Automotive Oil

Fast Facts Guide

Image: Machinery Lubrication Magazine

How to use this guide:

In a handy A to Z format, just dip into this fast facts guide and find a topic of interest

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Valvoline National Account Manager

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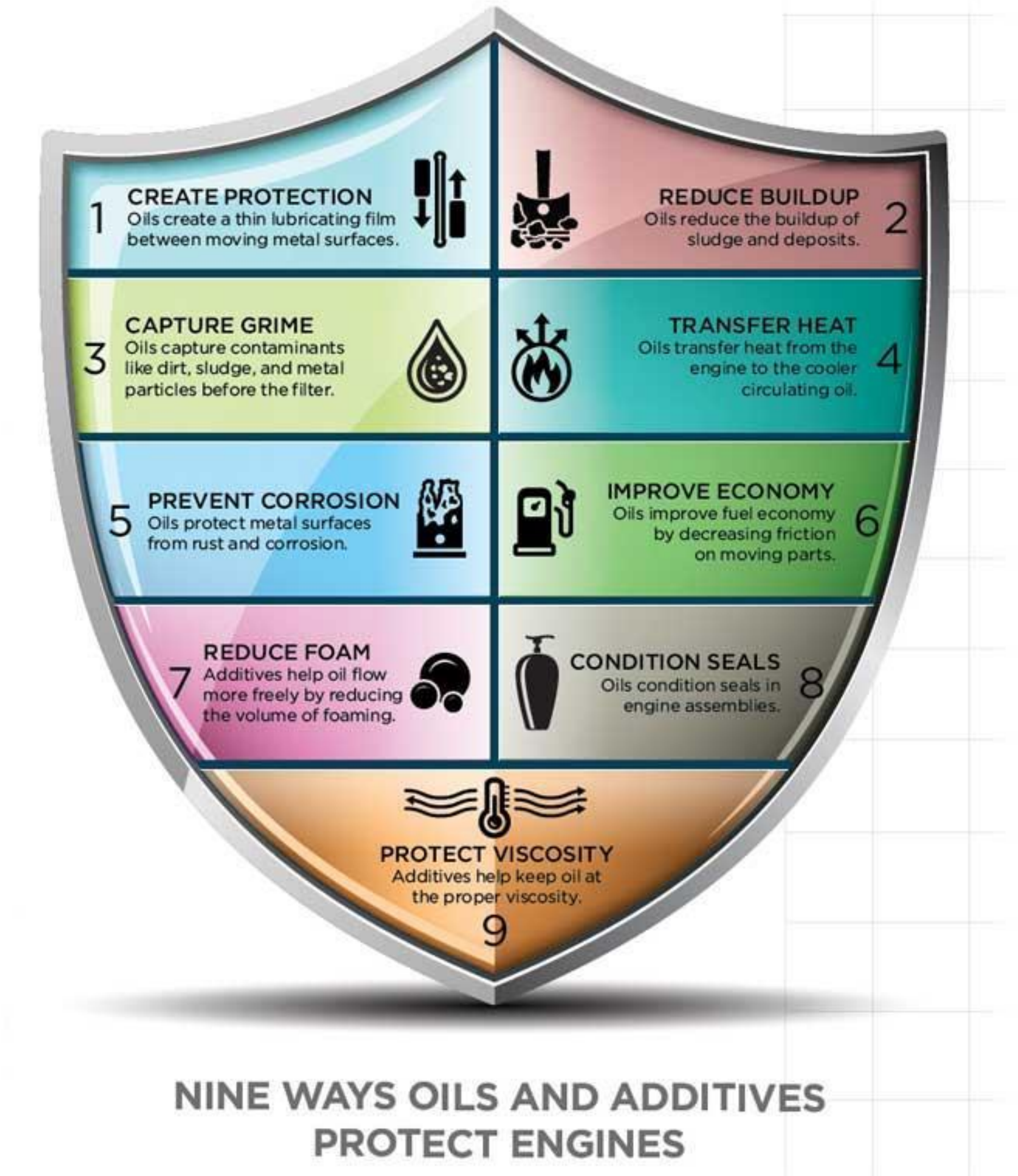
INTRODUCTION

How do automotive engine oils work?

They provide vital protection for engines in several ways:



1 **CREATE PROTECTION**
Oils create a thin lubricating film between moving metal surfaces.

2 **REDUCE BUILDUP**
Oils reduce the buildup of sludge and deposits.

3 **CAPTURE GRIME**
Oils capture contaminants like dirt, sludge, and metal particles before the filter.

4 **TRANSFER HEAT**
Oils transfer heat from the engine to the cooler circulating oil.

5 **PREVENT CORROSION**
Oils protect metal surfaces from rust and corrosion.

6 **IMPROVE ECONOMY**
Oils improve fuel economy by decreasing friction on moving parts.

7 **REDUCE FOAM**
Additives help oil flow more freely by reducing the volume of foaming.

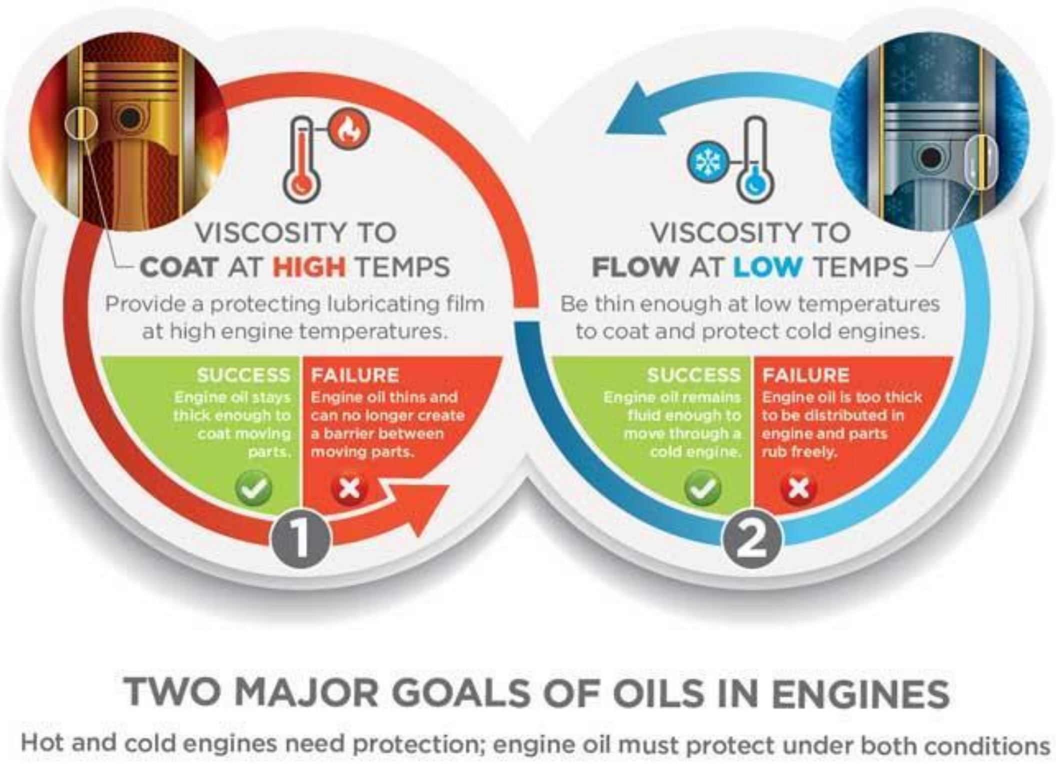
8 **CONDITION SEALS**
Oils condition seals in engine assemblies.

9 **PROTECT VISCOSITY**
Additives help keep oil at the proper viscosity.

NINE WAYS OILS AND ADDITIVES PROTECT ENGINES

Image: Machinery Lubrication Magazine

A

Absolute Viscosity	Viscosity is a fluid's resistance to flow. • Used to test the cold start and cold cranking viscosity for multigrade engine oil, measured in centipoise (cP) • Also known as Dynamic Viscosity Multigrade automotive engine oil viscosity measurements: • Dynamic Viscosity/Absolute Viscosity centipoise (cP) Cold start and cold cranking viscosity tests Named after a Frenchman called Jean Louis Poiseuille from the 1840s • Kinematic Viscosity centistokes (cSt) 40°C and 100°C viscosity tests Named after an Irishman called Sir George Stokes also from the 1840s • The third viscosity is High Temperature High Shear (HTHS) centipoise (cP) (HTHS) viscosity is tested at 150°C *(see Viscosity: Five definitions in automotive oil entry)* **Automotive oil goals**  Image: Machinery Lubrication Magazine

ACEA specifications

European Automobile Manufacturers Association (ACEA).
The ACEA sets the minimum performance specifications for lubricants.
The latest automotive oil sequences were launched in 2016, with new sequences expected during 2021.
All engine oil that is sold in Europe should meet an ACEA standard.
(see Four level approach to understanding oil specifications entry)

ACEA not Low SAPS car engine oil

	Petrol	Diesel	
Not Low SAPS	A3	B4	A3/B4
Not Low SAPS	A5	B5	A5/B5
Not Low SAPS	A7	B7	*A7/B7
*From 2021: Three new performance tests: LSPI, chain wear and turbocharger deposits			

ACEA Low SAPS car engine oil

Low SAPS	C1*	C2	C3
Low SAPS	C4	C5	C6**
*Removed in 2021			
**New in 2021: Three new performance tests: LSPI, chain wear and turbocharger deposits			

ACEA commercial engine oil

Low SAPS	E6	E8	E9	E11	F8*	F11*
Not Low SAPS	E4	E7				
						*Fuel economy
E8 & E11: Increased protection against oxidation, viscosity increase and piston deposits						
F8 & F11: HTHS viscosity of 2.9 to 3.2 cP for additional fuel economy benefits						

C1 to C5 oil
Examples: Valvoline oil

ACEA		
C1	SynPower™ ENV C1	5W-30
C2	SynPower™ ENV C2	0W-30
C3	SynPower MST C3	5W-30
C4	SynPower™ MST C4	5W-30
C5	SynPower™ XL-IV C5	0W-20

Additives

Chemicals are added to an automotive oil to perform specific tasks. Additives deplete within the engine, so regular oil changes are important.

Additives can counteract each other. Even to the degree to which additive gets to the surface first, forms the strongest layer and has the biggest effect.

Lubricant formulas need to balance the types and amounts of each of these additives in order to achieve the desired lubricant properties. For example, too much anti-wear additive is likely to affect the corrosion properties or friction modification performance of the lubricant.

The skill is with the additive and lubricant chemists to balance these challenges and create an automotive oil with all the desired characteristics.
(see Automotive oil – What determines a high quality automotive oil entry)

Typical additives in engine oil are:

Automotive oil additives	
Viscosity Modifier (VM)	Also known as Viscosity Index Improver (VII) Increases the base oil viscosity to the required SAE viscosity for multigrade oil at 100°C
Anti-wear additives	Help to combat wear on start-up, which is the boundary lubrication phase
Corrosion Inhibitor	Stops corrosion of metal components
Detergent	Keeps the engine clean of engine deposits and helps to neutralise corrosive acids
Dispersant	Stop soot from forming lumps and blocking the oil galleries
Oxidation Inhibitor	Reduces oxidation, which causes sludge and viscosity to increase
Pour Point Depressant (PPD)	Lowers the pour point of the oil. In cold conditions, (PPD) reduces the tendency of the oil to experience wax crystallisation. (PPD) is a polymer similar to the Viscosity Modifier additive. The pour point is the lowest temperature that the oil can be poured under test conditions
Rust Inhibitor	Similar to corrosion inhibitor
Anti-foam agent	Used to suppress the oil foaming in engines. It works by breaking up large bubbles into smaller bubbles. Foam can lead to an increased likelihood of oxidation of the oil
Friction Modifier	Reduces friction in an engine to enhance fuel economy

Additives enhance, suppress or impart new oil properties

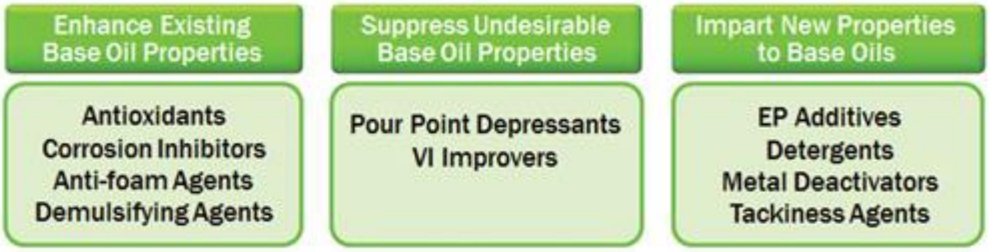


Image: Machinery Lubrication Magazine

Rust/corrosion inhibitor additive

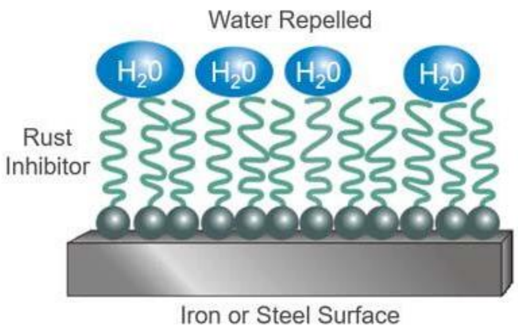


Image: Machinery Lubrication Magazine

Dispersant additive

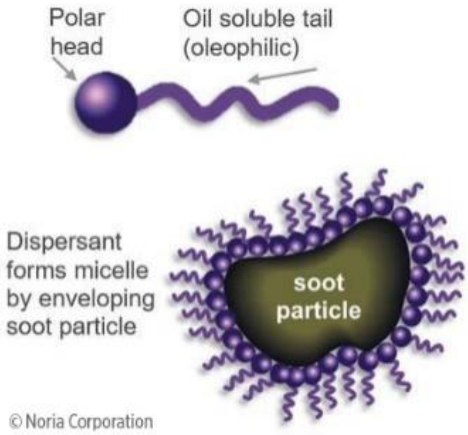


Image: Machinery Lubrication Magazine

Additive manufacturers	Infineum, Lubrizol, Afton and Oronite are examples of specialist additive companies that do the research and testing of additives for oil companies. An example of an Infineum engine test is the "Mountain Drive Cycle". This engine test simulates the Grossglockner High Alpine Road in Austria. Ascending 2,405 metres, where the engine oil averages 123°C and peaks at 140°C. *Acknowledgement: https://www.infineuminsight.com/en-gb/articles/passenger-cars/testing-engine-oil-oxidation/* *(see Oil formulation entry)* **Engine test simulates the Grossglockner High Alpine Road in Austria**  *Image: Infineum website*
Additive separation or drop out	Additives should be dissolved thoroughly in the oil and should not come out of solution. Extended storage times can be a cause of this issue. Engine oils have a relatively short shelf life, due to the complex additive pack. The specification sheet will usually state an acceptable use time, which tends to be in the region of 2 years. *(see Additives entry*)
Alkali	A substance with alkaline properties (basic) as opposed to acidic. Alkali additives in engine oils neutralise acids to prevent acidic build, which leads to oxidation, sludge build and varnish. *(see Total Base Number (TBN) entry)*
Anti-foam agent	An additive that is used to suppress oil foaming. It breaks large air bubbles into smaller ones. Foam in engine oil can lead to an increased likelihood of oxidation of the oil. *(see Additives entry)*
Anti-oxidants	An additive used to slow down the rate of oxidation in engine oil. Oxidation is the breakdown of oil and causes sludge and varnish. Oxidation increases engine oil viscosity. Anti-oxidants also help reduce the build-up of acids. *(see Additives entry)*
Anti-wear additives (AW)	Additives that protect bearing surfaces, especially during the engine start phase. This stage of lubrication is called boundary lubrication. Zinc dialkyldithiophosphates. (ZDDP) is a popular anti-wear additive.

(see ZDDP and Boundary lubrication entries)

API specifications

American Petroleum Institute (API) is an engine oil licensing and certification system. A similar body operates in Europe called ACEA.
(see ACEA specifications entry)

Examples of API specifications:

- API SP: Introduced in May 2020. Designed to provide protection against low-speed pre-ignition (LSPI)
- API CK-4: Diesel engines designed to meet 2017 on-highway exhaust emission standards
- www.api.org/products-and-services/engine-oil/eolcs-categories-and-classifications/oil-categories

API specifications
Examples: Valvoline oil

API		
SL/CF	SynPower™ FE	SAE 5W-30
SN	SynPower™ XL-III C3	SAE 5W-30
SN/CF	SynPower MST C3	SAE 5W-30
SN & SN Plus RC (Resource Conserving)	Synpower™ DX1	SAE 5W-30
SN+ SN	SynPower™ XL-IV C5	SAE 0W-20

"Approved oil" by the car manufacturer

Approved oil means the oil has been tested physically by the relevant car manufacturer.
The oil testing is exhaustive, worldwide and expensive. The approval certificate is a clear and unambiguous statement of the quality and suitability of the oil.

More car manufacturers are developing bespoke oil specifications, in line with the technical complexity of their engines.

