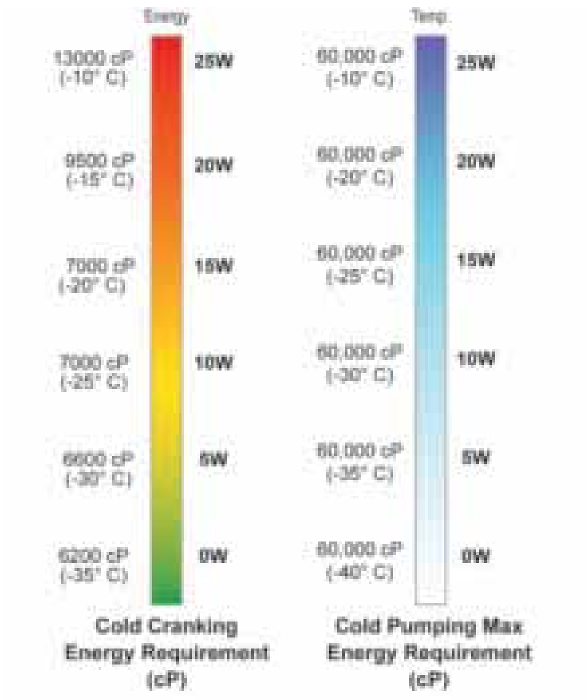



Figure 1.12
Winter grade oil energy requirements (measured in cP)

The Brookfield Pumping viscosity test evaluates the amount of energy it takes to pump an oil at a specified cold temperature; the lower the winter grade, the lower the temperature at which the Pumping test is performed.  For example, the 25W viscosity grade has the least rigorous temperature requirements for pumping viscosity (60,000 cP at -15°C) and the 0W grade has the most rigorous pumping viscosity requirement (60,000 cP at -40°C). Brookfield Viscosity is measured in centipoise (cP).

## Multigrade Oils

Multigrade oils combine the properties of low- and high-viscosity oils, and are the most common type of engine oil used in the United States for both passenger car and heavy-duty applications. Multigrade oils provide better protection in cold weather because they maintain viscosity over a wider temperature range than single grades. They also provide rapid and dependable cold-starting abilities. Multigrade oils are convenient for motorists because they perform over a wide range of temperatures and eliminate the need for seasonal oil changes.

| Key Benefits of Multigrade Oils | |
|---|---|
| **Low-Temperature Starting** | When oils thicken in cold temperatures, they exert more resistance and draw extra power from the vehicle's battery. This can send an already cold battery over the edge and drain it of all its available energy reserves.<br><br>Multigrade oils provide consistent viscosity over a broad temperature range and can improve starting performance in cold temperatures. |
| **Eliminate Seasonal Oil Changes** | Multigrade oils can eliminate the need for seasonal oil changes. Broad-temperature-range performance provides good flow and pumpability characteristics in low temperatures while maintaining sufficient film strength as temperatures rise.<br><br>It is important that the multigrade viscosity provides performance for the temperatures in which it will be used, as there are several multigrade viscosities. |
| **Low-Temperature Pumpability** | A monograde oil engineered for warm temperatures thickens in cold temperatures and loses the ability to be pumped through the system. This can cause oil starvation, engine wear and wear-related engine failure.<br><br>Multigrade oils provide consistent viscosity over a broad temperature range and will maintain pumpability down to their pumping max temperature (See SAE J300). |
| **Improved Fuel Economy** | Multigrade oils impart lower overall viscous drag on engine parts and help reduce fuel consumption. |

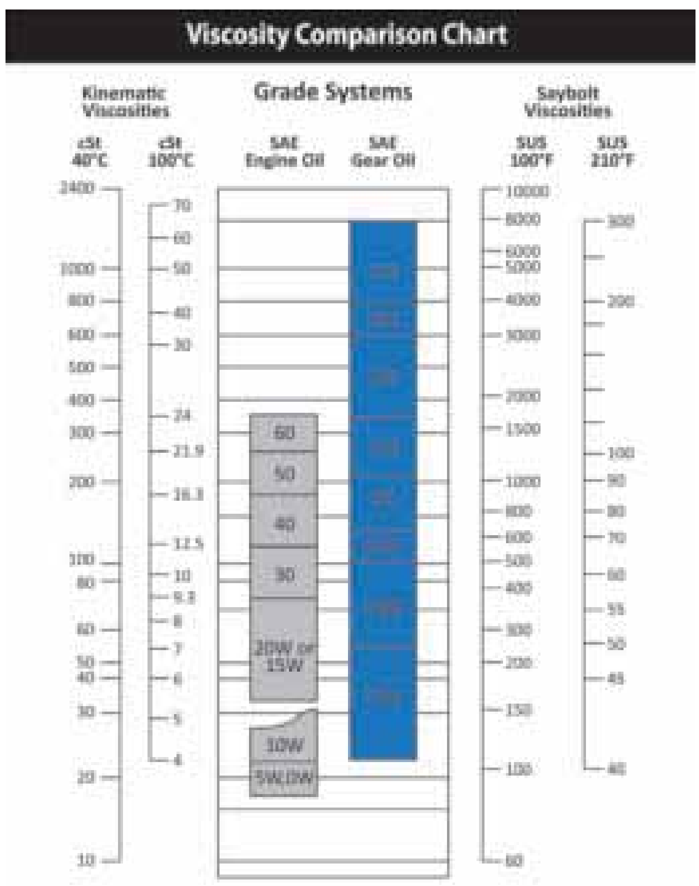



Figure 1.13
Viscosity comparison of SAE engine oils and SAE gear oils

## Engine Oil Requirements: Two- and Four-Stroke Engines

Because two- and four-stroke engines are lubricated in two very different ways, they require different oil formulations. Two-stroke oils are burned during the combustion process and the performance and formulation emphases are on engine cleanliness, wear protection and smoke reduction. Four-stroke oils are held in a dedicated sump and lubricate for an extended time until the next oil change; the performance and formulation emphases are on engine performance, wear protection and lubricant durability.

**Two-Stroke Engine Oils**

Two-stroke engine oil lubricates the engine once it is combined with fuel and burned during the combustion process (excluding DFI engines). For this reason, two-stroke engine oil is formulated to lubricate the engine and burn cleanly under these conditions.

Two-stroke oils are formulated with solvents that help them combine with fuel. The additive package is balanced with detergents and dispersants to prevent engine deposits. Additive packages that are not properly balanced can contribute to excessive smoke and deposits.

