A STUDY OF MOTORCYCLE OILS

AMSOIL Power Sports Group

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Overview

Motorcycles have long been used as a popular means of general transportation as well as for recreational use. There are nearly five million registered motorcycles in the United States, with annual sales in excess of three-quarters of a million units. This trend is unlikely to change. As with any vehicle equipped with an internal combustion engine, proper lubrication is essential to insure performance and longevity. It is important to point out that not all internal combustion engines are similarly designed or exposed to the same types of operation. These variations in design and operation place different demands on engine oils. Specifically, the demands placed on motorcycle engine oils are more severe than those placed on automotive engine oils. Therefore, the performance requirements of motorcycle oils are more demanding as well.

Though the degree may be debatable, few will disagree that a difference exists between automotive and motorcycle applications. In which area these differences are and to what degree they alter lubrication requirements are not clear to most motorcycle operators. By comparing some basic equipment information, one can better understand the differences that exist.

The following comparison information offers a general synopsis of both automotive and motorcycle applications.

Vehicle	Equipment Type	Engine cooling	Displacement	Lubricant Reservoir	Compression Ratio	Max. HP @ RPM	HP per C.I.
Honda Accord	Automotive	Water cooled	183 cu. in.	Single, engine only	10:1	240@6,250	1.3
Ford Explorer	Automotive SUV	Water cooled	281 cu. in.	Single, engine only	9.4:1	239@4,750	.85
Dodge Ram	L/D Truck	Water cooled	345 cu. in.	Single, engine only	9.6:1	345@5,400	.99
Chevrolet Corvette	Automotive Performance	Water cooled	366 cu. in.	Single, engine only	10.9:1	400@6,000	1.1
Honda CBR 1000 RR	Motorcycle Performance	Water cooled	61 cu. in.	Shared – engine & transmission	11.9:1	153@11,000	2.5
BMW R 1200 RT	Motorcycle Touring	Air & Oil cooled	71.4 cu. in.	Separate – engine & transmission	11.0:1	110@7,500	1.5
H/D Road King FLHRSI	Motorcycle Large Bore	Air cooled	88 cu. in.	Separate – engine & transmission	8.8:1	58@5,000	.66
Yamaha YZ450F	Motorcycle Moto-Cross	Water cooled	27.1 cu. in.	Shared, engine & transmission	12.3:1	47.2@8,700	1.7

There are six primary differences between motorcycle and automotive engine applications:

1. **Operational Speed** – Motorcycles tend to operate at engine speeds significantly higher than automobiles. This places additional stress on engine components, increasing the need for wear protection. It also subjects lubricating oils to higher loading and shear forces. Elevated operating RPMs also promote foaming, which can reduce an oil's load-carrying ability and accelerate oxidation.

2. **Compression Ratios** – Motorcycles tend to operate with higher engine compression ratios than automobiles. Higher compression ratios place additional stress on engine components and increase engine operating temperatures. Higher demands are placed on the oil to reduce wear. Elevated operating temperatures also promote thermal degradation of the oil, reducing its life expectancy and increasing the formation of internal engine deposits.

3. **Horse Power / Displacement Density** – Motorcycle engines produce nearly twice the horsepower per cubic inch of displacement of automobile engines. This exposes the lubricating oil to higher temperatures and stress.

4. **Variable Engine Cooling** – In general, automotive applications use a sophisticated water-cooling system to control engine operating temperature. Similar systems can be found in motorcycle applications, but other designs also exist. Many motorcycles are air-cooled or use a combination air/oil design. Though effective, they result in greater fluctuations in operating temperatures, particularly when motorcycles are operated in stop-and-go traffic. Elevated operating temperature promotes oxidation and causes oils to thin, reducing their load carrying ability.