An oil that claims to 'meet the specification' has not been through the car manufacturer/oil company testing and approval process.
(see Manufacturer oil specifications entry)

Manufacturer approved oil
Examples: Valvoline oil

Manufacturer approval		
Jaguar Land Rover (JLR)	SynPower™ ENV C1	SAE 5W-30
Peugeot Citroen (PSA)	SynPower™ ENV C2	SAE 0W-30
BMW, General Motors, Mercedes Benz, VW	SynPower MST C3	SAE 5W-30
Renault	SynPower™ MST C4	SAE 5W-30
Volkswagen, Porsche	SynPower™ XL-IV C5	SAE 0W-20

Arrhenius rule

The Arrhenius rule tells us that for every 10 degree Celsius increase, there is an approximate doubling of thermal breakdown and associated sludge and oxidation formation.
Elevated temperature is probably the biggest contributor to oil oxidation.
(see Thermal breakdown and oil oxidation entries)

Asperities

Microscopic projections on bearing surfaces.
(see Anti-wear additives, ZDDP and Boundary lubrication entries)

<table>
<tr><td>**ASTM International (ASTM)**</td><td>ASTM International (ASTM), known formerly as the American Society for Testing and Materials, is an international standards organisation. ASTM standards are found on oil specification sheets.
(see Specification sheet (How to interpret it) entry)

<table><tr><th colspan="3">ASTM standards
Example: Valvoline SynPower MST 5W-30 C3</th></tr><tr><td>Kinematic viscosity</td><td>**ASTM D-445**</td><td>12.1 cSt, mm2 /s @ 100 ºC</td></tr></table></td></tr>
<tr><td></td><td></td></tr>
<tr><td>**ATIEL**</td><td>ATIEL is the technical association representing manufacturers, developers and marketers in the European Lubricants Industry. www.atiel.org
(see ACEA specifications entry)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>**Automotive oil – What determines a high quality automotive oil**</td><td>Four crucial aspects determine high quality automotive oil:
• High quality base oil - Modern automotive oil is blended from Group III, severely hydrocracked or Group III Gas to Liquid (GTL) base oil. Group IV Polyalphaolefin (PAO) base oil is also used
• Carefully selected and balanced additives, at the correct treat rates
• A robust and long lasting Viscosity Modifier (VM) to ensure that the oil does not lose its' viscosity
• Blended by experienced research and development chemists to create a matched and balanced automotive oil
(see Group III base oil and synthetic oil entries)

Experienced research and development chemists blend balanced automotive oil

Image: Machinery Lubrication Magazine</td></tr>
<tr><td>**Automotive oil – How it is blended from base oil**</td><td>Base oil provides the start point. Valvoline's automotive oil, for example, uses high quality Group III base oil. Other methods include Gas to Liquid (GTL) or Group IV Polyalphaolefin (PAO) base oil.

With a 5W-30 multigrade oil, the "30" relates to a viscosity of 9.3 to <12.5 cSt at 100°C. To achieve this viscosity, a 4, 6 or 8 cSt base oil is used.
Viscosity Modifiers (VM), known also as Viscosity Index Improvers (VII), are added to "thicken" the oil's viscosity when it is at 100°C. By using a low viscosity base oil, with thickeners, the cold start and normal operation temperature viscosity standards can be achieved, as set out by the SAE Automotive Lubricant Viscosity Grades: Engine Oils – SAE J300.

Oil chemists develop a balanced set of additives that play specific roles but do not counteract each other.</td></tr>
</table>

“Selecting which base oil and additives to use for a particular application requires a great deal of experience, skill, testing and refinement.” – David Whitby: “Lubricants Blending and Quality Assurance”

Typical engine oil additives

Viscosity Modifier (VM)	Detergent	Dispersant	Oxidation Inhibitor
Pour point depressant	Corrosion Inhibitor	Anti-foam agent	Friction Modifier
Anti-wear additive			

The table below shows an example of an oil company’s percentage levels of additive and base oil to achieve the desired fully synthetic multigrade oil.
(see Base oil categories entry)

Use of low viscosity base oil to create multigrade engine oil

	0W-20	**0W-30**	**0W-40**	**5W-30**	**5W-40**	**5W-50**	**10W-60**
Base oil 4 cSt	17%	29%	34%	43%	49%	43%	
Base oil 6 cSt	67%	50%	40%				
Base oil 8 cSt				40%	29%	32%	71%
Base oil	83%	79%	74%	83%	77%	74%	71%
Additives	14%	14%	14%	14%	14%	14%	14%
Viscosity Modifier	3%	7%	12%	3%	9%	12%	14%
Total additives %	17%	21%	26%	17%	23%	26%	28%
	100%	100%	100%	100%	100%	100%	100%

Note how the three low viscosity base oils are used to create higher viscosity multigrade oil, by the inclusion of the Viscosity Modifier

B

Barrel and Drum size terminology	Drum is the correct term for the automotive oil container used in garage workshops. 208 litres = 44 UK (imperial) gallons = 55 US gallons. In the UK, a "barrel" of automotive oil can contain 199, 200, 205, 208 or 209 litres. The "upstream" oil industry barrel size is: 42 US gallons = 35 imperial gallons = 159 litres. *(see Crude oil and Base oil categories entries)*  Image: Machinery Lubrication Magazine **Outdoor storage protection for barrels**  Image: Machinery Lubrication Magazine

Base

A material that neutralises acids. Same as Alkali or Alkalinity.
(see Total Base Number (TBN) entry)

Base oil categories

Base oils are, primarily, hydrocarbons – i.e. a molecule with hydrogen and carbon atoms.

The American Petroleum Institute (API) categorises base oils into five groups: Group I, II, III, IV, and V, based on the Saturates, Sulphur and Viscosity Index.

Automotive oil requires base oil with high levels of saturates. The hydrocarbon molecules are saturated with hydrogen. High saturates levels mean that the molecular bond of the oil is stronger. This increases the resistance to oil oxidation and the reduction in viscosity.
Low sulphur levels are required for automotive oil. Sulphur reacts with oxygen and can cause corrosion and oxidation. It can also damage catalytic converters.

Viscosity Index is a scale that measures the oil's change of viscosity due to temperature.
The higher the Viscosity Index (VI) number, the better, because it represents a smaller change in the oil viscosity as temperatures change. Viscosity is measured at 40 °C and 100 °C.
VI is useful for comparison purposes with an oil analysis report.

American Petroleum Institute (API) – Base oil categories

	Saturates %	Sulphur %	Viscosity Index	Process
I	Less than 90%	Greater than 0.03%	80 to 120	Solvent processing - High in sulphur
II	Greater than 90%	Less than 0.03%	80 to 120	Hydrotreating
III	**Greater than 90%**	**Less than 0.03%**	**Greater than 120**	**Severely hydrocracked automotive oil**
IV	n/a	n/a	n/a	Polyalphaolefin (PAO) automotive oil
V	All other Base Stocks which are not covered in Group I to IV Polyglycols, PAG, Esters, Silicons, Polyisobutenes (PIBs) etc			

Modern automotive oil is blended from Group III or Group III Gas to Liquid (GTL) base oils.
Both types of Group III are classed as fully synthetic in most countries. However, in Germany, Group III base oil is classed as HC Synthesetechnologie.
Group IV Polyalphaolefin (PAO) is also a fully synthetic engine oil.
(see Group III base oil entry)

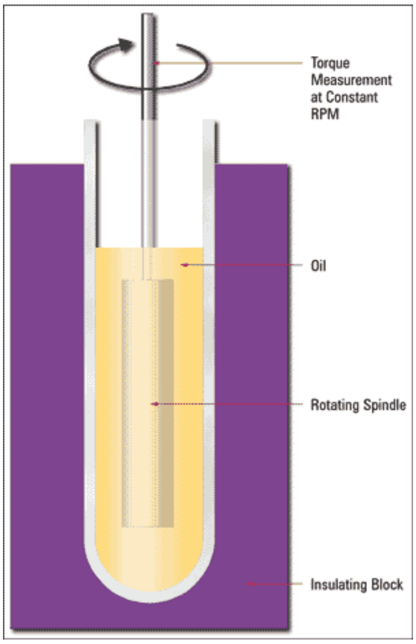
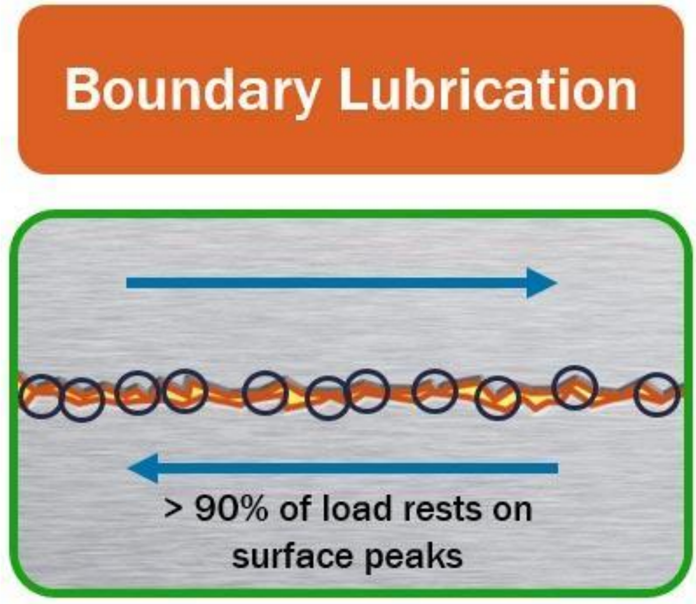
Typical properties of Group III base oil

	4 cSt	5cSt	6 cSt	7 cSt	8 cSt
Colour	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%
Density	0.830	0.835	0.836	0.839	0.843
Kinematic Viscosity at 100°C cSt	4.20	5.10	6.00	6.90	8.00
Kinematic Viscosity at 40°C cSt	18.6	25.3	32.4	39.4	50.5
Viscosity Index (VI)	127	126	133	135	128
Pour point	-18	-15	-15	-18	-15
Flash point	220	240	234	240	260
Sulphur content	<0.01	<0.01	<0.01	<0.01	<0.01
NOACK % weight 250°C	15	9	8	4	3

Acknowledgement: Pathmaster Marketing Ltd

Things to note from the base oil properties table:	
Kinematic Viscosity at 100°C cSt	The Viscosity Modifier (VM) will boost the viscosity at 100°C to the required value, for example, SAE 30 grade
Pour point	Pour point depressant additive will significantly lower this temperature
NOACK %	The evaporation of the oil decreases as the viscosity increases

Base oil interchange (BOI)	During the late 1980s, the major oil blenders realised that the costs involved in changing between different base oil suppliers were getting prohibitive. This was because the laboratory and engine tests required to meet the American Petroleum Institute (API) specifications had to be repeated using the new base oil. The costs could run into thousands of dollars per test. In 1989 API introduced guidelines for those tests that had to be repeated. The Base oil interchangeability (BOI) guidelines ensure the performance of engine oils are not affected when different base oils are interchanged. *(see Automotive oil – What determines a high quality automotive oil entry)*
Blending	Automotive oils are produced by mixing one or more base oils with a carefully selected set of additives, in a procedure known as "blending". *(see Automotive oil – What determines a high quality automotive oil entry)*
Biodiesel	Fatty Acid Methyl Esters (FAME) is the chemical term for biodiesel, derived from renewable sources, using a process called transesterification of vegetable oils and animal fats. Biodiesel increases the rate of engine oil oxidation and the formation of sludge and acids. *(see Oil oxidation entry)*
Brookfield Viscosity	This machine is used to measure the cold start viscosity, as determined by the Automotive Lubricant Viscosity Grades: Engine Oils – SAE J300. The Dynamic/Absolute Viscosity of the oil is measured in centipoise (cP). *(see Viscosity: Five definitions in automotive oil entry)*

	Rotary Viscometer ASTM D2983 used for measuring dynamic/absolute viscosity  *Image: Machinery Lubrication Magazine*
Boundary lubrication	One of four stages of lubrication within an engine. Boundary lubrication is related to metal-to-metal contact. This is especially relevant during start-up or low-speed and subsequent high-load conditions. The oil is not thick enough to overcome the microscopic roughness in the bearings (asperities). Friction tends to be at its highest during boundary lubrication. 70% of engine wear can occur during start-up. *(see Mixed, Hydrodynamic, elastohydrodynamic lubrication* and *asperities entries)* **Boundary lubrication - 90% of the load rests on the asperities**  *Image: Machinery Lubrication Magazine*

Sliding forces at boundary lubrication stage

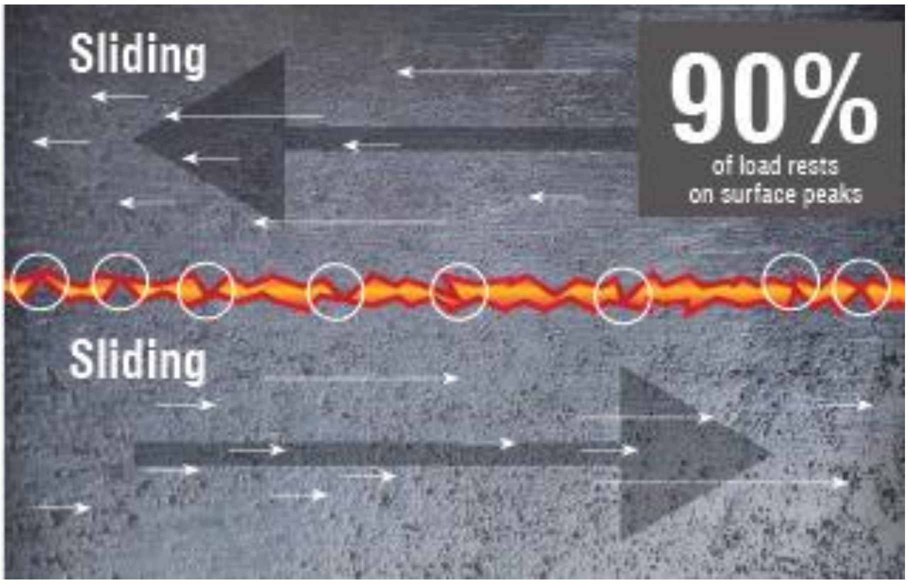


Image: Machinery Lubrication Magazine

Boundary lubrication, heat and load forces

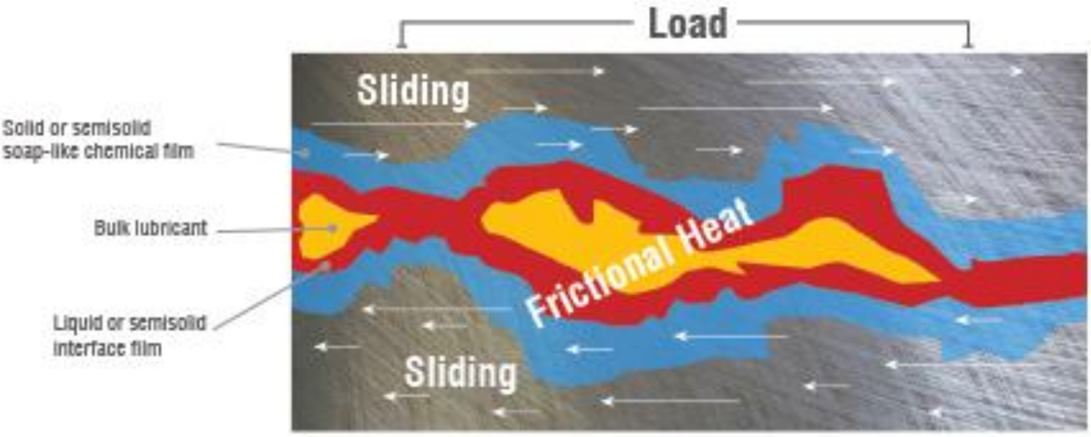


Image: Machinery Lubrication Magazine

<table>
<tr><th colspan="2">C</th></tr>
<tr><td>Capillary Viscometer</td><td>Used to measure the Kinematic viscosity of engine oils.

Viscosity is measured in centistokes (cSt) at 40°C and 100°C as required for multigrade oils, SAE Automotive Lubricant Viscosity Grades: Engine Oils – SAE J300.
<i>(see Viscosity: Five definitions in automotive oil entry)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Catalytic converter</td><td>Controls exhaust emissions. Three-way catalytic converters use a process of reduction that converts nitrogen oxides (NOx) into harmless nitrogen (N) and oxygen gases (O). Simultaneously, a process of oxidation converts carbon monoxide (CO) into carbon dioxide (CO2) and turns unburned hydrocarbons (HC) into carbon dioxide (CO2) and water (H2O).
<i>(see Diesel Particulate Filter (DPF) entry)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Centipoise (cP)</td><td>Centipoise (cP) is known also as the SI unit Millipascal-second (mPa.s).
Viscosity measurement for dynamic/absolute oil viscosity.

The cold start viscosity and cranking performance of multigrade oil are determined by the SAE Automotive Lubricant Viscosity Grades: Engine Oils – SAE J300.

Named after a Frenchman called Jean Louis Poiseuille from the 1840s.
<i>(see Viscosity: Five definitions in automotive oil entry)</i>

<table>
<tr><th colspan="3">Centipoise viscosity (cP)
Example: Valvoline SynPower MST C3 5W-30</th></tr>
<tr><td>Cold Start Performance</td><td><6,200 mPa-s or (cP) @ -30°C</td><td>Viscosity mPa-s -30°C
ASTM D-5293</td></tr>
</table>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Centistoke (cSt)</td><td>The measurement for Kinematic viscosity (cSt), also known by the SI unit mm2/s.

Centistokes (cSt) measure the viscosity of engine oil at 40°C and 100°C. As determined by the SAE Automotive Lubricant Viscosity Grades: Engine Oils – SAE J300.

Named after an Irishman called Sir George Stokes from the 1840s.
<i>(see Viscosity: Five definitions in automotive oil entry)</i>

<table>
<tr><th colspan="3">Centistoke viscosity (cSt)
Example: Valvoline SynPower MST C3 5W-30</th></tr>
<tr><td>Viscosity at 100°C</td><td>12.1 mm^2/s or (cSt)</td><td>Viscosity mm^2/s @ 100°C
ASTM D-445</td></tr>
<tr><td>Viscosity at 40°C</td><td>72 mm^2/s or (cSt)</td><td>Viscosity mm^2/s @ 40°C
ASTM D-445</td></tr>
</table>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Chemistry and oil formulations</td><td>Oil companies employ teams of chemists in their Research and Development laboratories to develop the next generation of automotive oils.