Two-stroke air-cooled engines require a low-ash or ashless oil formulation to resist deposit formation. Two-stroke liquid-cooled engines require ashless oil formulations only.

**Four-Stroke Engine Oils**

Four-stroke engine oils require more stability than two-stroke oils because they have to tolerate the conditions of the engine for extended periods of time.

To provide oil longevity, four-stroke engine oils are typically formulated with higher quality base oils and more additives than two-stroke engine oils.


Figure 1.14
The emphasis of two-stroke oils, left, is miscibility with fuel (solvent) and reduction of friction (lubricity agent). The emphasis of four-stroke engine oils, right, is robustness because the oil stays in the system for an extended period of time.

# Engine Oil Requirements: Fuel Types

## Gasoline Engine Oils

Gasoline engines characteristically operate at low-temperatures and under light loads. These operating conditions can result in unburned or partially burned fuel and solids, referred to as *blow-by*, contaminating the engine oil. Blow-by occurs as unburned fuel and exhaust particles blow past the piston rings and contaminate the oil in the oil sump. Certain driving conditions can increase the normal blow-by that occurs in mechanically sound engines, including excessive idling, stop-and-go driving and frequent short trips. If the engine oil becomes heavily contaminated with blow-by contaminants it can form acids and sludge.

Gasoline engine oils perform the following important functions and generally feature these formulation characteristics:

1. Carry heat away from engine components to prevent excessive friction and wear.
2. Contain anti-wear additives to help prevent wear to critical components like the valvetrain and camshaft.
3. Fortified with detergents and dispersants that control and inhibit deposits on engine parts.
4. Contain oxidation inhibitors that reduce thermal decomposition to help the oil resist acid, sludge and varnish.
5. Formulated for emissions-systems compatibility; if they are not, the oil can cause emissions systems fouling or failure.

## Diesel Engine Oils

Diesel engine oils are formulated to withstand high compression ratios, high operating temperatures, and high soot concentrations. To manage heavy loads characteristic of diesel applications, diesel oils are engineered with high-viscosity base oils and anti-wear additives that provide protection against wear for critical components like the valvetrain and camshaft.

To resist decomposition in high temperatures, diesel oils require oxidation inhibitors that inhibit the oxidation process. Detergents and dispersants are required to minimize deposit formation on engine surfaces. High alkalinity reserve (TBN) is necessary to combat acid formation, and corrosion inhibitors are added to protect soft metal components, such as bearings. Diesel engine oils are formulated for emissions systems compatibility; if they are not, the oil can cause emissions systems fouling or failure.

The operating conditions and duty cycle experienced by on- and off-road diesels are shown below. These conditions impact engine oil formulation and should be taken into account when determining the most appropriate oil for an application.

**Typical Diesel On- and Off-Road Conditions**

| | | |
|---|---|---|
| **Service Duty** | On-road | • Steady state operation (highways)<br>• Constant speed<br>• Continuous operation, not interrupted |
| | Off-road | • Stop-start operation with periods of short trips and high-load activity and low-speed idling |

**Typical Diesel On- and Off-Road Conditions**

| | | |
|---|---|---|
| **Operating Conditions** | On-road | • Travel long distances<br>• Wide range of weather conditions<br>• Operate on generally cleaner road surfaces such as highways and surface roads<br>• Lower levels of contamination than off-road |
| | Off-road | • Travel shorter distances<br>• Dirty, dusty conditions (such as mining or construction sites)<br>• Higher levels of contamination than on-road |
| **Load** | On-road | • Heavy loads<br>• Not much variation in load<br>• Load and unload infrequently |
| | Off-road | • Very heavy loads (especially mining, construction, logging)<br>• Load and unload frequently |
| **Temperature** | On-road | • Lower engine and oil temperatures due to ram air (airflow over the engine from the movement of the vehicle) |
| | Off-road | • Higher engine and oil temperatures due to extreme operation and conditions; less benefit from ram air due to slower speeds |

## AMSOIL Advantage

As the operating environment inside the diesel engine has become more severe due to emissions system changes, diesel oil formulations have evolved in order to provide optimum performance and protection in emissions-compliant engines.

AMSOIL diesel oils are engineered with high alkalinity reserve (TBN) to provide oil performance and oil durability throughout extended drain intervals. An oil with a high TBN value is engineered with increased levels of neutralizing additives that eradicate harmful acids and soot generated during combustion.

AMSOIL diesel oils are formulated to provide steady TBN performance. They provide effective engine protection against acids and soot for extended-drain applications. Notice how the TBN depletion in the graph below is gradual over the entire 983-hour interval. Oils that demonstrate a sharp TBN decline, especially after initial installation, feature poor TBN performance.

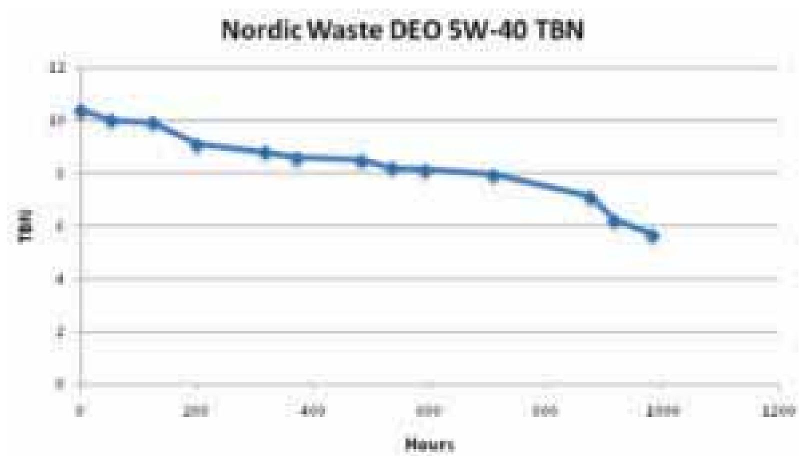



Figure 1.15
AMSOIL diesel engine oils provide steady TBN performance over the life of the extended drain interval for effective acid neutralization and soot dispersion.

### Liquid Natural Gas (LNG) Engine Oils

The functions of natural gas engine oil are similar to those of gasoline and diesel engine oils; it prevents wear, cools the engine, reduces corrosion, inhibits oxidation, controls deposits and inhibits nitration.

Natural gas engines are used in a variety of operating conditions and come in various engine designs. Many include catalytic converters to reduce the amount of exhaust emissions and require limits on some of the additive components in the oil. The combustion process of natural gas creates an accumulation of oxides and nitrogen, referred to as **nitration**. Nitration has to be monitored to evaluate both engine and lubricant life.