5. **Multiple Lubrication Functionality** – In automotive applications, engine oils are required to lubricate only the engine. Other automotive assemblies, such as transmissions, have separate fluid reservoirs that contain a lubricant designed specifically for that component. The requirements of that fluid differ significantly from those of automotive engine oil. Many motorcycles have a common sump supplying oil to both the engine and transmission. In such cases, the oil is required to meet the needs of both the engine and the transmission gears. Many motorcycles also incorporate a frictional clutch within the transmission that uses this same oil.

6. **Inactivity** – Motorcycles are typically used less frequently than automobiles. Whereas automobiles are used on a daily basis, motorcycle use is usually periodic and in many cases seasonal. These extended periods of inactivity place additional stress on motorcycle oils. Of critical concern are rust and acid corrosion protection.

It is apparent that motorcycle applications place a different set of requirements on lubricating oils. Motorcycle oils, therefore, must be formulated to address this unique set of high stress conditions.

Purpose

The purpose of this paper is to provide information regarding motorcycle applications, their lubrication needs and typical lubricants available to the end user. It is intended to assist the end user in making an educated decision as to the lubricant most suitable for his or her motorcycle application.

Method

The testing used to evaluate the lubricants was done in accordance with American Society for Testing and Materials (ASTM) procedures. Test methodology has been indicated for all data points, allowing for duplication and verification by any analytical laboratory capable of conducting the ASTM tests. A notarized affidavit certifying compliance with ASTM methodology and the accuracy of the test results is included in the Appendix of this document.

Scope

This document reviews the physical properties and performance of a number of generally available motorcycle oils. Those areas of review are:

1. An oil’s ability to meet the required viscosity grade of an application.
2. An oil’s ability to maintain a constant viscosity when exposed to changes in temperature.
3. An oil’s ability to retain its viscosity during use.
4. An oil’s ability to resist shearing forces and maintain its viscosity at elevated temperatures.
5. An oil's zinc content.
6. An oil’s ability to minimize general wear.
7. An oil’s ability to minimize gear wear.
8. An oil’s ability to minimize deterioration when exposed to elevated temperatures.
9. An oil’s ability to resist volatilization when exposed to elevated temperatures.
10. An oil’s ability to maintain engine cleanliness and control acid corrosion.
11. An oil’s ability to resist foaming.
12. An oil’s ability to control rust corrosion.

Individual results have been listed for each category. The results were then combined to provide an overall picture of the ability of each oil to address the many demands required of motorcycle oils.

Review Candidates

Two groups of candidate oils were tested, SAE 40 grade oils and SAE 50 grade oils. The oils tested are recommended specifically for motorcycle applications by their manufacturers.

SAE 40 Group

Brand	Viscosity Grade	Base	Batch Number
AMSOIL MCF	10W-40	Synthetic	LB 22259
Bel-Ray EXS	0W-40	Synthetic	AF1212
Castrol GPS	10W-40	Synthetic	3011020
Golden Spectro 4	10W-40	Syn / Petro Blend	13264
Maxima Maxum 4	10W-40	Syn /Petro Blend	16104
Mobil 1 MX4T	10W-40	Synthetic	X2904
Motul 300V Sport	10W-40	Synthetic	20507/A/69093
Pennzoil Motorcycle Oil	10W-40	Petroleum	HPLA192024/12143
Royal Purple Max-Cycle	10W-40	Synthetic	F02402
Torco T-4SR	10W-40	Synthetic	62395
Valvoline 4-Stroke	10W-40	Petroleum	H104C2