The three crucial areas are high quality base oil, a carefully formulated additive pack and a very specific Viscosity Modifier (VM).</td></tr>
</table>

	The chemical complexity is needed to overcome the hurdles of engine longevity, emission and fuel economy regulations, as well as meeting car manufacturers' requirements that are becoming ever-more bespoke. *(see Automotive oil – What determines a high quality automotive oil)* **Complex oil chemistry to overcome modern engine challenges**  Image: Machinery Lubrication Magazine
CO2 / Fuel Economy Testing	A key driver for car manufacturers (OEMs) oil specifications is the reduction of CO2. There are increasingly stringent targets set for OEMs to meet - currently 95 g/km for passenger vehicles. CO2 is a direct result of the combustion process and so cannot be altered by after treatment systems. It can only be improved by direct engine changes or reducing internal engine resistance. By reducing the oil viscosity or improving the friction characteristics of the additive package a reduction in internal engine resistance can be achieved which can lead to an improvement of fuel economy. The testing is one of the longest duration tests of an OEM engine approval. There are up to 14 days of engine and lubricant testing, using a chassis dynamometer against a specified test cycle. A comparison is made between the levels of carbon in the fuel with the level of carbon in the exhaust gases. *(see Worldwide Harmonised Light Vehicle Test Procedure (WLTP))* *Acknowledgement: Graeme Wilcock: ISP Testing Institute Germany*  Image: ISP website
Cold Cranking Simulator (CCS)	A machine that is used to measure the cold crank performance of multigrade oil. There are two low temperature tests. The engine needs to turn over and start and the oil has to reach all the engine galleries quickly. The viscosity is measured in centipoise (cP). The test criteria are determined by the SAE Automotive Lubricant Viscosity Grades: Engine Oils – SAE J300. *(see SAE Grade entry)*

SAE Automotive Lubricant Viscosity Grades: Engine Oils – SAE J300
Cold cranking and cold pumping temperatures

SAE viscosity grade	Low temperature cranking (cP)	Low temperature pumping (cP)
0	-35°C	-40°C
5	-30°C	-35°C
10	-25°C	-30°C
15	-20°C	-25°C
20	-15°C	-20°C
25	-10°C	-15°C

Commercial truck oils

Commercial oil tends to have two categories - Super High Performance Diesel (SHPD) and Ultra High Performance Diesel (UHPD).

- Super High Performance Diesel (SHPD) is a category that describes the European OEM formulation strategy, based on oil service life and performance.
- Ultra High Performance Diesel (UHPD) is a category that is based on extended oil service life, higher fuel economy and lower CO2 emission strategies.

Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR) after-treatment systems are employed in these applications in commercial vehicles.
(*see (SHPD) and (UHPD) entries)*

ACEA E6 & E9 commercial oil

E6 Low SAPS	Extended drain	Up to 140,000K *	Steady duty cycles	Highway use	10W-40 5W-30
E9 Low SAPS	Standard drain	Up to 70,000K *	Extreme duty cycles	Harsh stop start conditions	15W-40 10W-40 10W-30

*See handbook

ACEA commercial engine oil

Low SAPS	E6	E8	E9	E11	F8*	F11*
Not Low SAPS	E4	E7				
						*Fuel economy
E8 & E11: Increased protection against oxidation, viscosity increase and piston deposits						
F8 & F11: HTHS viscosity of 2.9 to 3.2 cP for additional fuel economy benefits						

Corrosion Inhibitor

An additive that is used to protect metal surfaces from corrosion by water, acids and other contaminants.
Corrosion inhibitors work by coating the metal surface with a hydrophobic layer of additive which prevents the ingress of water.
(see Additives entry)

Crude oil

Crude oil is also referred to as “upstream” and base oils are also referred to as “downstream".

The term “crude oil” can be interchanged with the term *Petroleum* (not to be confused with petrol, or gasoline). Petroleum literally means "rock oil". Petroleum comes from the Latin word "*petra*", meaning rock, and "*oleum*", meaning oil.

Crude oil is the remains of organisms that lived and died millions of years ago, mainly mud-buried plankton. Crude oil is refined into base oil.
(See API Base oil categories and Group III Base oil entries)

Refining crude oil to base oil

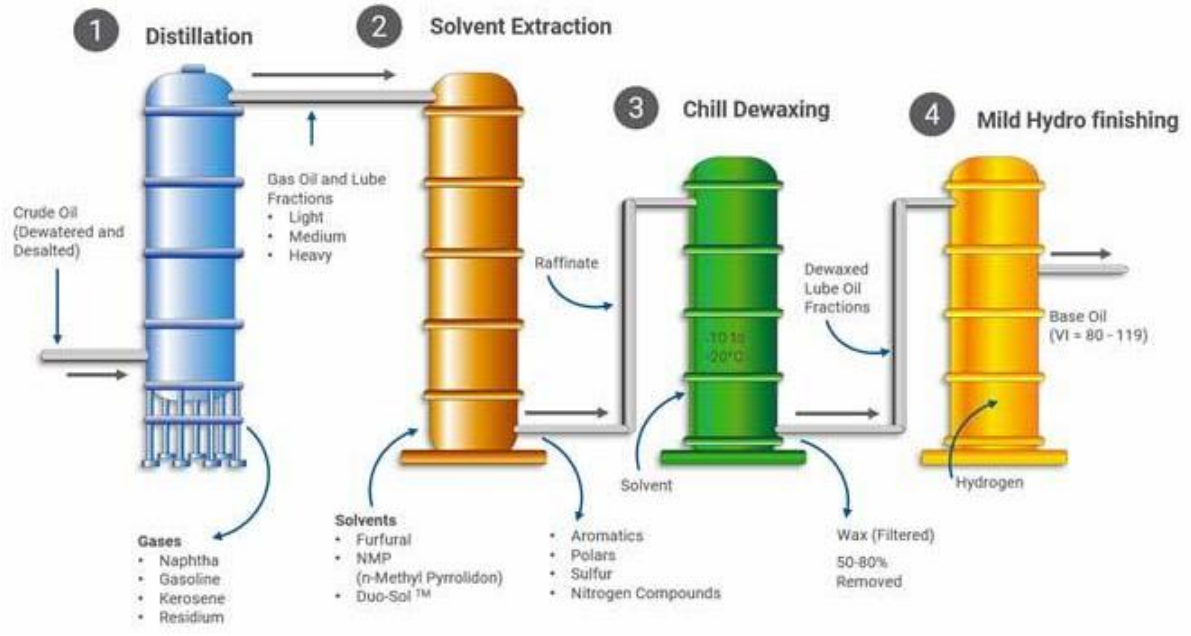


Image: Machinery Lubrication Magazine

Oil refinery

Image: Machinery Lubrication Magazine

D	
Degradation	Describes oil deterioration over time. Oil degradation can be due to oxidation, heat, contamination, additive depletion, or a combination of these factors. *(see Oil oxidation entry)*
Depletion of additives	Additives diminish with use as they protect the engine. The Viscosity Modifier (VM) can have their molecular chains ruptured, leading to viscosity loss. High quality engine oil should remain "shear stable" throughout the oil change interval. Gradual deterioration of the protection highlights why oil drain intervals should not be exceeded. *(see Additives entry)*
Deposits	Oxidation, due to the breakdown of oil, promotes sludge, varnish, lacquer and carbon deposits which can block oil galleries. *(see Oil oxidation entry)*
Detergent	An additive that keeps engine internals clean by preventing deposits from forming. Detergents work with dispersants to keep the soot particles in suspension until the next oil drain. Diesel engines especially experience high soot levels within the crankcase, which the engine oil must control to prevent harmful deposit build. Detergent also controls the acidity levels. Barium-based detergents began to be phased out during the 1970s due to toxicity fears, whilst the new magnesium-based detergents took their place. *(see Additives entry)*
Detergent Inhibitor pack (DI pack)	Additive manufacturers produce pre-prepared additive packs. The DI pack will contain the essential additives designed for the specific application. For automotive use, the additive pack may contain detergent, dispersant, oxidation inhibitor and anti-wear additives. The Viscosity Modifier (VM) is a separate entity. *(see Additives entry)*

Example of a Detergent Inhibitor pack (DI pack) for automotive use	
Detergent	23%
Dispersant	60%
Oxidation inhibitor	9%
Anti-wear	8%
	100%

Acknowledgement "Lubricant Blending and Quality Assurance" David Whitby

Detonation	Uncontrolled explosion of the air/fuel mixture within the combustion chamber. Also known as "knock". *(In a modern engine context, see: Low Speed Pre Ignition (LSPI) entry)*
Diesel Particulate Filter (DPF)	Diesel Particulate Filters (DPF) became mandatory with Euro V emissions and work by capturing and storing soot. Engine oil that is not designated as "Low SAPS" can clog the DPF permanently.

ACEA has six Low SAPS specifications for cars and light commercial engine oils: ACEA C1, C2, C3, C4, C5, and C6.
(see ACEA specifications entry)

ACEA Low SAPS oil
Examples: Valvoline oil

ACEA Low SAPS		
C1	SynPower™ ENV C1	SAE 5W-30
C2	SynPower™ ENV C2	SAE 0W-30
C3	SynPower MST C3	SAE 5W-30
C4	SynPower™ MST C4	SAE 5W-30
C5	SynPower™ XL-IV C5	SAE 0W-20

Dispersant

An additive used to ensure that soot and other insoluble particles cannot accumulate and form deposits within the engine's oil galleries and restrict oil flow.

Diesel engines are especially susceptible to soot, the particles of which are 98% carbon and can be less than 1 micron in size.

Dispersants are the highest volume additive used in engine lubricants.

The oil should be dark when drained, showing that soot was held in suspension by the dispersant additive.
(see Additives entry)

Keeping soot particles in suspension

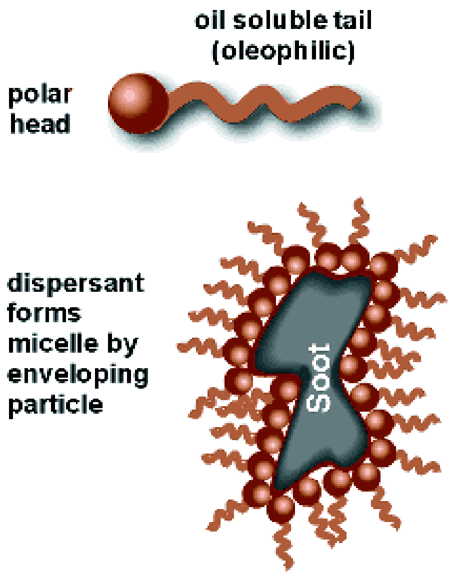


Image: Machinery Lubrication Magazine

Duty cycle

The duty cycle highlights an engine's typical operating conditions i.e. how much it runs at low-load, idling, stop-start, high speed etc.
(see Hybrid oils entry)

E

<table>
<tr><td>Elastohydrodynamic lubrication (EHL)</td><td>This phenomenon occurs in roller bearings and camshaft lobes when the curve of the roller and the race are in opposite directions and have a very small contact area. Extremely high pressure is exerted on the bearing by the oil, in the region of 450,000 PSI and there is momentary elasticity or a temporary deformation of the metal bearing. The bearing returns to its normal shape as the rotation continues. The oil film thickness is in the region of 1 micron. The good news is the surface asperities are in the order of 0.4 to 0.8 microns.
<i>(see Boundary, Mixed and Hydrodynamic lubrication entries)</i>

Elastohydrodynamic Lubrication (EHL)


<i>Image: Machinery Lubrication Magazine</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Electric vehicles (EV)</td><td>Specific oils are being developed for certain types of hybrid engines. The cycle of the engine starting and stopping repeatedly means that the engine runs hot and cold. These conditions risk further oxidation, corrosion and water dilution in the oil due to condensation.

Hybrid oils combat all three issues. Valvoline offers dedicated oils to meet the different challenges that each hybrid engine type presents:
<i>(see Hybrid oils entries)</i>

<table>
<tr><th colspan="2">Definitions: Electric Vehicles (EV)</th></tr>
<tr><td>Mild Hybrid Electric Vehicle</td><td>Mild HEV</td></tr>
<tr><td>Full Hybrid Electric Vehicle</td><td>Full HEV</td></tr>
<tr><td>Plug-in Hybrid Electric Vehicle</td><td>PHEV</td></tr>
<tr><td>Range Extended Electric Vehicle</td><td>REEV</td></tr>
<tr><td>Battery Electric Vehicle</td><td>BEV</td></tr>
<tr><td>Fuel Cell Electric Vehicle</td><td>FCEV</td></tr>
<tr><td>Conventional Internal Combustion Engine</td><td>ICE</td></tr>
</table></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Emulsion</td><td>A mix of oil and water. Creates a cloudy appearance. This can be the sign of a failed head gasket or normal condensation within the crankcase, especially if present at the engine’s highest point.
<i>(see Fuel dilution entry)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Engine deposits</td><td>Sludge, varnish and carbon residues, present on the engine metal surfaces. Oil oxidation tends to be the culprit.
<i>(see Oil oxidation entry)</i></td></tr>
<tr><td></td><td></td></tr>
</table>

Ester	An additive that might be added to Group III, or Group IV, base oils. Ester additives provide good lubricity, whilst not being excessively volatile and are biodegradable. Esters also help to control seal material compatibilities. *(see Group V base oil entry)*
European Engine Lubricants Quality Management System (EELQMS)	The (EELQMS) embraces various European, North American and global quality standards, test methods and procedures, together with industry Codes of Practice and the requirements of the ACEA European Oil Sequences. It is used to help guarantee the quality of European automotive engine oils. www.eelqms.eu *(see ACEA specifications)*
Exhaust Gas Recirculation (EGR)	Exhaust Gas Recirculation (EGR) reduces Nitrous Oxide (NOx) emissions and assists engine efficiency by influencing cylinder temperatures. It permits a controlled quantity of exhaust gas to enter the intake manifold. *(see also Selective Catalytic Converter (SCR) entry)*

Image: Machinery Lubrication Magazine

F

Film strength

The ability of an oil film to withstand pressure due to load, temperature and speed. A loss of film strength promotes metal to metal contact, creating wear. A shear-stable oil retains its film strength. An oil can lose its shear stability by the depletion of the Viscosity Modifier (VM).
(see Viscosity Modifier (VM) entry)

Catastrophic bearing failure

Image: Machinery Lubrication Magazine

Flash point

The temperature at which oil vapours will ignite. The test is used to detect fuel dilution in engine oil. Diesel engines in particular suffer from fuel dilution.
(see Fuel dilution entry)

Flash Point Example: Valvoline SynPower MST C3 5W-30		
Flash Point	**230°C**	COC* °C ASDM D-92 *Cleveland Open Cup

Cleveland Open Cup (COC) machine used to test oil flash point

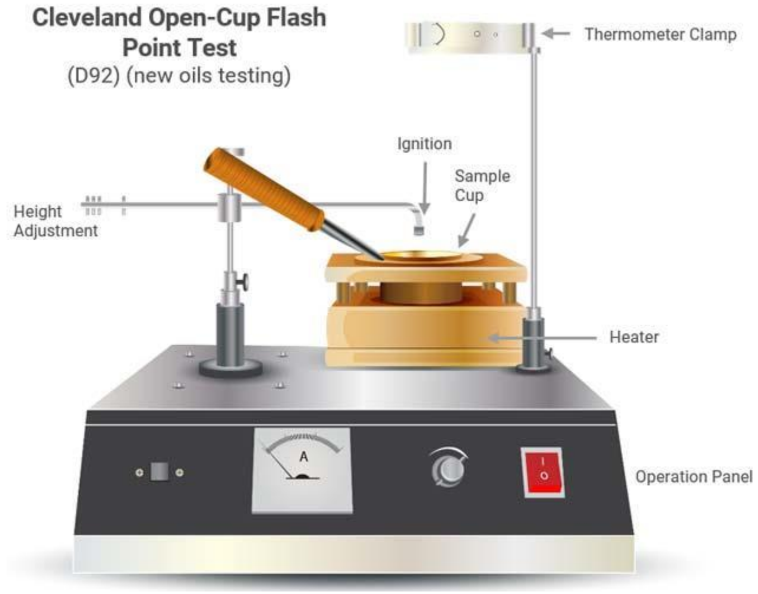


Image: Machinery Lubrication Magazine

Foam Inhibitor

Foam in engine oil can lead to oxidation of the oil, risking flow, pressure and cavitation issues. The additive works by breaking up large bubbles into smaller ones.
(see Additives entry)

Foam Inhibitor at work

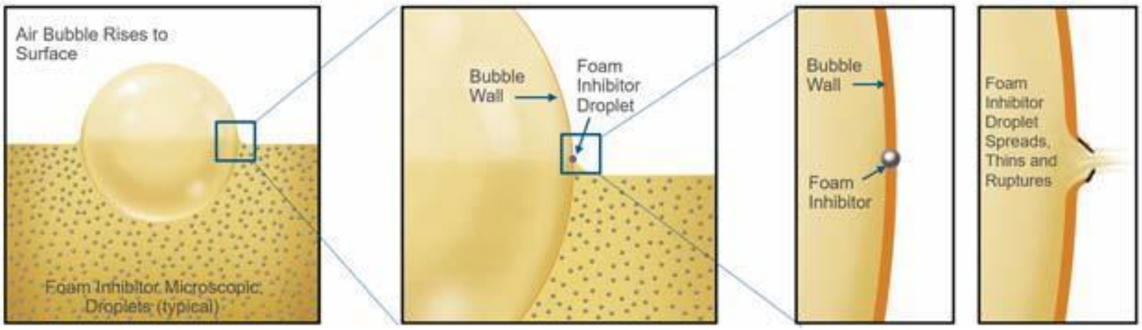


Image: Machinery Lubrication Magazine

Formulating and developing a new automotive engine oil

Automotive oils are among the most complex of oils.

The table below shows the steps an oil company will go through to develop a new oil or improve an existing oil.

At any stage, modifications may have to made and the process has to revert to the formulate product stage. Engine tests are very expensive and great care and planning are taken to ensure the process of automotive oil formulation is as efficient as possible.

Usually, it is not too difficult to meet a single engine test, in isolation. It is a combination of requirements that causes the most problems. Conflicts and compromises can be caused, for example, by sludge performance versus corrosion inhibition or anti-wear performance. Another example would be dispersancy and detergency versus anti-foam performance.

The ACEA specifications (July 2020 Rev 3 for "Gasoline and Diesel engines with aftermarket devices"), list nine different engine tests and fifteen different laboratory tests for the Low SAPS C1 to C5 engine oils.