Because natural gas engines usually operate under heavy load, they require high-viscosity oil and anti-wear additives for adequate wear protection. Natural gas engine oils are prone to deposit formation, so detergent and dispersant additives are engineered in natural gas oils to help reduce the formation of large deposits and prevent them from adhering to engine surfaces. Detergent additives can increase deposit formation, however, so a balanced package is necessary to provide optimal protection and performance for natural gas engines.

Detergent/dispersant additives burn off, leaving behind a fluffy, grey ash residue. This ash is made up of various metal sulfates and helps prevent valve recession by acting as a cushion as the valve seats in the valve seat area. However, some of the additive content, like zinc and phosphorus, have to be added at balanced concentrations so that they do not deactivate catalyst metals in the emissions system.

## Engine Oil Requirements: Specialty Applications

### Break-in Oils

Break-in oils provide controlled friction to new engine components. They promote ring sealing in the cylinder while still providing adequate protection for extreme-pressure areas like the valvetrain. Adequate sealing/seating of the rings against the cylinder wall is critical for the engine's long-term operation and to prevent oil consumption. Break-in oils are heavily fortified with ZDDP; major compounds of which are zinc and phosphorus.

### Motorcycle Oils

Motorcycles operate under more severe conditions than passenger cars do. They usually run faster, are air cooled and have less oil to lubricate more parts because a single oil sump is shared between the engine, clutches and gears. They are engineered with high viscosity to help prevent gear pitting, oil burn-off and oil consumption.

Motorcycle oils are typically formulated with high frictional characteristics that provide quick reaction for the clutches. Friction modifiers used to enhance fuel economy in passenger car and light-duty truck applications are not used in motorcycle oils because they increase oil lubricity and cause clutch slippage.

**AMSOIL Advantage**

Motorcycle oils are multifunctional lubricants that must protect the engine as well as the gears inside the transmission. The performance properties of motorcycle oils are carefully balanced to provide performance and protection to both systems.

Motorcycle engines operate in severe conditions. Critical components, like the bearings, are exposed to intermittent loading and the force of wide-open throttle operation. Continuous force and high temperatures put them at risk of boundary lubrication, which can cause excessive friction and wear in these critical components, ultimately leading to failure. The motorcycle transmission is a demanding environment for the lubricant; it must endure high-pressure sliding and shearing forces that can permanently reduce oil viscosity, it's most protective property.

The FZG gear wear test evaluates a lubricant's ability to minimize gear scuffing. In the test, two steel gears are partially immersed in the test oil and run for a single stage at 90°C (194°F) under load and 1,450 RPM for 21,700 revolutions. When the stage is complete, wear scuffing is measured; if the scuffing is less than 20mm, another load stage is conducted. Wear scuffing greater than 20mm ends the test. The FZG wear test can be conducted for 13 stages. Final results are reported for the load stage passed and size of wear scuffing.

AMSOIL results for the FZG wear test are shown on the right of Figure 1.16. AMSOIL 20W-50 Synthetic Motorcycle Oil passed the FZG wear test, completing all 13 load stages with no scuffing, and proving that it provides critical protection under high-speed and high-load conditions.

Figure 1.16
AMSOIL 20W-50 Synthetic Motorcycle Oil is shear stable under high temperature and high stress conditions to provide critical protection to the engine.

## ATV/Snowmobiles

ATV and snowmobile applications both require extreme-temperature performance because they are often used in very cold temperatures.

Cooling systems affect operating temperatures; air-cooled applications typically run hotter than water-cooled applications.

Snowmobiles can be air-cooled or water-cooled, creating variation in operating temperature between different equipment. Oils used in these applications need to be engineered for broad temperature performance to accommodate all possible ambient and operating temperatures that may be encountered.

Most ATVs share the oil sump with the engine, clutches and transmission and are air-cooled. To provide optimal lubrication to this type of design, oils are formulated for shear stability and frictional properties for the clutch materials.

ATVs and snowmobiles usually operate under severe service because they endure temperature extremes, heavy loads and high contamination levels. They must be engineered with good cleaning properties to prevent deposit buildup.

### Watercraft

Watercraft engines typically operate under severe service, enduring wet environments and varying loads. These engines are liquid-cooled and require good deposit control to prevent deposit buildup and ring sticking, as they can be an issue for cooler-operating engines. Ashless oils are best suited for liquid-cooled outboard motors. Watercraft engine oils are formulated for rust and corrosion protection due to the wet and humid environments in which they operate.

The performance certifications for inboard and outboard engines are different. Performance requirements for liquid-cooled outboard engines are defined by the National Marine Manufacturers Association (NMMA). Two-stroke, air-cooled and inboard engine performance requirements usually fall under API and JASO two-stroke engine classifications.

### Hand-Held: Small Engine

Hand-held small engines like weed trimmers and chainsaws are used in dirty environments and operate under high-RPM conditions with intermittent shock loading. They require good lubricity to reduce cylinder wall scratching and piston skirt scuffing. Oxidation stability is required to prevent deposit accumulation that can impair engine performance. Hand-held small-engine oils have low-ash formulations to help resist deposits.

Rust and corrosion protection is necessary to protect occasionally used equipment, which is often stored in dirty, wet environments. Two-stroke small-engine oils require low-ash formulations to reduce the amount of smoke produced as the oil is burned with the fuel. This reduces pollution and improves operator experience because operators are exposed to significantly reduced levels of noxious smoke.

### Industrial: Small Engine

Industrial small engines like generators, compressors and pumps operate in a wide range of environments, from enclosed, heated garages to dirty, dusty outbuildings where they are stored intermittently.

Because of these varied and extreme challenges, small-engine industrial applications require high-quality base oils that provide robust performance and durability.

### Racing Oils

Race applications operate under severe duty, sustaining intermittent operation under high load, high temperatures and dirty environments. To withstand these operating challenges, racing oils are formulated with high film strength to protect against wear.

Friction modifiers are used in racing oils to increase lubricity and reduce friction. They also reduce the energy required to keep the engine at high RPM.

Racing oil must have a high viscosity index to ensure that it maintains adequate viscosity and oil pressure inside the engine as oil temperature rises. This is required for adequate component protection during continuous, high-stress operation. Robust high-temperature/high-shear properties ensure that as oil temperatures rise under extreme shear conditions, viscosity remains stable.

**AMSOIL Advantage**

Racing applications operate at elevated RPM, high temperatures and frequent loading from acceleration. This exposes the engine to potential friction and wear on key components that endure rigorous and repetitive sliding contact. AMSOIL Dominator Synthetic Racing Oil delivers superior performance and protection in harsh racing applications. Its shear-stable formulation is engineered to provide maximum horsepower without sacrificing engine protection.