SAE 50 Group

Brand	Viscosity Grade	Base	Batch Number
AMSOIL MCV	20W-50	Synthetic	LB 22355
Bel-Ray EXS	10W-50	Synthetic	AF1319
BMW	15W-50	Synthetic	13286
Castrol GPS	20W-50	Syn / Petro Blend	3006260
Castrol V-Twin	20W-50	Syn / Petro Blend	4103005
Golden Spectro 4	20W-50	Syn / Petro Blend	13036
Golden Spectro American 4	20W-50	Syn / Petro Blend	11838
Mobil 1 V-Twin	20W-50	Synthetic	X22H4
Motul 300V Competition	15W-50	Synthetic	20407/A/69015
Pennzoil Motorcycle	20W-50	Petroleum	None indicated on containers
Royal Purple Max-Cycle	20W-50	Synthetic	H11402
Screamin Eagle Syn3	20W-50	Synthetic	0461301314
Torco T-4SR	20W-50	Synthetic	L 58418 LORJB CR
Valvoline 4-Stroke	20W-50	Petroleum	F294C1
Yamalube 4-R	10W-50	Syn / Petro Blend	2 x 1494451, 2 x 99071 1235*1515

Physical Properties, Performance Results, and Prices

SAE Viscosity Grade (Initial Viscosity - SAE J300)

A lubricant is required to perform a variety tasks. Foremost is the minimization of wear. An oil's first line of defense is its viscosity (thickness). Lubricating oils are by nature non-compressible and when placed between two moving components will keep the components from contacting each other. With no direct contact between surfaces, wear is eliminated. Though non-compressible, there is a point at which the oil film separating the two components is insufficient and contact occurs. The point at which this occurs is a function of an oil's viscosity. Generally speaking, the more viscous or thicker an oil, the greater the load it will carry. Common sense would suggest use of the most viscous (thickest) oil. However, high viscosity also presents disadvantages. Thicker oils are more difficult to circulate, especially when an engine is cold, and wear protection may be sacrificed, particularly at start-up. Thicker oils also require more energy to circulate, which negatively affects engine performance and fuel economy. Furthermore, the higher internal resistance of thicker oils tends to increase the operating temperature of the engine. There is no advantage to using an oil that has a greater viscosity than that recommended by the equipment manufacturer. An oil too light, however, may not possess sufficient load carrying ability to meet the requirements of the equipment.

From a consumer standpoint, fluid viscometrics can be confusing. To ease selection, the Society of Automotive Engineers (SAE) has developed a grading system based on an oil's viscosity at specific temperatures. Grading numbers have been assigned to ranges of viscosity. The equipment manufacturer determines the most appropriate viscosity for an application and indicates for the consumer which SAE grade is most suitable for a particular piece of equipment. Note that the SAE grading system allows for the review of an oil's viscosity at both low and high temperatures. As motorcycle applications rarely contend with low temperature operation, that area of viscosity is not relevant to this discussion.

The following chart identifies the viscosities of the oils before use. The purpose of testing initial viscosity is to ensure that the SAE grade indicated by the oil manufacturer is representative of the actual SAE grade of the oil, and that it is therefore appropriate for applications requiring such a fluid. The results were obtained using American Society for Testing and Materials (ASTM) test methodology D-445. The fluid test temperature was 100° C and results are reported in centistokes. Using SAE J300 standards, the SAE viscosity grades and grade ranges for each oil were determined and are listed below.

SAE 40 Group

Brand	Indicated Viscosity Grade	Measured Viscosity @ 100° C. cSt	SAE Viscosity Range for 40 Grade	Within Grade
AMSOIL MCF	10W-40	14.14		Yes
Bel-Ray EXS	0W-40	15.06		Yes
Castrol GPS	10W-40	15.09		Yes
Golden Spectro 4	10W-40	15.91		Yes
Maxima Maxum 4	10W-40	14.39	12.5 to <16.3	Yes
Mobil 1 MX4T	10W-40	13.92		Yes
Motul 300V Sport	10W-40	14.01		Yes
Pennzoil Motorcycle Oil	10W-40	13.0	12.5 to < 16.3	Yes
Royal Purple Max-Cycle	10W-40	13.33		Yes
Torco T-4SR	10W-40	15.03		Yes
Valvoline 4-Stroke	10W-40	14.94		Yes