The task is not finished with the oil passing the engine and performance tests and targets. The oil now has to be evaluated by car manufacturers (OEMs). This may involve several field trials and can take several years to complete and get that all-important certificate of "Manufacturer approved oil".
(see Chemistry and oil formulations and Automotive oil – What determines a high quality automotive oil entries)

Developing or improving a new oil
Select base oil
Select additives and appropriate treat rates
Formulate product
Laboratory tests
Bench rig tests
Approval tests
Field trials
Commercialise

Trial blends submitted for tests against specifications

Key test property of the oil	Modification required
Kinematic viscosity at 100°C.	Change base oil, Viscosity Modifier (VM) or treat rate
Pour point	Alter pour point depressant
Cold start: CCS dynamic viscosity (CCS: Cold Cranking Simulator)	Alter base oil or Viscosity Modifier (VM)
Cold cranking: MRV dynamic viscosity (MRV: Mini-Rotary Viscometer)	Alter base oil, Viscosity Modifier (VM), or pour point depressant
Volatility (NOACK)	Base oil mix
Shear Stability	Viscosity Modifier (VM). Use a different molecular weight (VM)
High Temperature High Shear viscosity (HTHS)	Viscosity Modifier type and or molecular weight

Acknowledgement: "Lubricant Blending and Quality Assurance" – David Whitby

Fourier Transform Infrared (FTIR)

Used in oil analysis. An infrared light detects oxidation and additive depletion in engine oil.
(see Oil analysis entry)

Four level approach to understanding oil specifications

This strategy helps you to decipher whether an oil is suitable for a particular application:
(see Manufacturer specifications and ACEA entries)

Four key questions to understanding oil specifications

Q1.	↓	Is the oil Mineral, Semi Synthetic or Fully Synthetic?
Q2.		What is the viscosity of the oil? E.g. 5W-30?
Q3.		What is the ACEA or ILSAC specification? e.g. C1, C2, C3, C4, C5, C6 or ILSAC GF6-A, GF6-B?
Q4.		Is there a manufacturer specification? e.g. BMW LL-17FE

The manufacturer specification is the most important for warranty terms and conditions

Fuel dilution

Unburnt fuel that contaminates the engine oil. Diesel vehicles with faulty DPFs are at a notable risk.

The problems associated with excessive contamination beyond 3% are:
- There can be a reduction of oil viscosity, due to diesel having a lower viscosity than engine oil
- In the longer term, there can be an increase in oil oxidation or sludge. Either event is worth avoiding by regular oil changes
- The oil's flash point is also lowered, leading to a higher fire risk

Fuel dilution leads to elevated oil levels, which can be forced through oil seals, risking severe mechanical failure, engine runaway, or even a fire. Fuel dilution can also be linked to and can affect cars fitted with after treatment systems that use post-combustion fuel injections to re-generate the DPF.
(see Oil oxidation entry)

Friction Modifier (FM)

Friction modifiers are additives that reduce wear and friction between surfaces, particularly during the crucial boundary lubrication stage. For example, molybdenum dialkyldithiocarbamate (MoDTC).
(see Additive entry)

G

Gas to Liquid (GTL)	A process that uses natural gas to create Group III base oil. The first step uses natural gas to make Syngas, followed by the Fischer-Tropsch synthesis process. GTL base oil has a high Viscosity Index (VI) with good oxidative stability. *(see Group III base oil entry)*
Gasoline Direct Injection (GDI)	GDI engines have petrol injected directly into the combustion chamber. This is distinct from manifold/port/indirect fuel injection systems, which inject fuel behind the intake valve, called Port fuel injected (PFI) engines. GDI engines are susceptible to Low Speed Pre Ignition (LSPI). *(see Low Speed Pre Ignition (LSPI) entry)*
Gasoline Particulate Filter (GPF)	GPFs are constructed of ceramic material and contain channels that run through the filter. Particles in the exhaust gases are trapped by the channel walls. The next generation of (GPFs) will have lower size limits for particulates, reduced from 23 nanometres to 10 nanometres (0.023 microns down to 0.01 microns). ACEA Low SAPS oil, in particular ACEA C5, is often stipulated in the manufacturer oil specifications, to ensure that the (GPF) does not get blocked by particulate contaminates. *(see Diesel Particulate Filter entry)*
Gear oils and gearbox terms	• Dual Clutch Transmission (DCT) o Volkswagen Group use the term Direct Shift Gearbox (DSG) o Porsche Doppelkupplungsgetriebe (PDK) o Audi's S-tronic o Ford PowerShift BorgWarner o BorgWarner, Getrag, LuK, Ricardo, ZF Friedrichshafen • Other types of transmissions o Continuously Variable Transmission (CVT) o ZF automatic transmission 6, 8, 9 speed o ATF Automatic Transmission • Traditional gear oils e.g. 75W-80, 75W-90 What is the difference between GL-4 and GL-5 in traditional gear oils? GL-4 has a reduced Extreme Pressure additive (EP). The Sulphur/Phosphorus (EP) additive can react aggressively to the copper bronze synchromesh in gearboxes. GL-5 has roughly 50% more (EP) additive compared to GL-4. • Limited Slip Differential oil (LS or LSD) have unique applications in Limited Slip Differentials • The SAE use Automotive Gear Lubricant Viscosity Classification SAE J306

Gear teeth failure

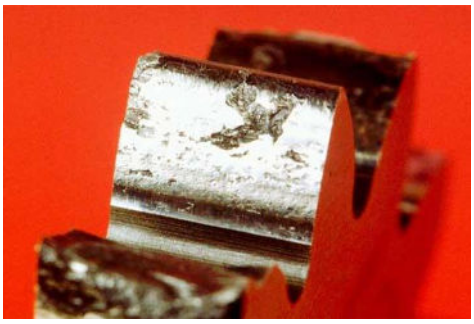


Image: Machinery Lubrication Magazine

Bearing failure

Image: Machinery Lubrication Magazine

Grease - National Lubricating Grease Institute (NLGI)

Grease is made up of three components: base oil, additives and a thickener. The thickener's job is to act like a sponge and hold the base oil and additives together.

Common grease additives are oxidation and rust inhibitors, extreme pressure, anti-wear, and friction-reducing agents.

The National Lubricating Grease Institute (NLGI) uses a "Penetrometer" that determines the viscosity. The test is based on the "penetration" of a cone of given weight that is allowed to sink into a grease for five seconds at a standard temperature of 25°C. The depth to which the cone sinks into the grease is the penetration.

National Lubricating Grease Institute (NLGI)

NLGI number	Penetration at 25°C	Appearance
000	445-475	fluid
00	400-430	semi-fluid
0	355-385	very soft
1	310-340	soft
2	265-295	normal grease
3	220-250	firm
4	175-205	very firm
5	130-160	hard
6	85-115	very hard

Example: Valvoline grease

Valvoline grease	NLGI number	Characteristics
Multipurpose calcium 2	2	Calcium based. Water resistant
Multipurpose complex red 2	2	Lithium Complex. Extreme pressure/temperature
Multipurpose lithium 2	2	Lithium based
Multipurpose lical 2/3	2/3	Lithium/Calcium. Water resistant
Bio Lical 1 Biodegradable	1	Biodegradable
Bio Lical 2 Biodegradable	2	Biodegradable
Lithium complex red 2	2	Lithium. High performance
Multipurpose lithium EP 2	2	Lithium. High pressure
Multipurpose lithium EP-X 2	2	Lithium. High impact, High temperature
Multipurpose moly 2	2	Lithium. Molybdenum disulfide
Lithium synthetic 2	2	Lithium. Synthetic base oil
Semi fluid 00	00	Lithium. Pumpable
Marine calcium 2	2	Lithium. Extreme water resistance

Colours for a multitude of grease applications

Image: Machinery Lubrication Magazine

Grease: Base oil, additives and a thickener

Image: Machinery Lubrication Magazine

Group I base oil

A simpler and cheaper refining process called solvent refined. Demand for Group I oil is declining, due to its high sulphur content. Sulphur reacts with oxygen and can cause corrosion and oxidation. Group I oils are used in less demanding circumstances such as industrial and marine applications.
(see Crude oil entry)

American Petroleum Institute (API) – Base oil categories

	Saturates	Sulphur	Viscosity Index	Special process
I	Less than 90%	Greater than 0.03%	80 to 119	Solvent processing High in sulphur

Group 1 base oil refined from crude oil

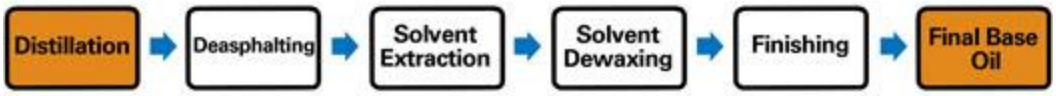


Image: Machinery Lubrication Magazine

Group II base oil

Introduced in the late 1970s and early 1980s and called Hydrotreated. Hydrogen is added to enhance and purify the base oil.
(see Crude oil entry)

American Petroleum Institute (API) – Base oil categories				
	Saturates	**Sulphur**	**Viscosity Index**	**Special process**
II	Greater than 90%	Less than 0.03%	80 to 119	Hydrotreating

Group III base oil

The category from which the majority of modern automotive synthetic oil is blended. It is classed as synthetic engine oil in most countries in the world.

American Petroleum Institute (API) – Base oil categories				
	Saturates	**Sulphur**	**Viscosity Index**	**Special process**
III	Greater than 90%	Less than 0.03%	Greater than 120	**Severely hydrocracked automotive oil**

Group III base oil achieves 99% saturates. This is a very good thing. The molecular bond is stronger, there is greater resistance to oxidation and the base oil possesses a high Viscosity Index (VI). The higher the VI, the smaller the change in the oil viscosity with temperature. The oil is clear and colourless. The technical oil description is “water white”.

Notably, Group III base oil is severely hydrocracked, which is a much more robust and expensive process than the simple hydrotreating of Group II.

Hydrocracking breaks apart the bonds and the adding of hydrogen, under intense pressure (3,000PSI) and high temperatures of (420 degrees Celsius), whilst in the presence of a catalyst. This process stabilises the unstable hydrocarbon molecules. The severity of the hydrocracking is the determining factor of how close the base oil gets to 100% saturates level.

Group III base oil also incorporates a variant called Gas to Liquid (GTL) - a process using natural gas to create synthetic base oil.
(see Automotive oil – What determines a high quality automotive oil entry)

Group III base oil refined from crude oil

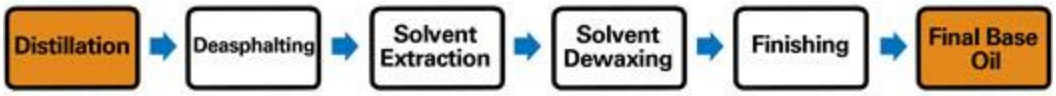


Image: Machinery Lubrication Magazine

Group IV base oil

Called also Polyalphaolefin oil (PAO). Produced from a process called Synthesising.
(see Synthetic oil entry)

American Petroleum Institute (API) – Base oil categories				
	Saturates	**Sulphur**	**Viscosity Index**	**Special process**
IV	n/a	n/a	n/a	Polyalphaolefin (PAO) automotive oil

<table>
<tr><td></td><td></td></tr>
<tr><td>Group V base oil</td><td>This group covers all other base stocks which are not covered in Group I to IV. These include PAG oil used in air conditioning systems and is a constituent of brake fluid.
<i>(see Polyalkylene glycol oil (PAG) entry)</i>
<table>
<tr><th colspan="2">American Petroleum Institute (API) – Base oil categories</th></tr>
<tr><td>V</td><td>All other Base Stocks which are not covered in Group I to IV
Polyglycols, PAG, Esters, Silicons, Polyisobutenes (PIBs) etc.</td></tr>
</table>
</td></tr>
</table>

Image: Machinery Lubrication Magazine

<table>
<tr><th colspan="2">H</th></tr>
<tr><td>Heavy Duty Diesel Engine Oil (HDDEO)</td><td>Collective term for all types of commercial engine oil.
<i>(see Super High Performance Diesel (SHPD) and Ultra High Performance Diesel (UHPD) entries)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>High Temperature High Shear (HTHS)</td><td>High Temperature High Shear (HTHS) viscosity measures the viscosity of an engine oil at 150°C.
It simulates the narrow tolerances and high speeds between moving parts within a hot engine, in particular bearings, camshaft, piston rings and cylinder liners.
The viscosity measurement is in centipoise (cP).
<i>(see Five definitions in automotive oil viscosity entry)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Hybrid oils</td><td>Hybrid engines place particular demands on engine oils. Hybrid engine oils are designed specifically for hybrid cars, from low voltage vehicles employing start stop, to high voltage vehicles that can be driven on pure-electric power alone.

Hybrid vehicles use combustion engines that work on a far higher stop and restart frequency than conventional combustion engine vehicles. This risks higher levels of oxidation and water contamination. Hybrid oils are designed to combat these issues. Valvoline has a set of specifically designed hybrid oils.
<i>(see Electric vehicles (EV) and Oil oxidation entries)</i>

<table>
<tr><th colspan="4">Examples: Valvoline Hybrid engine oil</th></tr>
<tr><th></th><th>SAE</th><th>ACEA</th><th>API</th></tr>
<tr><td>Valvoline Hybrid C5</td><td>0W-20</td><td>C5</td><td>SN SP</td></tr>
<tr><td>Valvoline Hybrid C3</td><td>5W-30</td><td>C3</td><td>SN SP</td></tr>
<tr><td>Valvoline Hybrid C2</td><td>5W-30</td><td>C2</td><td>SN SP</td></tr>
</table>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Hydrodynamic lubrication</td><td>When an engine is in the hydrodynamic lubrication stage, a robust film of oil supports the working surfaces. The wedge of oil that was formed in the mixed lubrication phase grows. The shaft lifts away from the bearing surface, so there is little asperity contact. The engine experiences little wear and it is at its optimum lubrication regime.

The film thickness can now be a comfortable 2 microns and there is a pressure build-up of the oil by the hydrodynamic wedge.

The Stribeck Curve shows how these lubrication phases come together.
<i>(see Stribeck Curve, Boundary, Mixed and Elastohydrodynamic lubrication entries)</i>

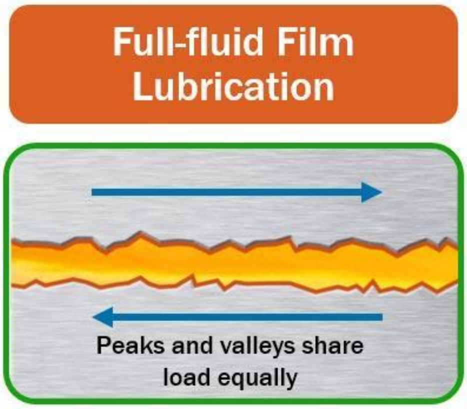
Hydrodynamic lubrication gives full protection


Image: Machinery Lubrication Magazine</td></tr>
</table>

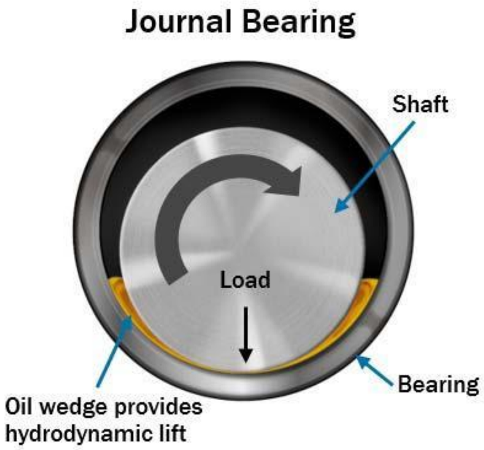
	The hydrodynamic wedge  *Image: Machinery Lubrication magazine*

Image: Machinery Lubrication Magazine

I	
Initial pH (IpH)	Measurement of the relationship between the acidic and basic elements of the oil, demonstrated by the Initial pH (IpH). *(see Total Base Number (TBN) and Oil analysis entries)*
Internal Combustion Engine (ICE)	The term can refer to an internal combustion engine in a conventional or hybrid car. *(see Electric vehicles (EV) entry)*
The International Lubricant Standardization and Approval Committee (ILSAC)	This North American organisation develops new oil performance standards. Examples: ILSAC GF6-A (5W-20 and 0W-20) and GF6-B (0W-16). *(see ACEA and API specifications entries)*

J	
Japanese Automobile Standards Organization (JASO)	JASO defines motorcycle oil performance standards. MA and MA2 categories are for wet clutch motorcycles. MB is for separate engine and gearbox type motorcycles. The three JASO MA and MA2 clutch tests are: 1. Dynamic Friction Index DFI - How does the clutch feel when engaging? 2. Static Friction Index SFI - How much torque can be applied to a fully engaged clutch before slipping? 3. Stop Time Index STI - How fast the clutch engages when the lever is released? Two stroke motorcycles have performance standards. FA, FB, FC, FD. A (JASO) car oil standard has been developed for Japanese car manufacturers: JASO GLV-1, Ultra Low Viscosity oils, for example 0W-12 and 0W-8. *(see Motorcycle oil, and Ultra Low Viscosity oils (ULV) oils entries)*
Japanese Automobile Manufacturers Association (JAMA)	An industry association comprising of Japan’s 14 manufacturers of passenger cars, buses, trucks and motorcycles.

K

Kinematic Viscosity

A fluid's resistance to flow under gravity at a specific temperature, assessed in centistokes (cSt). Kinematic viscosity, for multigrade automotive oils, is measured at 40°C or 100°C, as determined by the SAE Automotive Lubricant Viscosity Grades: Engine Oils – SAE J300.