AMSOIL Dominator Racing Oil is fortified with high levels of zinc and phosphorus additives that provide long-term wear protection. Dominator Racing Oil provides exceptional film strength and wear protection under the high-temperature/high-shear conditions characteristic of racing engines.

The engine parts shown in Figure 1.17 were taken from a Mercury 525 marine racing application with over 3,000 miles of racing and testing. The piston skirt developed virtually no wear; it has a smooth, polished finish, demonstrating that a fluid barrier was maintained during rigorous operation. The high film strength and shear-stable properties are evidenced on the engine's camshaft, which shows no signs of wear or bluing.

Figure 1.17
Engine parts from a marine racing application after more than 3,000 hours. The piston has a smooth, polished finish with virtually no wear and no signs of wear or bluing on the camshaft.

## Engine Oil Requirements: Engine Components

Engines rely on proper lubrication to do their job efficiently and operate safely without incurring damage. Engine oils are formulated with base oils that meet the temperature and film-strength needs of the application, and a careful balance of additives are formulated with the base oils to meet the dynamic needs of all the lubricated engine components.

Base oils provide an engine oil's film strength, which plays a critical role in all areas that endure extreme-pressure contact.

One or two critical additive components are also listed for each engine component listed below; however, this is not an exhaustive list. It merely represents common additives used in the industry and in no way represents how AMSOIL, or any other oil products, are engineered.

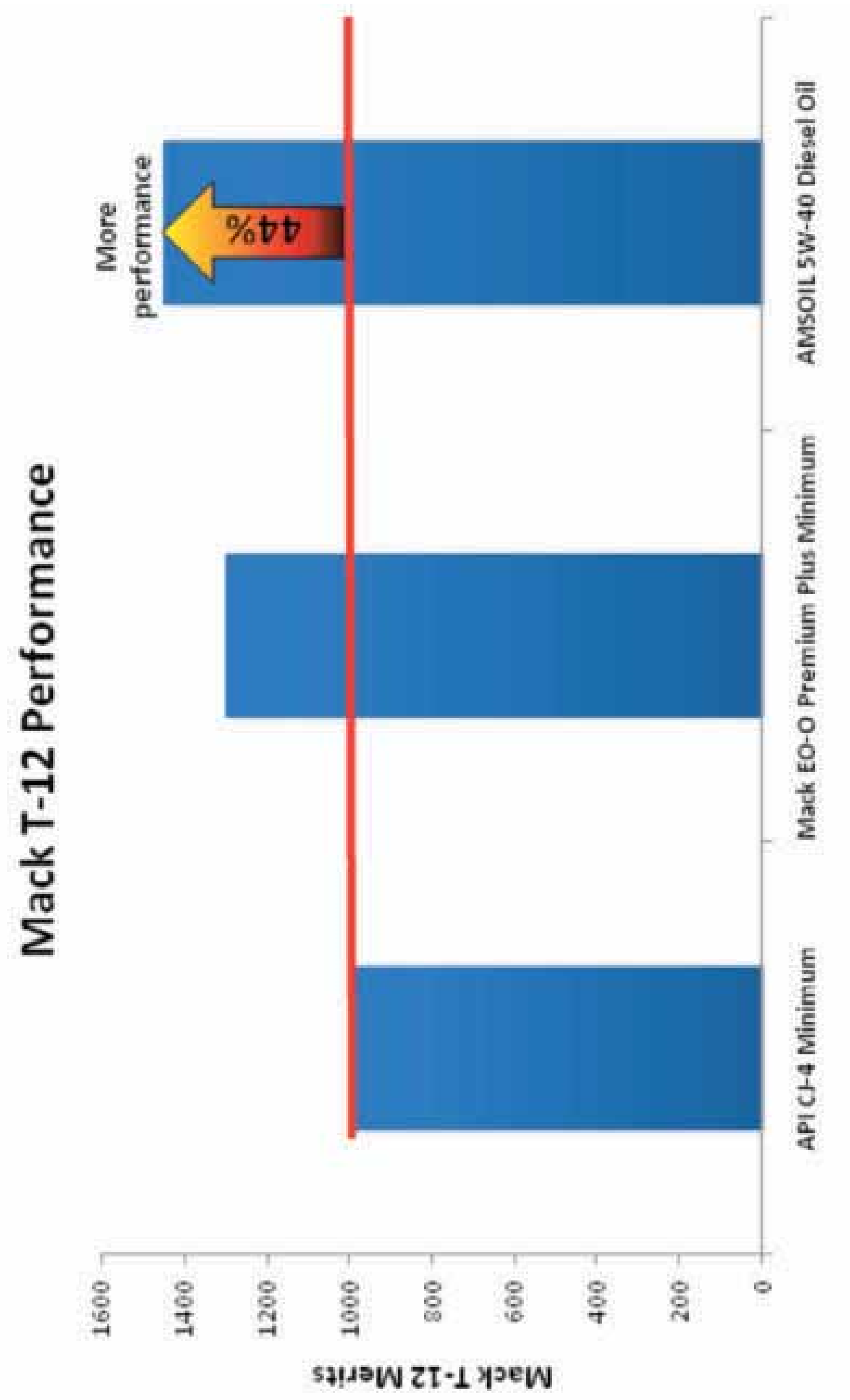
| **Piston, Piston Rings & Cylinders** | |
|---|---|
| **Component Function** | The piston is responsible for compressing the air-fuel mixture in preparation for combustion.<br><br>The piston rings help disperse oil along the cylinder wall to lubricate the piston and minimize wear and friction as the piston moves up and down the cylinder. The piston rings form a seal against the cylinder wall to separate the cylinder from the crankshaft.<br><br>These parts are exposed to extreme high temperatures from combustion. As the piston moves through the power stroke, temperatures begin to drop drastically, increasing the stress on the components. These parts are in very close contact, with only an oil film barrier between them. |
| **Engine Oil Function** | Engine oil cools these components to prevent distortion or warping, excessive wear and engine seizure. An adequate barrier is required to prevent excessive wear and friction.<br><br>Proper viscosity is essential. Oil that is too thick will not spread adequately over the piston and may expose components to metal-to-metal contact; oil that is too thin will break down under the high temperatures and fail to provide an adequate barrier and seal. |
| **Key Additives** | Detergents and dispersants keep these components clean and free from deposits to promote efficient operation and reduce the likelihood of deposit-induced malfunctions such as ring sticking and pre-ignition. |
| **Wrist Pins** | |
| **Component Function** | The wrist pin is located under the piston head and is exposed to high combustion temperatures and high combustion pressures. It attaches the piston to the connecting rod and allows it to slightly oscillate as it moves up and down in the cylinder. |
| **Engine Oil Function** | The engine oil cools the wrist pins to resist thermal degradation and inhibit the formation of deposits. |
| **Key Additives** | Antioxidants help keep the wrist pin clean and free of sludge and sticky deposits. Excessive deposits can lead to wear and increased temperatures. |