SAE 50 Group

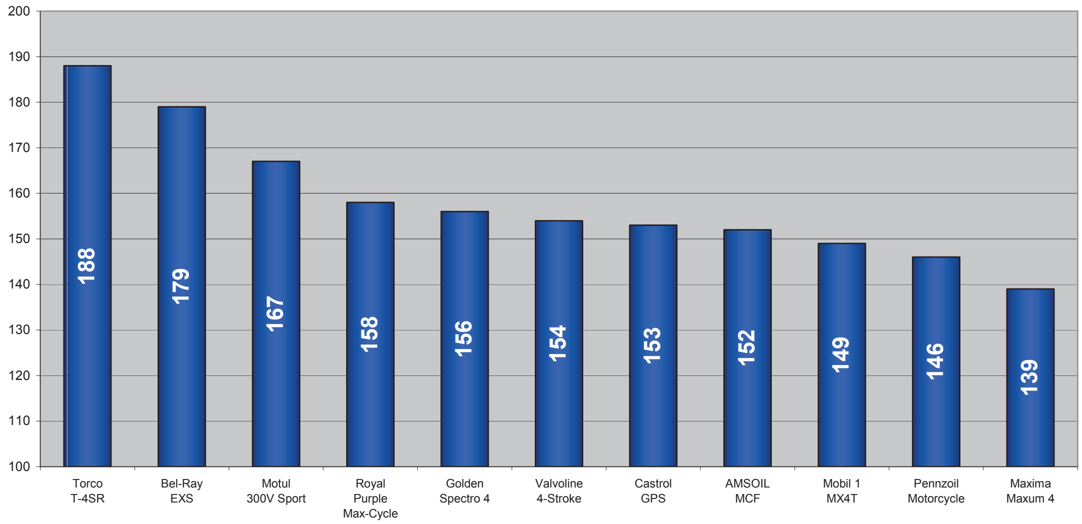
Brand	Indicated Viscosity Grade	Measured Viscosity @ 100° C. cSt	SAE Viscosity Range for 50 Grade	Within Grade
AMSOIL MCV	20W-50	20.04		Yes
Bel-Ray EXS	10W-50	17.09		Yes
BMW	15W-50	18.15		Yes
Castrol GPS	20W-50	19.52		Yes
Castrol V-Twin	20W-50	19.22		Yes
Golden Spectro 4	20W-50	20.24		Yes
Golden Spectro American 4	20W-50	19.61		Yes
Mobil 1 V-Twin	20W-50	20.9	16.3 to < 21.9	Yes
Motul 300V Competition	15W-50	17.7		Yes
Pennzoil Motorcycle	20W-50	16.84		Yes
Royal Purple Max-Cycle	20W-50	19.79		Yes
Screamin Eagle Syn3	20W-50	20.3		Yes
Torco T-4SR	20W-50	19.50		Yes
Valvoline 4-Stroke	20W-50	18.14		Yes
Yamalube 4-R	10W-50	19.48		Yes

The results show that all of the oils tested have a initial viscosities consistent with their indicated SAE viscosity grades. Therefore, they are appropriate for use in applications recommending these grades/viscosities.