Named after an Irishman called Sir George Stokes from the 1840s.
(see Viscosity: Five definitions in automotive oil entry)

Centistoke viscosity (cSt)
Example: Valvoline SynPower MST C3 5W-30

Viscosity at 100°C	**12.1 mm²/s or (cSt)**	Viscosity mm²/s @ 100°C ASTM D-445
Viscosity at 40°C	**72 mm²/s or (cSt)**	Viscosity mm²/s @ 40°C ASTM D-445

Capillary U-Tube Viscometer - used to measure kinematic viscosity

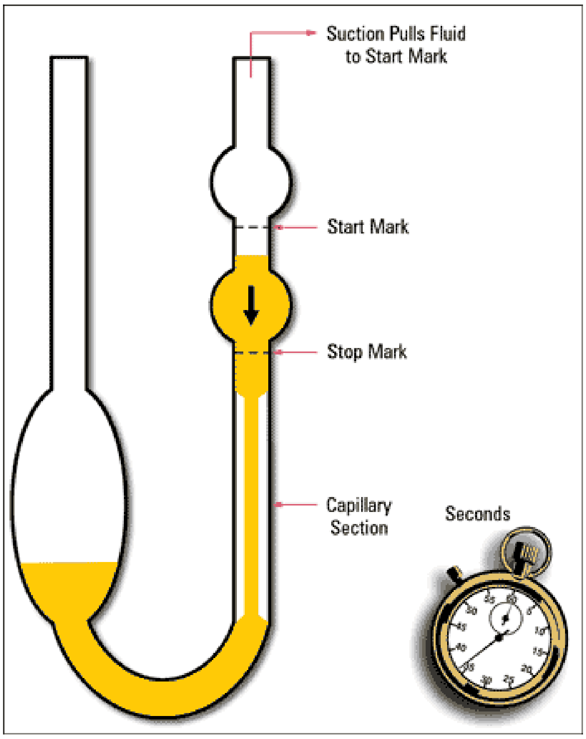


Image: Machinery Lubrication Magazine

Knock

Uncontrolled explosion of the air/fuel mixture within the combustion chamber. Also known as "Detonation".
(see Low Speed Pre Ignition (LSPI) entry)

KOH

Chemical symbol for the alkaline compound potassium hydroxide.
Used to determine the oil's Total Base Number (TBN) and Total Acid Number (TAN). As the engine oil progresses towards a drain interval, it can experience a reduction of the TBN and an increase in the acid TAN. More usually referred to now as BN and AN.
(see Total Base Number (TBN) and Total Acid Number (TAN) entries)

L

Lacquer

A deposit similar to, but harder than varnish, due usually to oxidation of the oil, when subjected to high temperatures.
(see Oil oxidation and Varnish entries)

Low SAPS engine oil (Low Ash oil)

An engine oil formulated with reduced Sulphated Ash, Phosphorus and Sulphur levels.

Low SAPS engine oils are designated by the ACEA Oil Sequences for Gasoline and Diesel engines with DPF’s and GPF’s to reduce premature clogging.

Phosphorus coats the catalysts in catalytic converters. When calcium, magnesium and sodium additives are burnt, they generate metallic ash that can block after-treatment systems.
(see ACEA specifications entry)

ACEA Low SAPS passenger car oils

ACEA Low SAPS	High Temperature High Shear (HTHS)	Sulphated Ash	Phosphorous	Sulphur	Fuel Economy
C1	≥2.9	≤0.5	≤0.05	≤0.2	≥3%
C2	≥2.9	≤0.8	≥0.07 ≤0.09	≤0.3	≥2.5%
C3	≥3.5	≤0.8	≥0.07 ≤0.09	≤0.3	≥1%*
C4	≥3.5	≤0.5	≤0.09	≤0.2	≥1%*
C5	≥2.6 <2.9	≤0.8	≥0.07 ≤0.09	≤0.3	≥3%
C6	2021: Inclusion of three new tests: LSPI, chain wear and turbocharger deposits				

*For xW-30 only
No limit on xW-40

ACEA commercial engine oil

Low SAPS	E6	E8	E9	E11	F8*	F11*
						*Fuel economy

E8 & E11: Increased protection against oxidation, viscosity increase and piston deposits
F8 & F11: HTHS viscosity of 2.9 to 3.2 cP for additional fuel economy benefits

Low Speed Pre Ignition (LSPI)

Premature combustion of the air/fuel mixture in Gasoline Direct Injection engines (GDI).

The phenomenon occurs most commonly at low RPM and high engine loads. Extremely high cylinder pressures can be experienced, which can lead to serious engine damage.

High concentrations of calcium in the detergent additive of the oil has shown to increase the frequency of LSPI.

Dedicated oils have been formulated in an attempt to address the LSPI issue. These include the ILSAC GF6-A, in grades 5W-20 and 0W-20 and GF6-B in grade 0W-16.

GM dexos® 1 Gen 3 focuses on low speed pre ignition (LSPI) mitigation and fuel economy. It is anticipated to be launched in September 2021.
(see Detonation and Knock entries)

Low Speed Pre Ignition (LSPI) oil
Example: Synpower™ DX1 Motor Oil SAE 5W-30*

Synpower™ DX1 Motor Oil SAE 5W-30*	Approval: GM dexos1 Gen 2 (Pending)
	API: SN
	API: SN Plus RC (Resource Conserving)
	ILSAC GF-5
	*Check handbook for correct application

Lubricating regimes:

Boundary

Mixed

Hydrodynamic

Elastohydrodynamic

There are four lubricating regimes in an engine:
(see Boundary, Mixed, Hydrodynamic, Elastohydrodynamic lubrication and Stribeck curve entries)

Four lubrication regimes

1.	Boundary	Start-up conditions
2.	Mixed	The phase between start-up and full-flow lubrication
3.	Hydrodynamic	Full-flow lubrication
4.	Elastohydrodynamic	Full-flow lubrication for roller bearings and camshaft lobes
		See a detailed description of each regime in the relevant entry and the Stribeck curve

LubeWear®

LubeWear® provides very early wear detection. The process identifies metal debris in the sample, from less than 5 microns through to abnormal wear size of larger than 15 microns.

Normal wear size for automotive engines is less than 15 microns and any greater than this is considered abnormal wear.
(see Oil analysis, Particle count and Spectrochemical analysis entries)

Image: Machinery Lubrication Magazine

M

Machinery Lubrication

A gold mine of interesting oil articles: www.machinerylubrication.com

Manufacturer oil specifications

Most European car manufacturers (Original Equipment Manufacturers (OEMs)) have their own set of engine oil specifications.
(see Four levels of oil specifications entry)

Manufacturer oil specifications

BMW	LL-04	LL-12FE	LL-14FE	LL-17FE
Ford	WSS-M2C 913-D	WSS-M2C 948-B	WSS-M2C 950-A	
GM Vauxhall PSA*	GM dexos1™ Gen 2	GM dexos2™	GM dexos3™	
Jaguar Land Rover	STJLR 03.5004	STJLR 03.5006	STJLR 03.5007	STJLR 51.5122
Mercedes Benz	229.52	229.71	228.61	
PSA* (Peugeot Citroen)	B71 2290	B71 2312		
Porsche	A40	C30	C20	
Renault	RN0720	RN17	RN17FE	
VAG**	504.00/507.00	508.00/509.00		
Volvo	RBSO- 2AE			

*Stellantis: Owns PSA, Opel/Vauxhall, Fiat, Chrysler, Jeep, Alfa Romeo, Maserati and other brands. Stellantis is the world’s fifth-largest car maker (in unit sales) behind Volkswagen (the largest), Toyota, General Motors, and the Renault-Nissan-Mitsubishi alliance.
**Volkswagen Audi Group (VAG): Owns Volkswagen, Audi, Seat, Skoda, Bentley, Bugatti, Lamborghini, Porsche, Ducati, Volkswagen Commercial Vehicles: Scania and MAN.

Manufacturer oil specifications
Examples: Valvoline oil

BMW	BMW LL-04	SynPower MST C3	SAE 5W-30
Jaguar Land Rover (JLR)	STJLR 03.5005	SynPower™ ENV C1	SAE 5W-30
Peugeot Citroen (PSA)	PSA B71 2312	SynPower™ ENV C2	SAE 0W-30
Renault	Renault RN 0720	SynPower™ MST C4	SAE 5W-30
Volkswagen (VAG)	VW 508.00 509.00	SynPower™ XL-IV C5	SAE 0W-20

Micron

A micron is a metric unit of length. Also known as a micrometre (µm). A human hair is about 80 microns and the eye can see particles to about 40 microns. A soot particle in engine oil can be 1 micron in size.
(see Particle count entry)

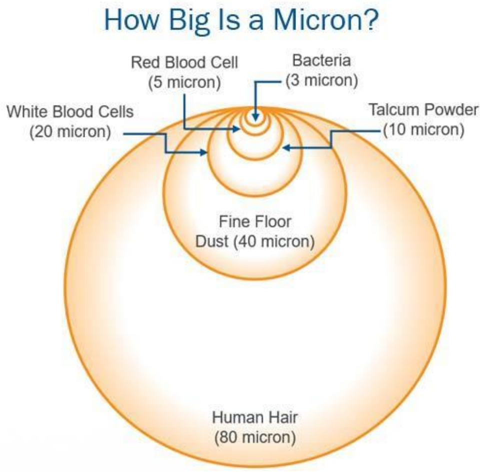
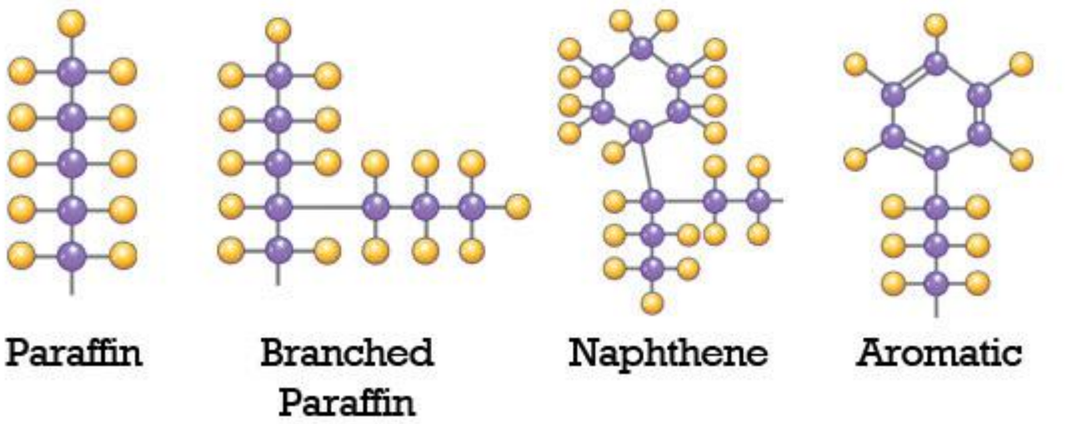


Image: Machinery Lubrication Magazine

Mineral oils	Mineral oils are blended from base oils that are primarily hydrocarbons. Paraffinic oil is the most widely used automotive base oil. The benefits of using Paraffinic oil for automotive oil use are: • High Viscosity Index (90-140) - fewer viscosity changes with temperature • High Saturate Levels (>90%), so the oil is more stable and will not degrade so easily • Very good oxidation resistance • Increased thermal stability means a greater resistance to thermal degradation and deposit formation Naphthenic and Aromatic base oils have double bonds and ring structures making them unstable, so they are not used for automotive base oil. *(see Crude oil and Base oil entries)* **Common Mineral Oil Molecules**  Image: Machinery Lubrication Magazine
Mineral, Semi and Fully Synthetic multigrade automotive oils	Traditional mineral oils tend to be blended from Group II base oils. Semi synthetic oil tends to be a blend of Group II and Group III base oils. Note, however, that semi synthetic oil is likely to contain less than 30% synthetic oil and sometimes significantly less and can still be called "semi synthetic oil". Synthetic oil is blended from either Group III base oil or Group III Gas to Liquid (GTL). Group IV PAO base oil is also used. *(see Group III base oil entry)*
Mixed lubrication phase	As the engine speed increases after start-up, lubrication moves from boundary to mixed lubrication. A wedge of oil is now, for the most part, keeping the moving elements apart. The asperities on the bearing surfaces are becoming protected with increasing thickness of oil film. The coefficient of friction, therefore, drops dramatically along with engine wear rates. Mixed film lubrication is the twilight zone between boundary and hydrodynamic (or elastohydrodynamic) lubrication. *(see Boundary, Hydrodynamic and Elastohydrodynamic lubrication entries)*

Mixed oil lubrication phase

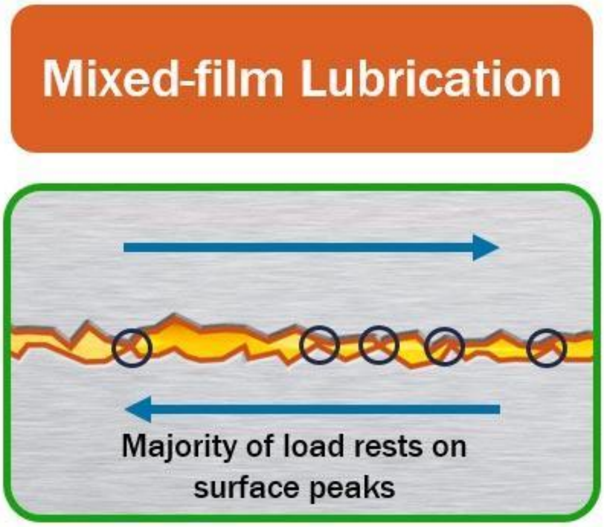


Image: Machinery Lubrication Magazine

Image: Machinery Lubrication Magazine

Motorcycle oils

Motorcycle oils are blended differently to reflect the very different environment in which a motorcycle engine operates, compared to passenger cars. They are higher revving, the sump capacity is smaller and can be air-cooled. This places the oil under extra strain.

Motorcycle and car oils use Viscosity Modifiers (VM), a polymer additive that thickens automotive and motorcycle base oil, to create the correct viscosity. However, many motorcycles have integrated engines and gearbox. The Viscosity Modifiers (VM) tend to get chopped into smaller pieces by the gears, reducing their effectiveness. Hence, motorcycle oil changes are specified at significantly shorter mileage and time intervals.

Do not use motorcycle oils in car engines and vice versa.
(see JASO specifications entry)

Motorcycle oil: JASO specification
Example: Valvoline motorcycle oil

		JASO
SynPower™ 4T	10W-40	MA2

Multigrade oil

An oil that meets the low temperature viscosity limits of one of the SAE W numbers, as well as the higher temperature 100°C viscosity limits as determined by the SAE Automotive Lubricant Viscosity. Grades: Engine Oils – SAE J300.

A monograde oil has a single SAE viscosity rating.
(see SAE grades entry)

Typical SAE multigrade oils

Cold start W						
0W	0W-8	0W-12	0W-16	0W-20	0W-30	0W-40
5W	5W-20	5W-30	5W-40	5W-50		
10W	10W-30	10W-40	10W-50	10W-60		
15W	15W-40	15W-50				
20W	20W-50					
25W						

Not all multigrade oils are available in every market

Multigrade oil
Examples: Valvoline oil

SAE grade		
0W-20	SynPower™ XL-IV	C5
0W-30	SynPower™ ENV	C2
5W-20	SynPower™ FE	C5
5W-30	SynPower™ ENV	C1
5W-40	SynPower™ MST	C3
5W-50	VR1™ Racing	
10W-40	MaxLife™	
10W-60	VR1™ Racing	
20W-50	VR1™ Racing	

N	
National Marine Manufacturers Association (NMMA)	Marine oils for both two and four stroke engines. Two stroke: TC-W3 Four stroke: FC-W, FC-W (CAT) Catalyst Compatible These categories are for small marine engines, used mainly for pleasure, not the large engines used in ships and ferries. https://www.nmma.org/certification/oil
Neutralisation Number	Another term for TBN, or TAN, which is a measure of the acidity, or basicity (alkalinity) of an oil. The number is the mass in milligrams of the amount of acid, or base (KOH), required to neutralise one gram of oil. TBN and TAN are more usually referred to now as BN and AN. *(see Total Base Number (TBN) entry)*
Newtonian Fluid	Single grade oils are Newtonian fluids. A Newtonian fluid is defined by the viscosity not changing with either force (shear stress) or speed (shear rate). The viscosity only changes with temperature or pressure. An example being water. *(see Non-Newtonian fluid entry)*
Nitration	Nitration is due to excess air being present during the combustion process. It is highly acidic, will promote deposits in combustion areas and will accelerate oxidation rapidly. *(see Oil oxidation entry)*
Non-Newtonian Fluid	Multigrade oils are non-Newtonian, due to the oil requiring Viscosity Modifiers (VM). The viscosity of a Non-Newtonian fluid is affected by the shear stress (force) applied to it. *(see Newtonian fluid entry)*

O

Oil analysis	Analysis of the engine oil to identify five key aspects: • Wear and fatigue • Contamination levels • Additives used/remaining • Physical properties, for example, viscosity increase, or decrease • Fuel dilution rates Oil analysis helps to determine the cause of automotive engine failure. A laboratory can look at the evidence of the analysis and point in the direction of the cause. Analysis can be performed on 100ml of engine oil. Example of an oil analysis laboratory: www.oilanalysislab.com *(see Particle count and LubeWear® entries)* **Oil analysis can help find the cause of bearing failure** 
Oil filter	Solid contaminants and wear debris are generally referred to as being the most destructive. However, fuel, glycol, water, the wrong oil, all contribute to overall engine condition. External contamination of engine oil by dust (silica and aluminium oxide) is generally regarded as the most harmful to engine surfaces. Both of these common particles are harder than a hacksaw blade. Approximately 80 per cent of the weight of typical road dust is smaller than 25 microns. Oil filter characteristics: 1. Capture efficiency - Test particles of 20 microns are used in the ISO 4548-12 and SAE HS806. Particles in the 10-20 micron range cause the most damage and wear to an engine. Particle counters are positioned upstream and downstream of the filter and laboratory test dust is introduced. The particles that are upstream of the filter will always be higher than the concentration downstream. The capture efficiency ratio % ratio is calculated. 2. Dirt-holding capacity - The filter's ability to trap and hold particles and dirt (silica) until the next oil change. *(see Oil analysis entry)*