| | |
|---|---|
| **Valvetrain, Valves & Valve Seals** | |
| **Component Function** | The valvetrain, valves and valve seals manage the gases that enter and exit the cylinder at the correct time in the combustion cycle. The valve seals maintain a pressurized cylinder; they prevent the air-fuel mixture from leaking out during compression and the by-products of combustion from leaking back into the cylinder through the exhaust port. |
| **Engine Oil Function** | Engine oil protects the valvetrain and valves from excessive wear; it must resist deposit formation on these finely tuned components.<br><br>Engine oil cools the valves to prevent thermal wear and stress, both of which can cause the valves to fail prematurely. |
| **Key Additives** | Anti-wear additives are necessary to protect the valvetrain from wear, but the content cannot be so great that sticky deposits are left behind. Valve deposits can cause valve sticking, which negatively affects engine performance. They can also cause the valve to run too hot, or to burn. This is especially true for the exhaust valve, which is subjected to high exhaust temperatures.<br><br>In natural gas engines, the ash in the oil is added at precise concentrations to protect the valve as it seats into the piston head. |
| **Camshaft & Lifters** | |
| **Component Function** | The camshaft and lifters are responsible for actuating the finely tuned movements of the valvetrain. |
| **Engine Oil Function** | Engine oil forms a barrier between the camshaft and flat-tappet lifter to minimize wear and prevent failure. |
| **Key Additives** | Anti-wear additives are used to form a protective barrier; without it, camshafts and lifters would fail from the force of operation. |
| **Main Bearings** | |
| **Component Function** | The main bearings allow the crankshaft to rotate while maintaining a fluid barrier inside the unit to prevent friction, wear and overheating. The oil inside the bearing is subject to high levels of shear stress. |
| **Engine Oil Function** | Engine oil is responsible for maintaining an adequate oil film to keep surfaces separated.<br><br>Use of unsuitable oil can result in bearings running too hot, which will make the component vulnerable to wear, metal-to-metal contact and failure. |
| **Key Additives** | Corrosion inhibitors form a protective barrier on vulnerable metal surfaces such as alloy bearings and other yellow-metal components. |
| **Crankshaft & Crank Pin** | |
| **Component Function** | The crankshaft converts the movement of the pistons into rotary motion that is transferred to the driveshaft.<br><br>The crankpin transmits power from the piston to the crankshaft. It is very important that it is adequately lubricated. |
| **Engine Oil Function** | Engine oil cools the crankshaft, crankpin and main bearings.<br><br>Crankpin lubrication protects against metal-to-metal contact and excessive wear. |
| **Key Additives** | Anti-wear additives protect heavily loaded surfaces and help prevent friction and wear.<br><br>Foam inhibitors reduce the surface tension of any foam that forms from the rapid spinning and churning of the crankshaft in the oil pan. |

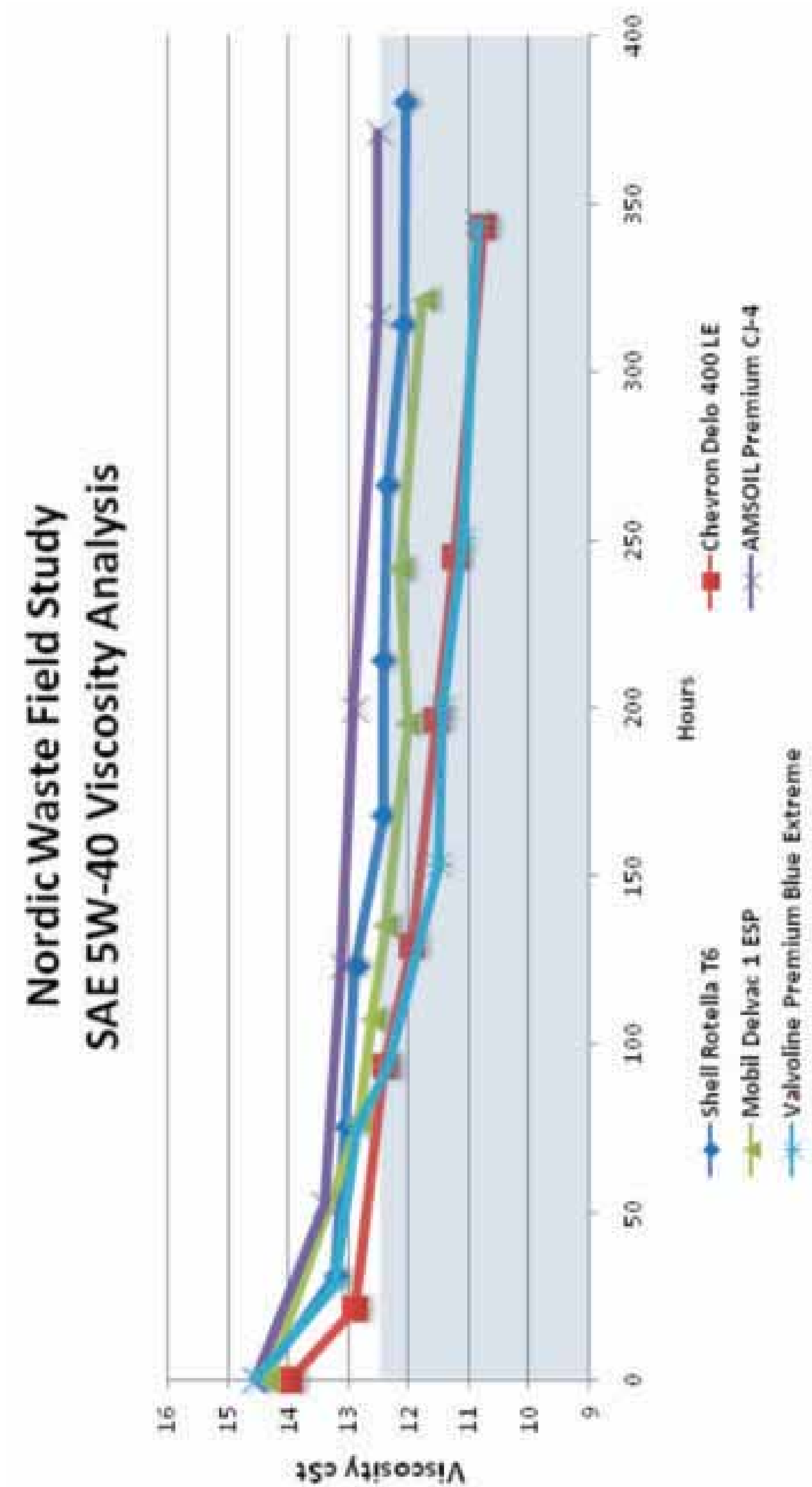
| Seals | |
|---|---|
| **Component Function** | An engine's main seals, found on the crankshaft, keep the engine oil from leaking out of the engine. |
| **Engine Oil Function** | Engine oil does not play a direct role for the main seals; however, it carries seal conditioner additives to these components. |
| **Key Additives** | Seal conditioners prevent the seals from becoming brittle and drying out, and help prevent oil leaks. |
| **Fuel Injector (direct inject/in cylinder)** | |
| **Component Function** | Direct injection engines have fuel injectors positioned inside the cylinder. Direct injection fuel injectors spray finely atomized fuel into the cylinder at precise intervals during the combustion cycle, allowing for quicker response, improved performance, reduced emissions and improved fuel economy. |
| **Engine Oil Function** | Heavy-duty diesel engines that incorporate the hydraulic electronic unit injector (HEUI) fuel system use engine oil to open the fuel injectors under extreme oil pressure (up to 3,500 psi). Engine oil must be extremely shear-stable to withstand those pressures and resist viscosity loss from shear forces. |
| **Key Additives** | Detergent and dispersant additives prevent deposits from accumulating on injectors. |