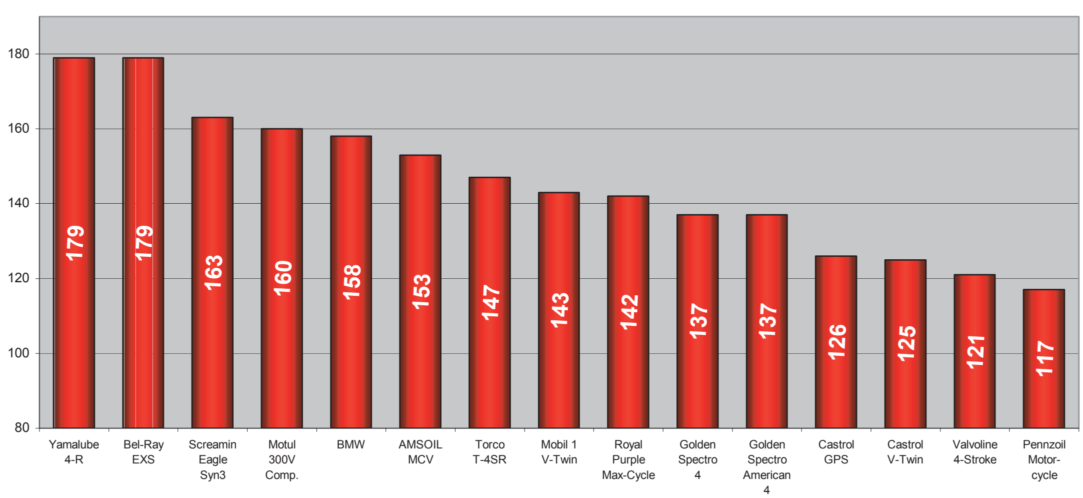
Viscosity Index (ASTM D-2270)

The viscosity (thickness) of an oil is affected by temperature changes during use. As the oil's temperature increases, its viscosity will decrease along with its load carrying ability. The degree of change that occurs with temperature is determined by using ASTM test methodology D-2270. Referred to as the oil's *Viscosity Index*, the methodology compares the viscosity change that occurs between 100° C (212° F) and 40° C (104° F). The higher the viscosity index, the less the oil's viscosity changes with changes in temperature. While a greater viscosity index number is desirable, it does not represent that oil's high temperature viscosity or its load carrying ability. Shearing forces within the engine, and particularly the transmission, can significantly reduce an oil's viscosity. Therefore, oils with a lower viscosity index but higher shear stability (discussed below) can, in fact, have a higher viscosity at operating temperature than one with a higher viscosity index and lower shear stability.

Results, Viscosity Index, SAE 40 Group



Results, Viscosity Index, SAE 50 Group

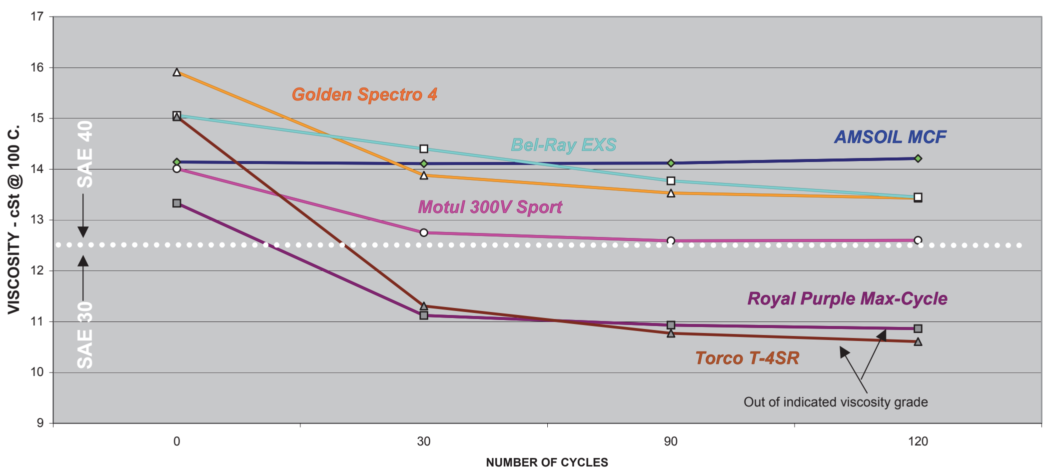


Viscosity Shear Stability (ASTM D-6278)