Oil filter debris upstream and downstream

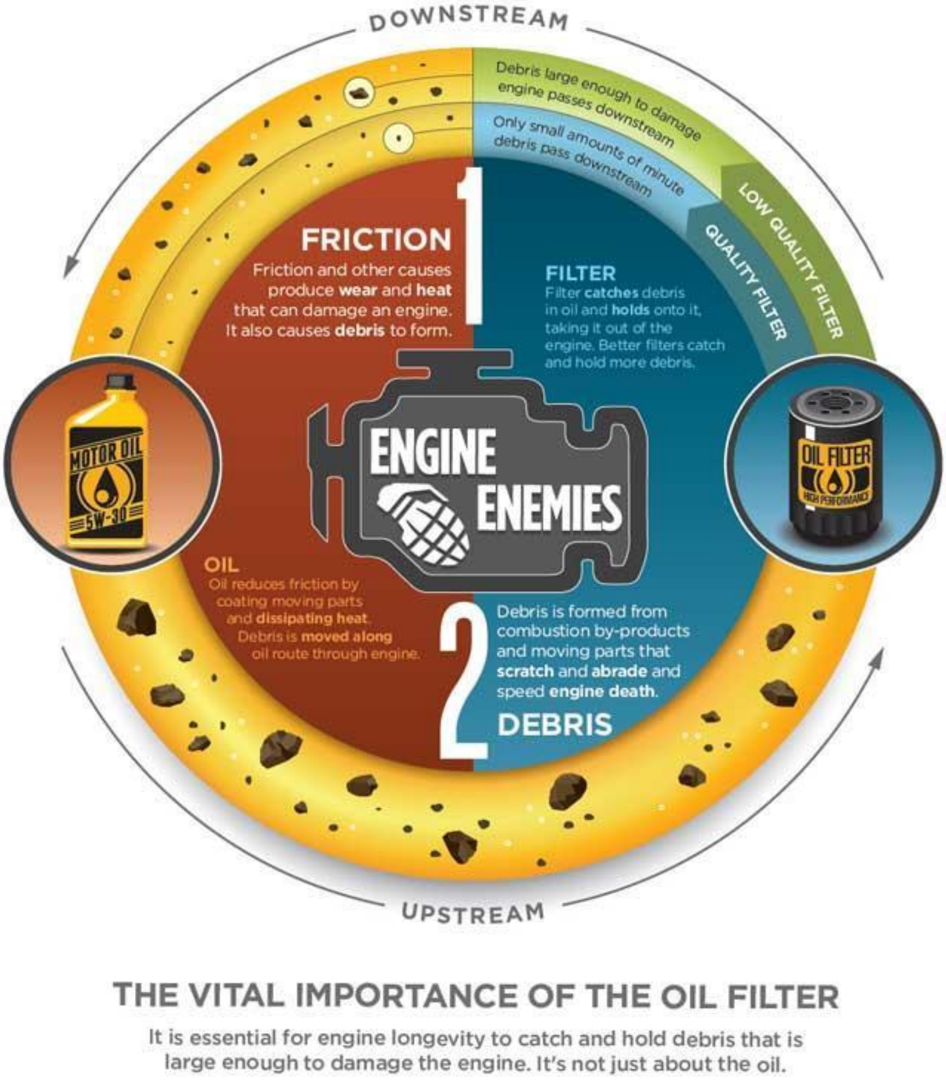


Image: Machinery Lubrication Magazine

Exploded view of an oil filter

Image: Machinery Lubrication Magazine

Capture efficiency of the oil filter

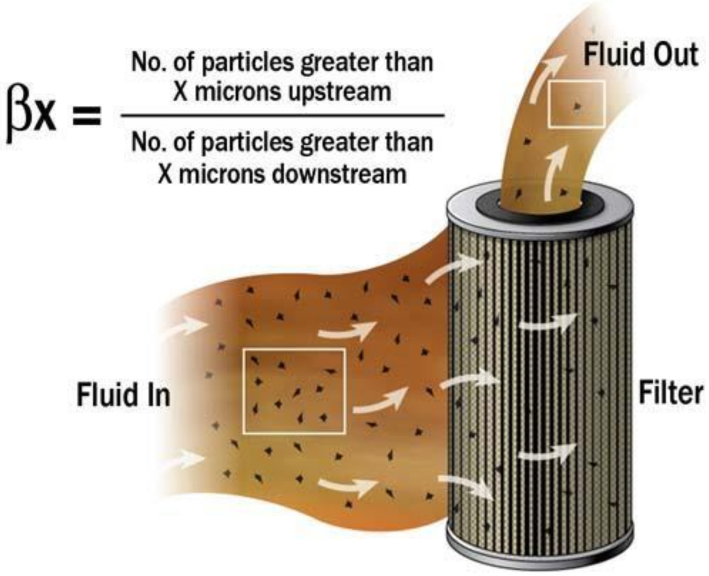


Image: Machinery Lubrication Magazine

Oil formulation

Lubrizol has developed a specification comparison chart, allowing easy comparison of ACEA or manufacturer specifications.

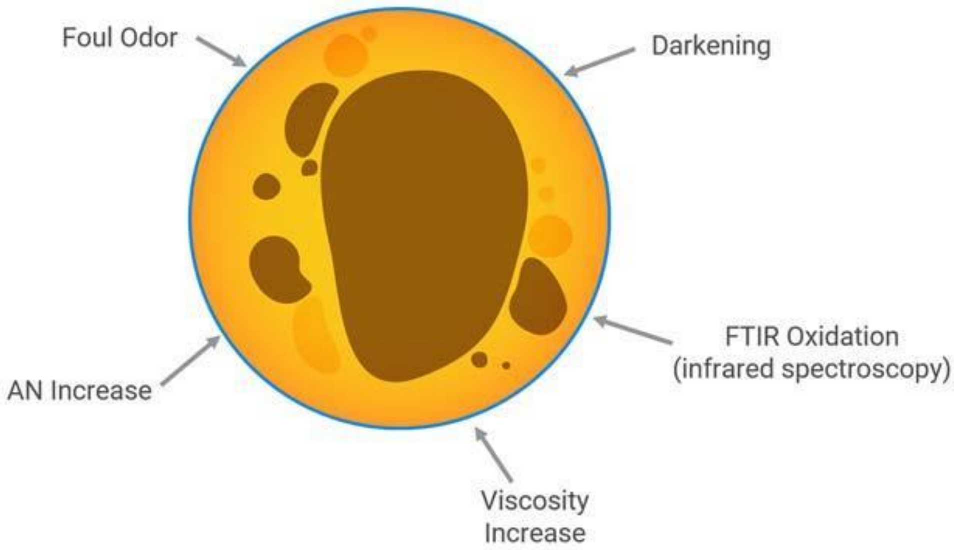
The example below looks at ACEA C5 oil specification. One set of specifications can be overlaid onto another to give a comparison.
(see ACEA specifications entry)

Lubrizol: Specification comparison **Example: ACEA C5**				
Soot Thickening	After-treatment Compatibility	Fuel Economy	Oxidative Thickening	Piston Deposits
Sludge	Wear			

Acknowledgement: https://360.lubrizol.com/Resources/Relative-Performance-Tools

Lubrizol performance tool allows oil specification comparison

Image: Lubrizol

Oil oxidation	Oxidation is the chemical reaction between oxygen and oil. Oxygen attacks the oil and increases its viscosity. The oxidation process promotes sludge and varnish. Sludge can build and block the oil galleries. The Total Base Number (TBN) of the oil will fall and the Total Acid Number (TAN) will rise. Fuel, or coolant, dilution will also cause oil oxidation. Corrosion develops due to increased oil acidity. The higher the temperature, the more susceptible an oil becomes to oxidation. The Arrhenius rate rule states: The rate of oxidation approximately doubles for every 10°C rise in temperature. Svante Arrhenius was a Swedish scientist in the late 19th/ early 20th century. *(see Thermal breakdown and Arrhenius rate entries)* **Oil oxidation: The engine killer**  Image: Machinery Lubrication Magazine **Heavily oxidised engine oil**  Image: Machinery Lubrication Magazine
Oxidation stability	An oil must remain stable by resisting oxidation and deterioration, caused by excessive temperatures, fuel dilution, contamination and exposure to oxygen. Anti-oxidant additives play a major part in controlling the oxidation process. *(see Oil oxidation entry)*

P

Particle count

The term is used in oil analysis to categorise contamination particles in three key sizes.
The ISO Cleanliness Code 4406.99 uses particle size of 4, 6, 14 microns (µm), which cause the most damage to moving surfaces.

Example below: Using an ISO code of 18/14/9, the particle count can be determined.
(see Oil analysis and LubeWear® entries)

Example of the ISO code

Particles		**ISO**
> 4 Microns	1,820	**18**
> 6 Microns	142	**14**
> 14 Microns	16	**11**

ISO Code 18/14/11		
Code	Actual Particle Count	
24	80,000	160,000
23	40,000	80,000
22	20,000	40,000
21	10,000	20,000
20	5,000	10,000
19	2,500	5,000
18	1,300	2,500
17	640	1,300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2.5	5
8	1.3	2.5
7	0.64	1.3
6	0.32	0.64

Parts per million (ppm)

Used as a measurement in additive treat rates and oil analysis.
(see Additives and Oil analysis entries)

Parts per million (ppm) compared to percentage	
Parts Per Million (ppm)	%
1,000,000	100%
100,000	10%
10,000	1.0%
1,000	0.1%
100	0.01%

	Wear particles  *Image: Machinery Lubrication Magazine*
Passenger Car Motor Oil (PCMO)	Engine oil designed specifically for passenger cars and light commercial vehicles. *(see Automotive oil – what determines a high quality automotive oil entry)*
Permanent viscosity loss (PVL)	This occurs when an oil's viscosity is reduced permanently, by the Viscosity Modifier (VM) polymers being rendered ineffective. Rupturing of their chains by the engine parts are the most common causes where the polymers are cut into smaller pieces by the engine parts. Motorcycle oils suffer from PVL due to the gearbox also being lubricated by engine oil, where the gearwheels' teeth chop up the VM polymers. *(see Temporary viscosity loss (TVL) and Shear stability index (SSI entry)*
pH	A measure of acidity, or alkalinity. 7 is neutral, akin to that of pure water. Below 7 is acidic and above 7 is alkaline. *(see Total Base Number (TBN) entry)*
Polar (in additives)	Polar is the attraction of oil additive molecules to other polar materials. Any compound that has a positive or negative charge is seen as polar. A metal surface is polar. Detergents and dispersant additives use particle enveloping as a mechanism for the additive to cling to the particle surface and envelop it. Polar additives tend to be sacrificial and become depleted when there are no polar additive molecules left in the oil to envelop contaminants, such as soot. *(see Additives entry)*
Polyalkylene glycol oil (PAG)	PAG is an API Group V base oil. This type of oil is used in air conditioning systems and is an ingredient of brake fluid. *(see Base oil categories entry)*

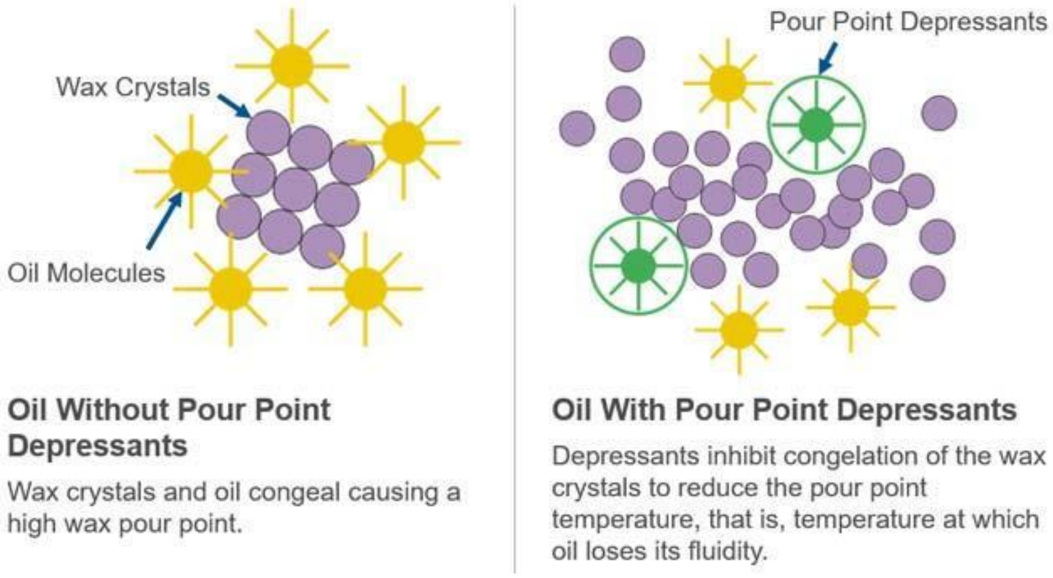
<table>
<tr><td>Polyalphaolefin oil (PAO)</td><td>PAO are API Group IV base oils. The lubricant is manufactured from ethylene gas. PAO is synthesised from “normal-alphaolefins” (NAO).

PAO is a synthetic oil, with good high and low temperature performance, high Viscosity Index (VI) and oxidative stability. Metallocene polyalphaolefin (mPAO) is part of the PAO family of oils.
<i>(see Base oil categories)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Pour point</td><td>Under test conditions, the lowest temperature to which an oil can be exposed while remaining sufficiently fluid to be poured.
<i>(see Additives and Pour point depressant (PPD) entries)</i>

<table>
<tr><th colspan="3">Pour Point
Example: Valvoline SynPower MST C3 5W-30</th></tr>
<tr><td>Pour Point</td><td>-42°C</td><td>°C ASDM D-5949</td></tr>
</table></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Pour Point Depressant (PPD)</td><td>An additive that is used to lower the pour point of an oil.

In cold conditions, a PPD reduces the tendency of wax crystallisation. PPD is a polymer similar to that of the Viscosity Modifier (VM) additive. The PPD does not prevent the forming of wax in an oil on cooling, but changes the nature of the wax, so it is not harmful.

At temperatures below about -30°C, most mineral oils, even with added pour point depressant additives, start to solidify, as the wax molecules start to precipitate out of the solution.
<i>(see Pour point entry)</i>

Pour point depressant additive

<i>Image: Machinery Lubrication Magazine</i></td></tr>
<tr><td>R</td><td></td></tr>
<tr><td>Rust Inhibitor</td><td>An additive that is used to protect metal surfaces from corrosion. Also known as a Corrosion Inhibitor.
<i>(see Corrosion Inhibitor and Additives entries)</i></td></tr>
</table>

S

SAE Grade

Society of Automotive Engineers.

The SAE issues the Automotive Lubricant Viscosity Grades for Engine Oils: SAE J300.

Using the example of a 5W-30 multigrade engine oil:

- The 5W is the cold start performance (W stands for winter)
- The 30 is the viscosity measured in centistokes (cSt) at 100°C

(see Multigrade oil entry)

Typical SAE multigrade oils

Cold start W						
0W	0W-8	0W-12	0W-16	0W-20	0W-30	0W-40
5W	5W-20	5W-30	5W-40	5W-50		
10W	10W-30	10W-40	10W-50	10W-60		
15W	15W-40	15W-50				
20W	20W-50					
25W						
Not all multigrade oils are available in every market						

Automotive Lubricant Viscosity Grades for Engine Oils: SAE J300

SAE viscosity grade	Low temp cranking (cP) Cold Cranking Simulator (CCS)	Low temp pumping (cP) Mini Rotary Viscometer (MRV)	Minimum Kinematic viscosity (cSt) @100°C	Maximum Kinematic viscosity (cSt) @100°C	High-temp High-shear HTHS viscosity (cP) @150°C
0W	6,200@ - 35°C	60,000@ -40°C	3.8		
5W	6,600@ -30°C	60,000@ -35°C	3.8		
10W	7,000@ -25°C	60,000@ -30°C	4.1		
15W	7,000@ - 20°C	60,000@ -25°C	5.6		
20W	9,500@ - 15°C	60,000@ -20°C	5.6		
25W	13,000@ - 10°C	60,000@ -15°C	9.3		
8			4	<6.1	1.7
12			5	<7.1	2.0
16			6.1	<8.2	2.3
20			6.9	<9.3	2.6
30			9.3	<12.5	2.9
40			12.5	<16.3	3.5 (1)
40			12.5	<16.3	3.7 (2)
50			16.3	<21.9	3.7
60			21.9	<26.1	3.7
(1) 0W-40 5W-40 10W-40			January 2015		
(2) 15W-40, 20W-40, 25W-40, 40 monograde					

Multigrade oil Examples: Valvoline oil		
SAE grade		Low SAPS
0W-20	SynPower™ XL-IV	C5
0W-30	SynPower™ ENV	C2
5W-20	SynPower™ FE	C5
5W-30	SynPower™ ENV	C1
5W-40	SynPower™ MST	C3
5W-50	VR1™ Racing	
10W-40	MaxLife™	A3/B4
10W-60	VR1™ Racing	
20W-50	VR1™ Racing	

The SAE classification

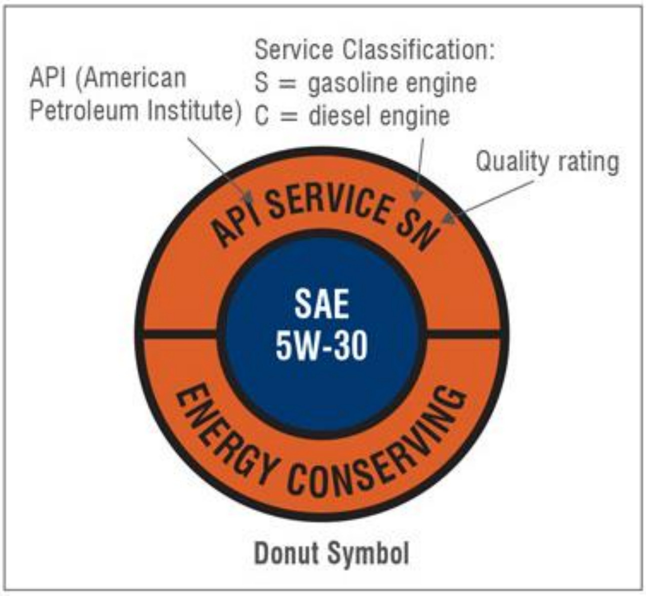


Image: Machinery Lubrication Magazine

SAE have a specific set of cold temperature oil classifications

Image: Machinery Lubrication Magazine

<table>
<tr><td></td><td></td></tr>
<tr><td>Selective Catalytic Reduction (SCR)</td><td>
A means of reducing Nitrogen Oxides (NOx) emissions further than that achieved by Exhaust Gas Recirculating (EGR).

It is achieved chemically, by injecting a urea/distilled water mix (AdBlue) onto an (SCR) catalyst, positioned just downstream of the (DPF) within the exhaust system. While used initially in trucks, many passenger cars have adopted the system to comply with Euro VI emissions legislation.
<i>(see Exhaust Gas Recirculating Valve (EGR) entry)</i>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Shear rate and Shear stress</td><td>
Shear rate: The rate, or speed, at which layers of oil move between each other. Expressed as an SI unit: Millipascal-second (mPa.s).