## Appendix

### Mack T-12 Performance

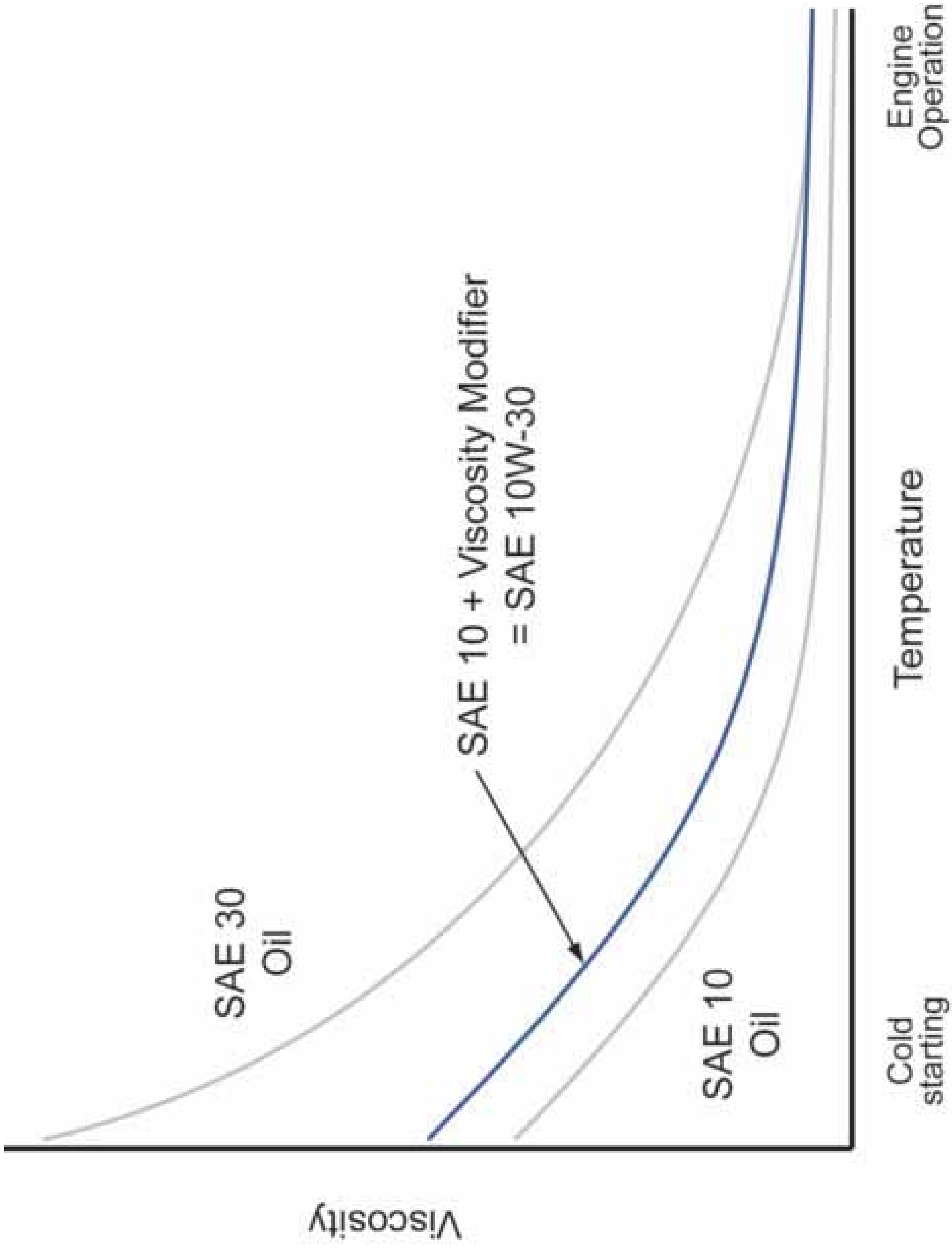


## Nordic Waste Field Study: SAE 5W-40 Viscosity Analysis




Appendix

**Viscosity Modifier Effect on SAE 40 Oil**



## SAE J-300 Engine Oil Viscosity Classification

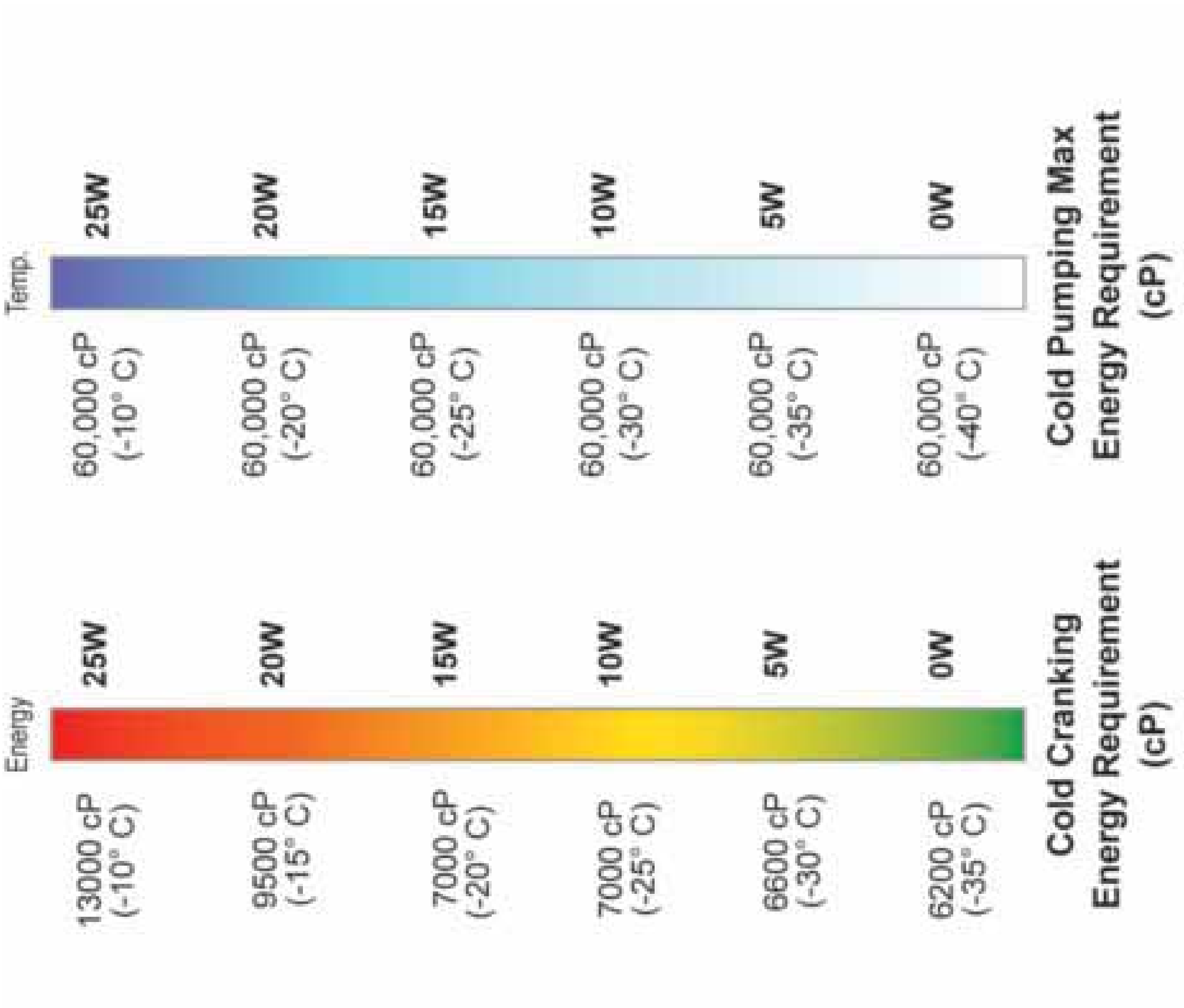
### SAE J-300 Engine Oil Viscosity Classification [1][2]

January 2009

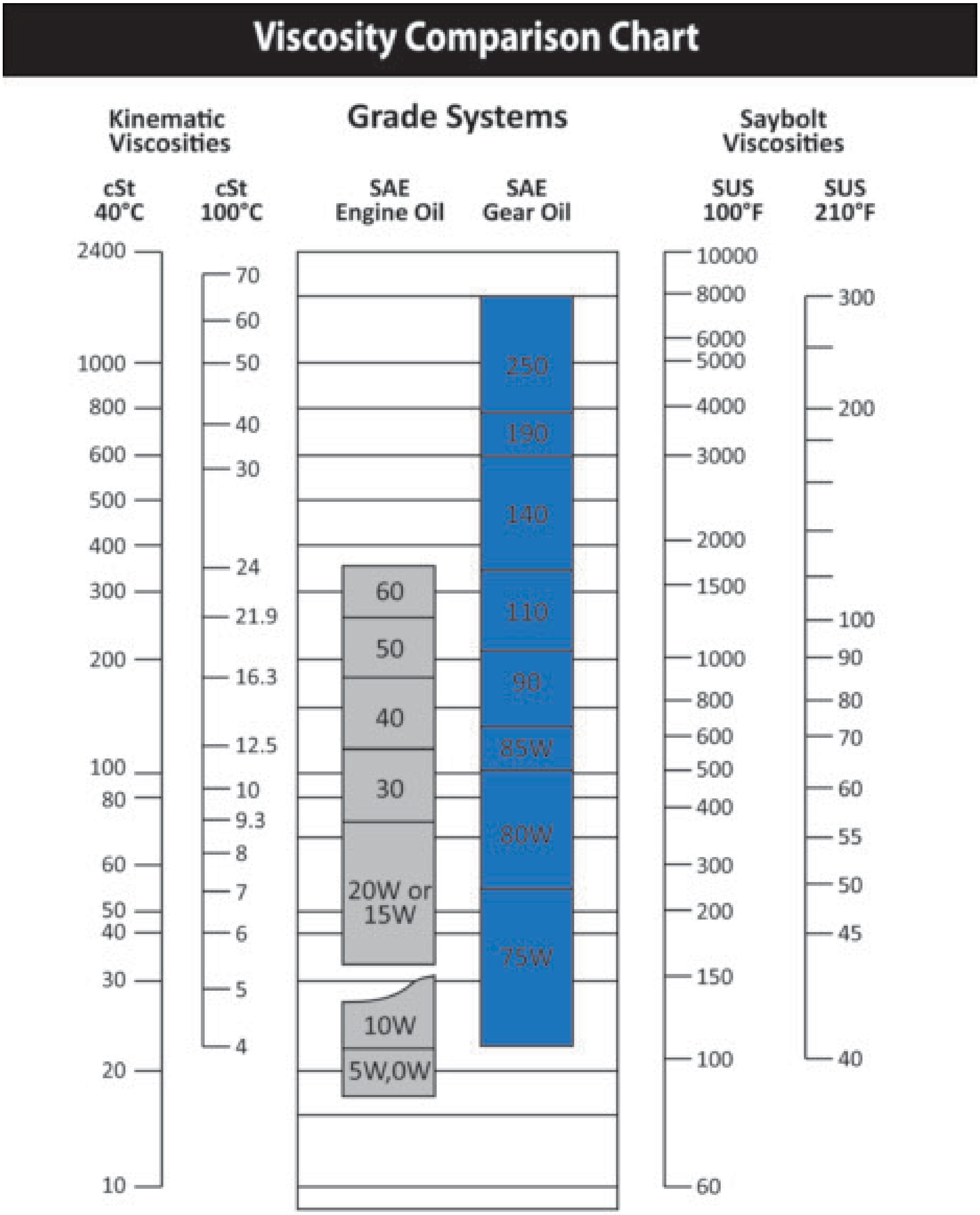
| SAE Viscosity Grade | Low-Temperature Viscosities | | High-Temperature Viscosities | | |
|---|---|---|---|---|---|
| | Cranking (cP) max at temp °C | Pumping (cP) max with no yield stress at temp °C | Kinematic (cSt) at 100°C min | Kinematic (cSt) at 100°C max | High Shear (cP) at 150°C and $10^6$ $s^{-1}$ min |
| 0W | 6200 @ -35 | 60,000 @ -40 | 3.8 | -- | -- |
| 5W | 6600 @ -30 | 60,000 @ -35 | 3.8 | -- | -- |
| 10W | 7000 @ -25 | 60,000 @ -30 | 4.1 | -- | -- |
| 15W | 7000 @ -20 | 60,000 @ -25 | 5.6 | -- | -- |
| 20W | 9500 @ -15 | 60,000 @ -20 | 5.6 | -- | -- |
| 25W | 13000 @ -10 | 60,000 @ -15 | 9.3 | -- | -- |
| 20 | -- | -- | 5.6 | < 9.3 | 2.6 |
| 30 | -- | -- | 9.3 | < 12.5 | 2.9 |
| 40 | -- | -- | 12.5 | < 16.3 | 2.9 (0W-40, 5W-40, and 10W-40) |
| 40 | -- | -- | 12.5 | < 16.3 | 3.7 (15W-40, 20W-40, 25W-40, and 40) |
| 50 | -- | -- | 16.3 | < 21.9 | 3.7 |
| 60 | -- | -- | 21.9 | < 26.1 | 3.7 |