Shear stress: The force needed to overcome one sliding layer of fluid to another. Force/area N/m^2
<i>(see Shear stability entry)</i>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Shear stability</td><td>
The ability of the oil to remain at its original viscosity, while withstanding shear stress. Viscosity Modifiers (VM) are used in multigrade oil to achieve the correct viscosity at 100°C.
However, Viscosity Modifiers (VM) deplete in use, causing the oil viscosity to reduce. This is why regular oil changes are essential.
<i>(see Viscosity Modifier (VM) entry)</i>

Temporary viscosity and permanent viscosity loss

<i>Image: Oronite website</i>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Shear Stability Index (SSI)</td><td>
This is an index to determine how effective the Viscosity Modifier (VM) is at coping with mechanical shear, which reduces the oil's viscosity. The lower the value, the better, because it shows that the VM has good resistance to mechanical stress and shear.

A well-formulated, multigrade engine oil will use a VM that achieves a low SSI. For example:

- a base oil of 4 cSt is used with a Viscosity Modifier (VM) to increase the oil's viscosity to 14 cSt
- the Viscosity Modifier (VM) contribution is, therefore, 10 cSt
- if, during the test for Permanent Viscosity Loss (PVL), the oil viscosity falls to 12 cSt, the oil has lost 2 cSt
- The calculation for the Shear Stability Index (SSI) is 2/10=20%.

<i>(see Temporary viscosity loss (TVL) and Permanent viscosity loss (PVL) entries)</i>
</td></tr>
</table>

Specific gravity

The density of a liquid compared to water.

Specific gravity is found on the oil specification sheet.
Specific gravity is used to convert centistokes to centipoise, or vice versa: cSt = cP/SG and cP = cSt*SG.
(see Viscosity: Five definitions in automotive oil entry)

Specific Gravity Example: Valvoline SynPower MST C3 5W-30		
Specific Gravity	**0.854**	@ 15.6°C ASDM D-4052

Specification sheet (How to interpret it)

Specification sheet data Example: Valvoline SynPower MST C3 5W-30	
SAE Viscosity Grade	5W-30
Viscosity mm²/s @ 100°C ASTM D-445	12.1 mm²/s
Viscosity mm²/s @ 40°C ASTM D-445	72 mm²/s
Viscosity Index ASDM D-2270	165
Viscosity mPa-s -30°C ASTM D-5293	<6,200 mPa-s
TBN mg KOH/g ASDM D-2896	7.5 mg KOH/g
Pour Point °C ASDM D-5949	-42°C
Specific Gravity @ 15.6°C ASDM D-4052	0.854
Flash Point COC °C ASDM D-92	230°C

SAE Viscosity Grade:
5W is the cold start performance (W stands for winter). The sequence is 0, 5, 10, 15, 20 and 25.
The 30 signifies the viscosity at normal operating temperature of 100°C. The sequence is currently 8, 12, 16, 20, 30, 40, 50, and 60.

Viscosity, mm2 /s @ 100 ºC. ASTM D-445 12.1 cSt:
The viscosity of the oil at 100°C.
This is useful for comparison purposes against an oil analysis report. Has the viscosity increased, or decreased?
The SAE J300 table sets out the allowable viscosities for each category. The viscosity is measured in centistokes (cSt).

Viscosity, mm2 /s @ 40 ºC. ASTM D-445 72 cSt:
The viscosity of the oil at 40°C.
Measured in centistokes (cSt). For automotive oil, the two test temperatures are 40°C and 100°C. These temperatures are used to calculate the Viscosity Index (VI).

Viscosity Index ASTM D-2270 165:
A scale that is used to measure the oil's change of viscosity due to temperature.
The higher the (VI) number the better, because it represents a smaller change in the oil viscosity due to temperature.
VI is a useful index for comparison purposes against an oil analysis report.

Viscosity, mPa.s –30°C. ASTM D-5293 <6,200:
The cold start performance, as determined by SAE J300 table. Measured in centipoise (cP).

TBN, mg KOH/g ASTM D-2896 7.5:
Total Base Number (TBN) of the oil. The oil's ability to neutralise acids.

If the TBN drops significantly, the oil is becoming more acidic. This can lead to oxidation and sludge formation. Fuel dilution can also oxidise the oil and create acid and lower the TBN.
TBN is also useful for comparison purposes against an oil analysis report.

Pour Point, ºC ASTM D-5949 -42°C:
The lowest temperature at which an oil can be poured, when cooled under test conditions.

Specific Gravity @ 15.6°C. ASTM D-4052 0.854:
Measures the density of a liquid. Used to convert the oil's viscosity from centistokes into centipoise or vice versa.

Flash Point, COC, ºC. ASTM D-92 230°C:
The lowest temperature at which oil vapours ignite. The test is used to detect fuel dilution in engine oil analysis.
(see Automotive oil – what determines a high quality automotive oil entry)

Spectrochemical analysis

This measures foreign particles in used oil. The machine measures all particles less than 5 microns.
(see LubeWear® and Oil analysis entries)

Stribeck curve

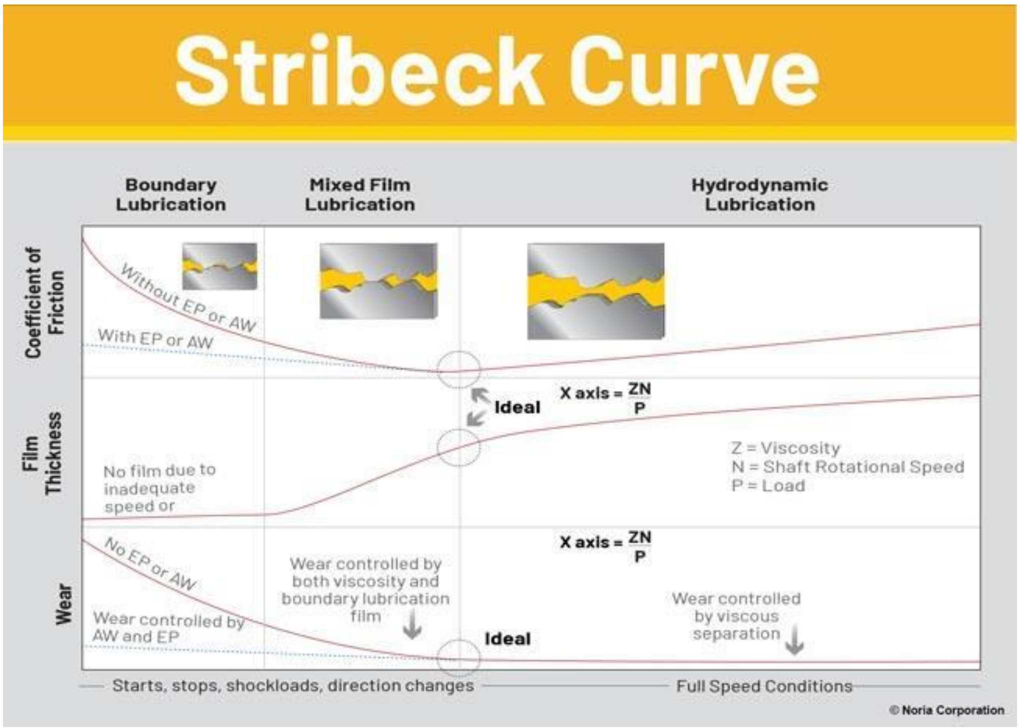
This highlights the relationship between the phases of oil lubrication and wear, film thickness and coefficient of friction.

The four phases of lubrication are boundary, mixed, hydrodynamic and elastohydrodynamic. The diagram below shows that a harmonious lubrication state exists at the juncture of boundary and hydrodynamic lubrication.

The Stribeck curve is named after a German mechanical engineer, Richard Stribeck, who pioneered the four lubrication phases in 1902.
(see Boundary, Mixed, Hydrodynamic, Elastohydrodynamic lubrication entries)

Stribeck curve

	Boundary	**Mixed**	**Hydrodynamic**	**Elastohydrodynamic**
Wear	Wear controlled by anti-wear additives	Potential for wear is dropping significantly	Wear is at its lowest	See Hydrodynamic lubrication
Film thickness	Film thickness is thin	Film thickness is increasing dramatically	Film thickness is at its highest	See Hydrodynamic lubrication
Co-efficient of friction	Co-efficient of friction is dropping	Co-efficient of friction is low	Co-efficient of friction is increasing slightly	See Hydrodynamic lubrication

	Stribeck curve: Three phases of lubrication  *Image: Machinery Lubrication Magazine*
Super Tractor Oil Universal (STOU)	General tractor oil that is unsuitable for wet-brake applications. *(see Universal Tractor Transmission Oil (UTTO) entry)*
Super High Performance Diesel (SHPD)	Oil designed specifically for commercial truck engines. *(see Ultra High Performance Diesel (UHPD) entry)*
Sludge	Sludge is a soft, black deposit that is caused by oil oxidation. Sludge build up in automotive engine oil tends to result from neglected oil changes or dilution from fuel or coolant. *(see Oil oxidation entry)*
Synthetic oil	Synthetic oils for automotive engine applications are blended from Group III base oils that have undergone the severe hydrocracking process to enhance their properties. Synthetic oil is composed of a narrow range of very similar or nearly identical molecules, whilst mineral oil is composed of a wide range of approximate molecules. The chemical and physical properties of a synthetic oil are much more uniform and predictable than those of mineral oil. This key difference is important in determining the cost, performance and applications of both types of oil. Group III base oils are classed as Fully Synthetic in most countries. However, in Germany, Group III base oil is classed as *HC Synthesetechnologie.* Group IV Polyalphaolefin (PAO) is a fully synthetic base oil, produced by chemical synthesis. This is a process of joining smaller molecules together to create consistently formed larger molecules. The

starting units may be derived from crude oil or natural gas, however the chemistry to synthesise or join these molecules together.

Automotive oil can be classed as Fully Synthetic, Semi Synthetic or Mineral oil. All modern engine oil is now Fully Synthetic.
(see Group III base oils entry)

Automotive synthetic oils	
High Viscosity Index (VI)	The higher the VI number, the better, because it represents a smaller change in the oil viscosity due to temperature. Viscosity is measured at 40 °C and 100 °C
Shear stable	The oil stays in grade better i.e. it retains the correct viscosity
Higher thermal stability	Able to handle high engine temperatures without thermal degradation
Higher oxidation stability	Higher operating temperatures without the oil oxidising
Modern oil blending	Can be blended into modern oils: 5W-20, 0W-20, 0W-16, 0W-12, and 0W-8
Lower pour point	Permits lower operating temperature
Lower volatility	Lower oil consumption
Better lubricity	Reduction in friction and or wear

> *"In 1999 the National Advertising Division (NAD) in the US adjudicated on a dispute between Castrol and Mobil, on the use of the word synthetic as a description of certain lubricants.*
>
> *Mobil objected that Castrol's hydroprocessed Sintec® was not synthetic. The NAD ruled that the Castrol product constituted a reasonable basis for the claim and that it was a synthetic motor oil. It is now generally accepted worldwide that Group III base oils are synthetic in that they enable the manufacture of lubricants that provide "synthetic performance"."*
>
> - *David Whitby "Lubricant Blending and Quality Assurance"*

Synthetic oil **Examples: Valvoline Oil**		
0W-20	SynPower™ XL-IV	C5
0W-30	SynPower™ ENV	C2
5W-20	SynPower™ FE	C5
5W-30	SynPower™ MST	C3
5W-40	SynPower™ MST	C3
5W-50	VR1™ Racing	
10W-60	VR1™ Racing	

Alpha-olefin molecule

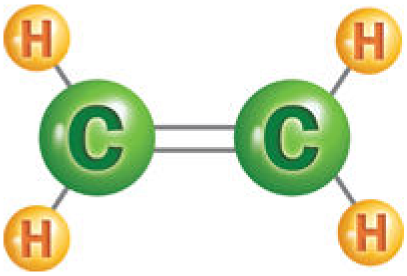


Image: Machinery Lubrication Magazine

<table>
<tr><th colspan="2">T</th></tr>
<tr><td>Temporary viscosity loss (TVL)</td><td>Temporary viscosity loss is due to oil shearing. The Viscosity Modifiers (VM) become progressively deformed and distorted. Yet the process is reversible and the polymers return their original state. This is a normal occurrence for multigrade engine oil.
<i>(see Permanent viscosity loss (PVL) and Thickening efficiency (TE) entries)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Thermal breakdown</td><td>How elevated temperatures destroy the oil’s molecular structure and cause oxidation and sludge.
The Arrhenius rule tells us that for every 10 degree Celsius increase, there is an approximate doubling of thermal breakdown and associated sludge and oxidation formation.

Under bench test conditions it can be difficult to differentiate between thermal and oxidative degradation whilst simulating real-world operating conditions.
<i>(see Oil oxidation entry)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Thickening efficiency (TE)</td><td>Thickening efficiency (TE) is the desired increase in the oil’s kinematic viscosity at 100°C when a specific amount of Viscosity Modifier (VM) is added.
<i>(see Permanent viscosity loss (PVL) and Temporary viscosity loss (TVL) entries)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total Acid Number (TAN)</td><td>This measures acid concentration within a lubricant. TAN is used in association with Total Base Number TBN. TBN and TAN are more usually referred to now as BN and AN.
<i>(see Total Base Number (TBN) entry)</i></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total Base Number (TBN)</td><td>The measure of alkaline concentration present in an oil. Alternative terms can be used that mean the same thing, including Base number (BN), Reserve Alkalinity and Neutralisation Number.

All of these terms reference the oil’s ability to neutralise acid. Measured in mg KOH/g-milligrams of potassium hydroxide required to neutralise all the acidic constituents present in one gram of sample oil.

Should the TBN drop significantly, the oil has become more acidic, causing an increased risk of oxidation. Diesel fuel dilution will increase oxidation, create acids and therefore, reduce the TBN. TBN and TAN are more usually referred to now as BN and AN. However, the oil specifications sheets tend to use the term TBN when referring to the BN.
<i>(see Total Acid Number (TAN) entry)</i>
<table>
<tr><th colspan="3">Total Base Number (TBN)
Example: Valvoline SynPower MST C3 5W-30</th></tr>
<tr><td>Total Base Number (TBN)</td><td>7.5 mg KOH/g</td><td>mg KOH/g ASDM D-2896</td></tr>
</table></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total Base Number (TBN)

Two different ASTM tests:
ASTM D-2896
ASTM D- 4739</td><td>Two ASTM testing methods establish the TBN but the differences can be significant.

ASTM D-2896 is listed on oil specification sheets and is the preferred controlled process for oil manufacturers. Yet, when ASTM D-2896 is employed for used oil analysis, it can give an exaggerated higher result and might mask an underlying issue. The reason is that the acid used reacts to every basic element in the oil and not just the alkaline reserve.</td></tr>
</table>

<table>
<tr>
<td></td>
<td>
The preferred method for used oil analysis is ASTM D-4739, which uses hydrochloric acid, which is weaker than perchloric acid. Therefore: ASTM D-2896 should be used for new lubricants and ASTM D-4739 should be used for used oil analysis.
(see Oil analysis entry)
<table>
<tr><th colspan="3">ASDM D-2896*
Example: Valvoline SynPower MST C3 5W-30</th></tr>
<tr><td>Total Base Number (TBN)</td><td>**ASDM D-2896***</td><td>7.5 mg KOH/g</td></tr>
<tr><td colspan="3">*ASTM D-2896: preferred controlled process for oil manufacturers</td></tr>
</table>
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<tr><td></td><td></td></tr>
<tr>
<td>**Treat rates**</td>
<td>
The quantity and range of additives that are blended with the base oil to achieve the required performance levels, desired by the manufacturer.

Automotive oil treat rates are part of the evolving understanding between additive chemistry and engine hardware.
(see Additives entry)

Correct additive treat rates are vital for the overall oil performance


Image: Machinery Lubrication Magazine
</td>
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</table>

U

Ultra High Performance Diesel (UHPD)

Ultra High Performance Diesel (UHPD).
Oil designed specifically for commercial truck engines.
(see Super High Performance Diesel (SHPD) entry)

Ultra Low Viscosity oils (ULV)

It has been proven that lower viscosity engine oils help to improve fuel economy.
SAE 16, 12, 8 and 4 viscosity oils are examples of Ultra Low Viscosity (ULV) oils.

A high viscosity oil requires more energy to be pumped around the engine, compared with a low viscosity one. Low viscosity oils have fuel economy and CO2 emission benefits.

For comparison purposes, the dynamic viscosity of water at 20°C is 1 cP.
(see SAE grade entry)

Low Viscosity oils (ULV)		
	Kinematic Viscosity (cSt) @ 100c	High Temperature High Shear (HTHS) centipoise (cP)
SAE 16	6.1 <8.2	2.3
SAE 12	5 <7.1	2.0
SAE 8	4 <6.1	1.7
SAE 4	TBA	>1.4

United Kingdom Lubricants Association Ltd (UKLA)

The UK Lubricants Association is a trade body that represents member company's interests both in the UK and overseas. www.ukla.org.uk/
(see Verification of Lubricant Specifications (VLS) entry)

Universal Tractor Transmission Oil (UTTO)

Oil for tractor and off-highway transmissions, hydraulic and differentials. UTTO oil is compatible and formulated for wet-brake applications.
(see Super Tractor Oil Universal (STOU) entry)

Image: Machinery Lubrication Magazine

V

Varnish

Varnish is a slightly softer form of lacquer and is a product of high temperature oil oxidation that is baked onto the metal surface. Varnish, lacquer and sludge are all caused by oil oxidation.
(see Oil oxidation entry)

Verification of Lubricant Specifications (VLS)

Verification of Lubricant Specifications (VLS) is an independent organisation in the UK that provides a trusted means to verify lubricant performance matches manufacturer specifications.
www.ukla-vls.org.uk/
(see United Kingdom Lubricants Association Ltd (UKLA) entry)

Viscometer

A machine that is employed to determine oil viscosity. One type measures Kinematic viscosity in centistokes (cSt). Other types measure viscosity in centipoise (cP).
(see Viscosity: Five definitions in automotive oil entry)

Viscosity

Measurement of a fluid's resistance to flow.
For multigrade automotive oils, there are five viscosity measurements.
(see Viscosity: Five definitions in automotive oil entry)

Viscosity Grade

The Society of Automotive Engineers (SAE) issues the Automotive Lubricant Viscosity Grades: Engine Oils SAE J300.