Reprinted with permission from SAE J300 Nov2007

## Multigrade Oil Energy Requirements

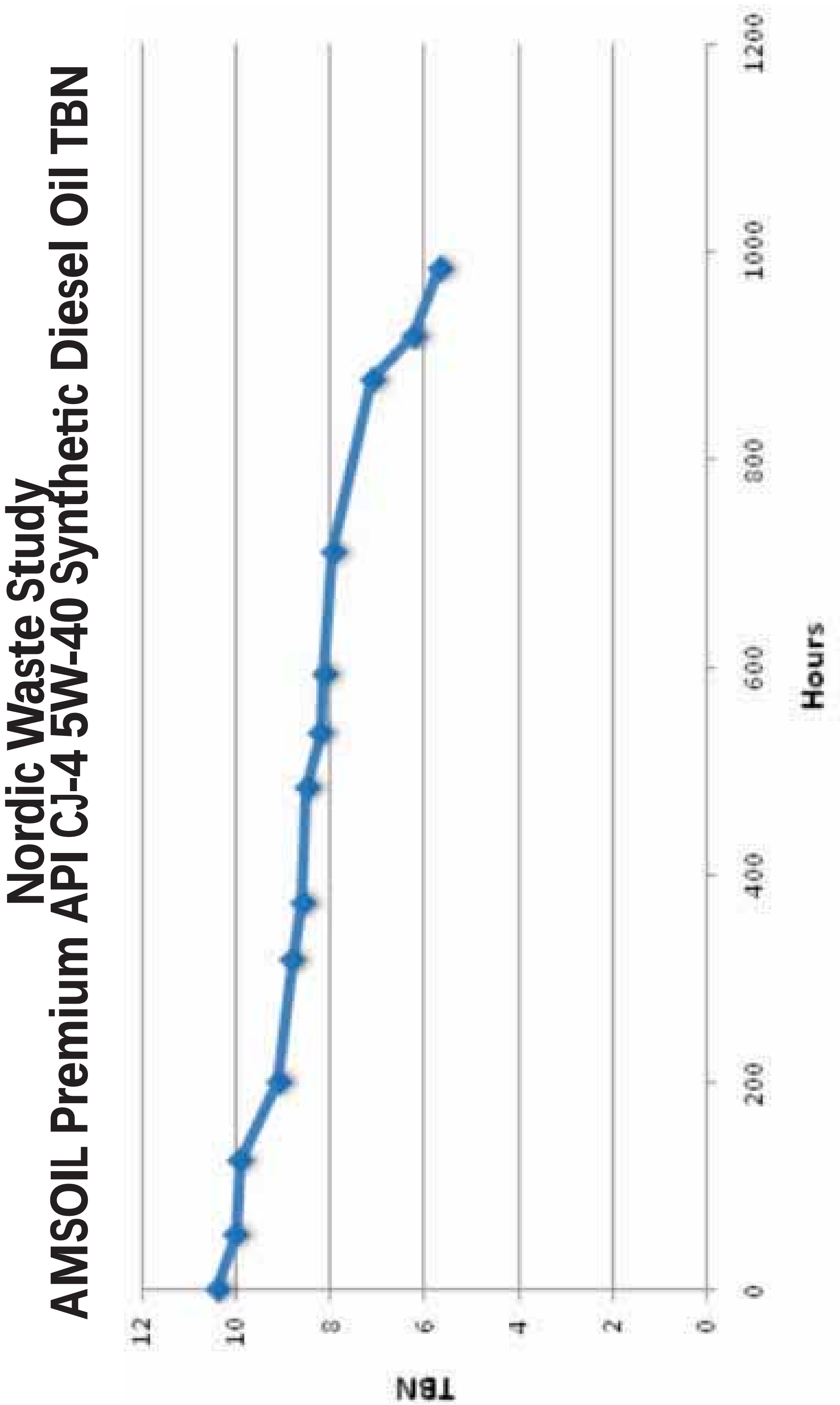


## Viscosity Comparison Chart




Appendix

**TBN Retention: Premium CJ-4 5W-40 Diesel Oil**



**FZG Gear Wear Test Results for AMSOIL 20W-50 Synthetic Motorcycle Oil**

Appendix

**Engine Parts from Marine Racing Application (3,000 + hrs)**

# Notes

# Notes

The First in Synthetics ®