Cold start performance (W stands for winter)					
0W	5W	10W	15W	20W	25W

Viscosity measured in centistokes (cSt) at 100°C							
8	12	16	20	30	40	50	60

Using the example of a 5W-30 multigrade engine oil:

- 5W is the cold start performance
- 30 is the viscosity measured in centistokes (cSt) at 100°C

The engine oil viscosity trend is driven by emission and fuel economy regulations, which necessitates thinner oils.
(see SAE grade entry)

Typical SAE multigrade oils						
Cold start W						
0W	0W-8	0W-12	0W-16	0W-20	0W-30	0W-40
5W	5W-20	5W-30	5W-40	5W-50		
10W	10W-30	10W-40	10W-50	10W-60		
15W	15W-40	15W-50				
20W	20W-50					
25W						
Not all multigrade oils are available in every market						

Viscosity Index (VI)

VI is a scale that measures the oil's change of viscosity due to temperature.

The higher the VI number the better, because it represents a smaller change in the oil viscosity due to temperature. Viscosity is measured at 40 °C and 100 °C.

VI is useful for comparison purposes with an oil analysis report.
(see Viscosity: Five definitions in automotive oil and viscosity modifier (VM) entries)

Viscosity Index (VI) Example: Valvoline SynPower MST C3 5W-30		
Viscosity Index (VI)	**165**	ASDM D-2270

Example: Valvoline oil Viscosity Index		
SynPower™ DT C2 Motor Oil SAE 0W-30	0W-30	**194**
VR1™ Racing Motor Oil SAE 5W-50	5W-50	**183**
SynPower™ Motor Oil SAE 0W-40	0W-40	**180**
SynPower™ MST C5 Motor Oil SAE 0W-20	0W-20	**177**
SynPower™ XL-IV C5 Motor Oil SAE 0W-20	0W-20	**176**
SynPower™ LL-12 FE Motor Oil SAE 0W-30	0W-30	**174**
SynPower™ XL-III C3 Motor Oil SAE 5W-30	5W-30	**166**
SynPower™ MST C3 Motor Oil SAE 5W-30	5W-30	**165**
Valvoline™ All-Climate Motor Oil C2/C3SAE 5W-30	5W-30	160

Viscosity Index Improvers (VII)

(see Viscosity Modifier (VM) entry)

Viscosity Modifier (VM)

Also known as Viscosity Index Improver (VII).

A high molecular weight polymer additive that is used to thicken the base oil to create the desired viscosity for a multigrade engine oil.

At low temperatures, they exist as tightly coiled chains, which have little effect on the oil viscosity. At higher temperatures, the chains become "solvated" and open up into the oil. An example would be an octopus or walking through a crowded room with arms wide open.

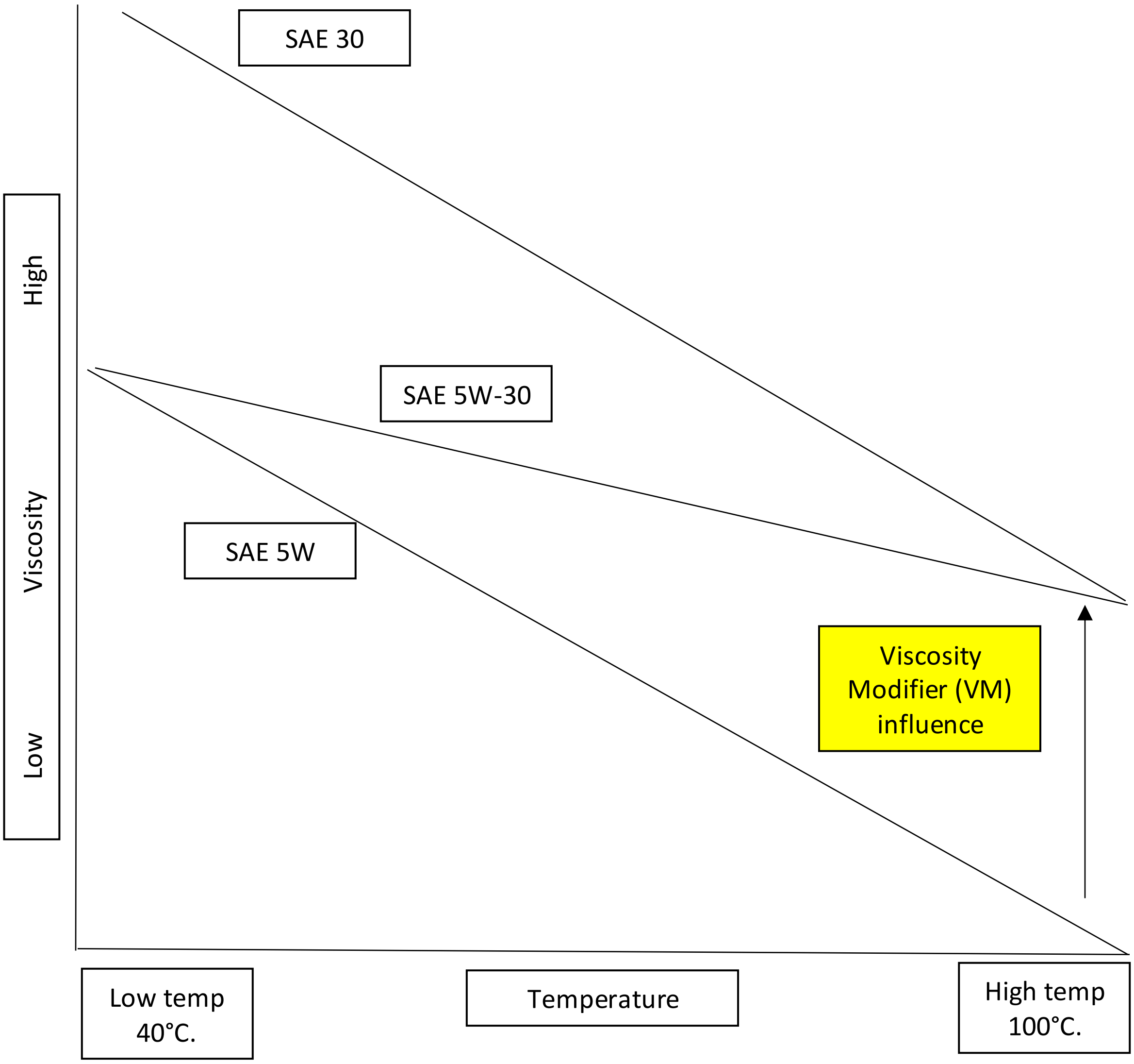
Automotive engine oil blended from a low viscosity base oil is used to ensure correct viscosity at low temperature. A Viscosity Modifier (VM) is added to ensure the correct viscosity at 100°C.

Common VMs:

- Olefin Copolymers (OCP) are often used in automotive oils due to their excellent engine performance
- Polymethacrylate (PMA) are used in fuel economy engine oils and have excellent low temperature performance

(see Additives and Temporary viscosity loss (TVL) entries)

Viscosity Index (VI)



How the Viscosity Modifier (VM) responds to changes in oil temperature

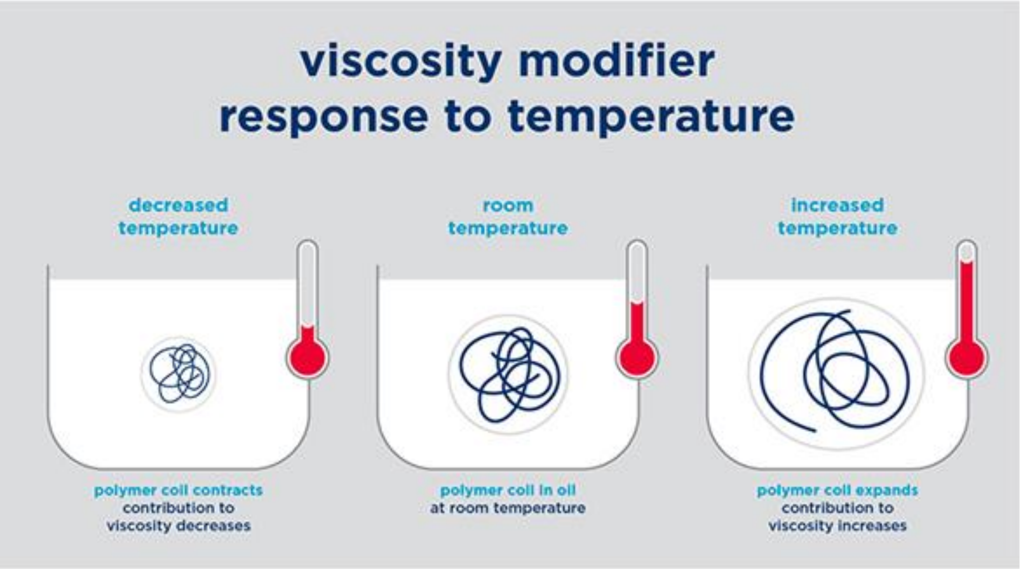


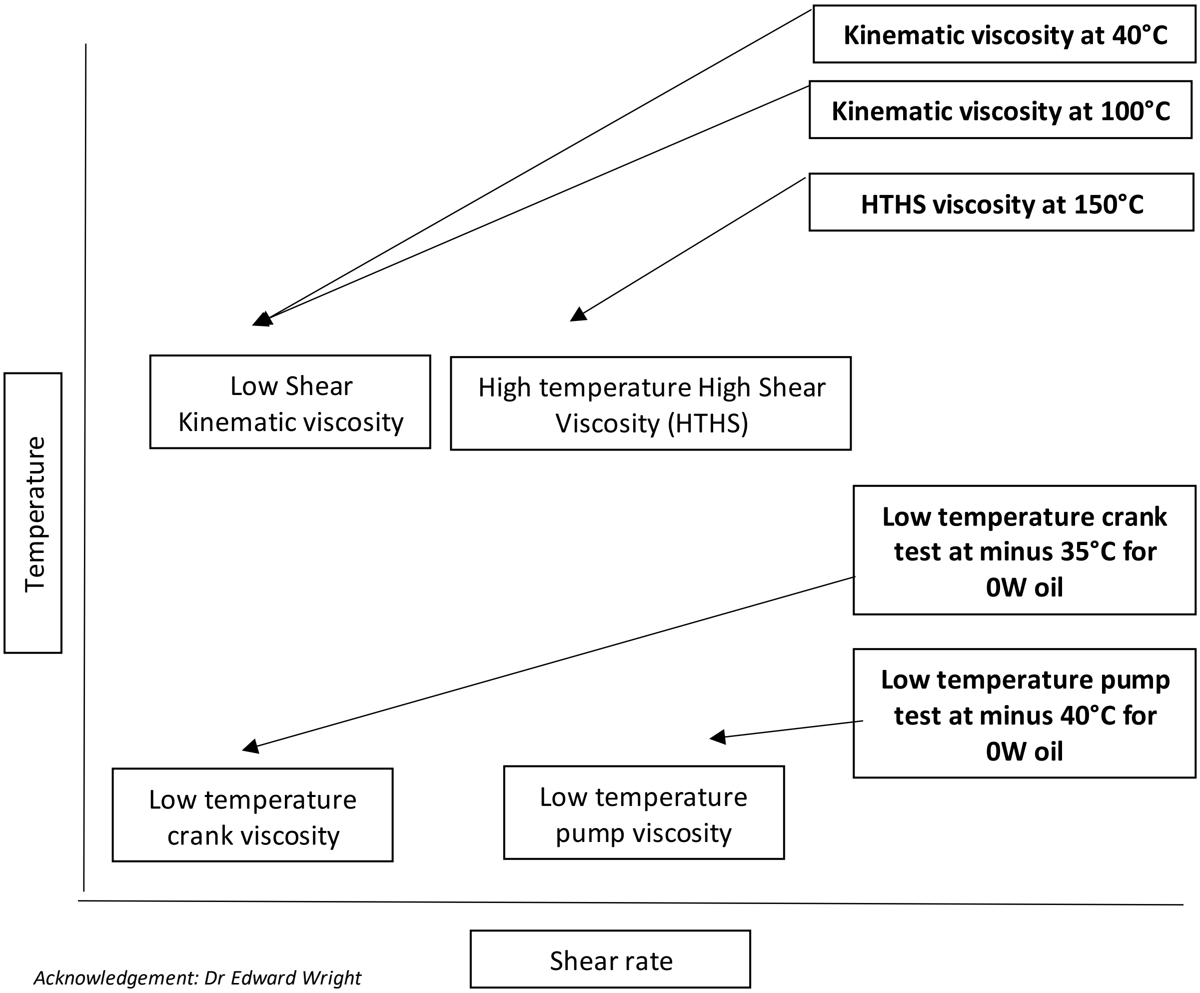
Image: Oronite website

Viscosity: Five definitions in automotive oil

Five viscosity definitions in automotive oil	
Viscosity at 100°C Kinematic Viscosity (cSt)	Determines the viscosity at operating temperature 100°C
Viscosity at 40°C Kinematic Viscosity (cSt)	Determines the viscosity at 40°C Used to calculate the (VI), using the oil's viscosity at 40°C and 100°C
Low temperature crank test Dynamic Viscosity centipoise (cP)	Example: 0W multigrade oil tested at -35°C
Low temperature oil pumping test Dynamic Viscosity centipoise (cP)	Example: 0W multigrade oil tested at -40°C
High Temperature High Shear (HTHS) Dynamic Viscosity centipoise (cP)	Viscosity tested at 150°C Extreme environment at crankshaft

(see Kinematic Viscosity, Dynamic or Absolute Viscosity entries)

Five viscosity definitions in automotive oil



Acknowledgement: Dr Edward Wright

Volatility

The degree and rate at which the automotive engine oil molecules evaporate.

Three reasons for low oil level:
- Oil has got past the piston rings and been burnt as part of the combustion process
- Oil leak
- Oil evaporation (NOACK)

The NOACK test is used as part of the ACEA standards.
Volatility is one of the properties of a base oil that cannot be corrected by the use of additives. If a low volatility automotive engine oil is the desired outcome (therefore low NOACK %), a low volatility base oil must be selected.
(see ACEA specifications entry)

NOACK* volatility
ACEA* specifications

ACEA specification	Less than or equal %
A3/B4	13%
A5/B5	13%
C1	13%
C1	13%
C3	13%
C4	11%
C5	13%
C6	TBA
	*ACEA 2016 *Noack test named after Dr Kurt Noack in the 1930s

Correct oil specifications are crucial

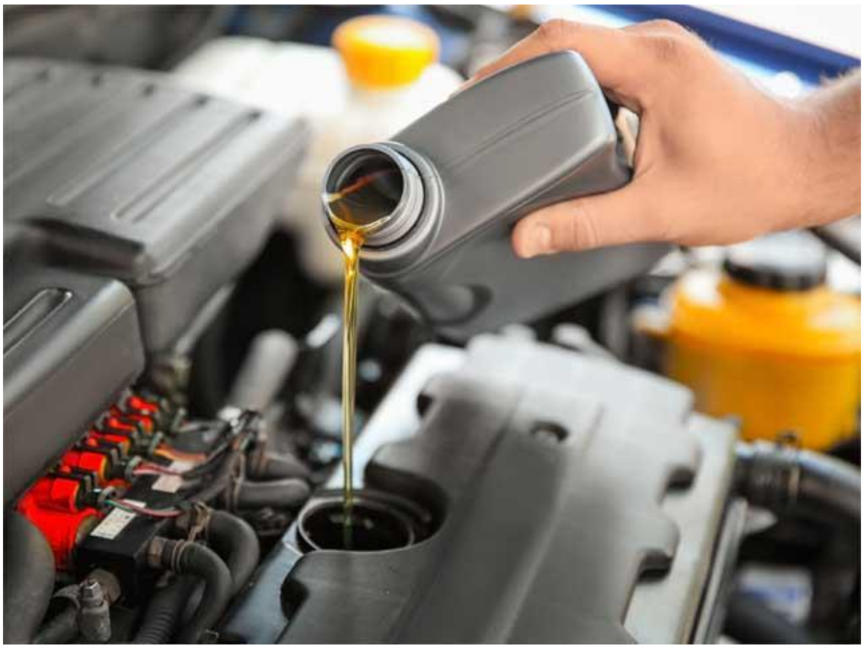


Image: Machinery Lubrication Magazine

Low or excessively high oil level

Image: Machinery Lubrication Magazine

W

Worldwide Harmonised Light Vehicle Test Procedure (WLTP)

The Worldwide Harmonised Light Vehicle Test Procedure (WHLTP) is a laboratory test used to measure fuel consumption and CO2 emissions from passenger cars, as well as their pollutant emissions.
www.wltpfacts.eu

(NEDC) - New European Driving Cycle – now obsolete, see WLTP
(WLTC) - Worldwide Harmonized Light vehicles Test Cycles – part of the WLTP
(CAFÉ) – Corporate Average Fuel Economy – US version
(see CO2 / Fuel Economy Testing)

Z

Zinc dialkyl dithiophosphates (ZDDP)

An anti-wear additive found in automotive engine oil called Zinc dialkyldithiophosphates (ZDDP).

Limits are set on the amount of ZDDP that can be used in engine oils. ZDDP can coat the precious metals on catalytic convertors, rendering them useless.

ZDDP has particular relevance at start-up, when the engine is in the boundary lubrication phase. A classic car oil, for example, Valvoline VR1 20W-50 has 1,400 ppm of ZDDP. A modern, well-formulated 5W-30 fully synthetic Low SAPS C3 oil will contain significantly less ZDDP, around 800 ppm.
(see Boundary lubrication entry)

Zinc dialkyl dithiophosphates (ZDDP)
Example: Valvoline VR1 20W-50

ZDDP	Valvoline VR1 20W-50	1,400 parts per million (ppm)
Modern fully synthetic oil	Valvoline MST C3 5W-30	800 parts per million (ppm)

Parts per million (ppm)
compared to percentage

Parts Per Million (ppm)	%
1,000,000	100%
100,000	10%
10,000	1.0%
1,000	0.1%
100	0.01%

Automotive Oil

Fast Facts Guide

Image: Machinery Lubrication Magazine

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David Whitby for his technical rigour. David spent 22 years with BP and as Programme Director for Lubricants Courses at the Oxford Princeton Programme. He is the author of the "Lubricant Blending and Quality Assurance" book.

Adam Cutler for his insight on oil analysis and overall checking. Adam is an oil analysis expert at Oil Analysis Laboratories.
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