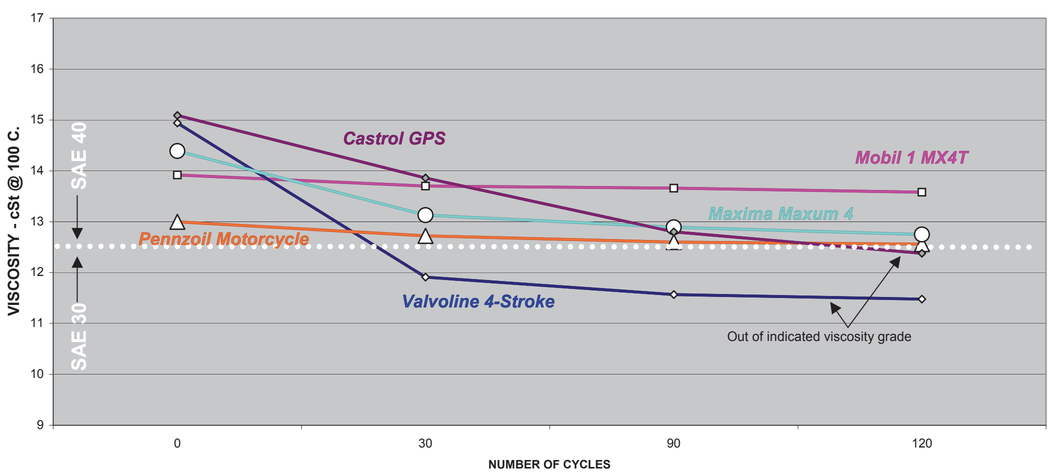
An oil's viscosity can also be affected through normal use. Mechanical activity creates shearing forces that can cause an oil to thin out, reducing its load carrying ability. Engines operating at high RPMs and those that share a common oil sump with the transmission are particularly subject to high shear rates. Gear sets found in the transmissions are the leading cause of shear induced viscosity loss in motorcycle applications.

The ASTM D-6278 test methodology is used to determine oil shear stability. First an oil's initial viscosity is determined. The oil is then subjected to shearing forces at 30 cycle intervals. Viscosity measurements are taken at the end of 30, 90 and 120 cycles and compared to the oil's initial viscosity. The oils that perform well are those that show little or no viscosity change. Oils demonstrating a significant loss in viscosity would be subject to concern. The flatter the line on the charts below, the greater the shear stability of the oil. Each SAE Grade was split into two or more groups to make the charts easier to reference.

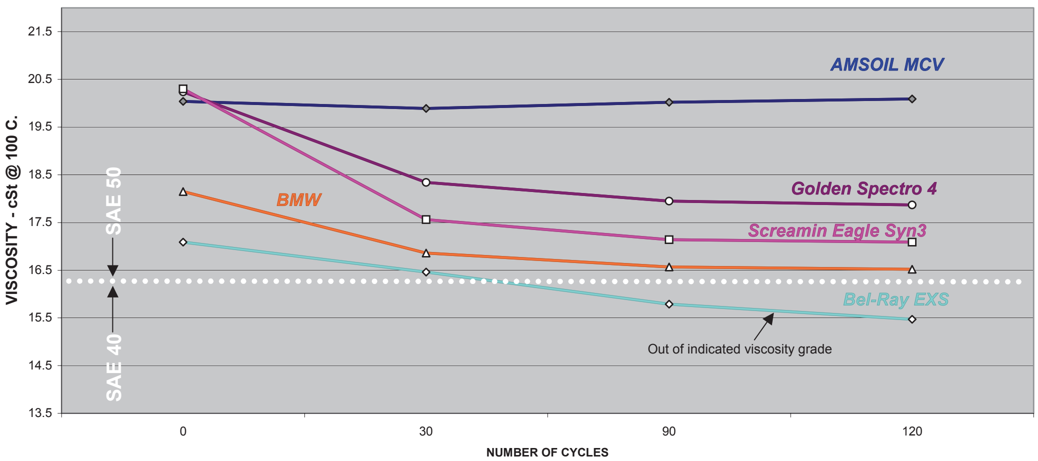
Results, Viscosity Shear Stability, SAE 40 Group 1



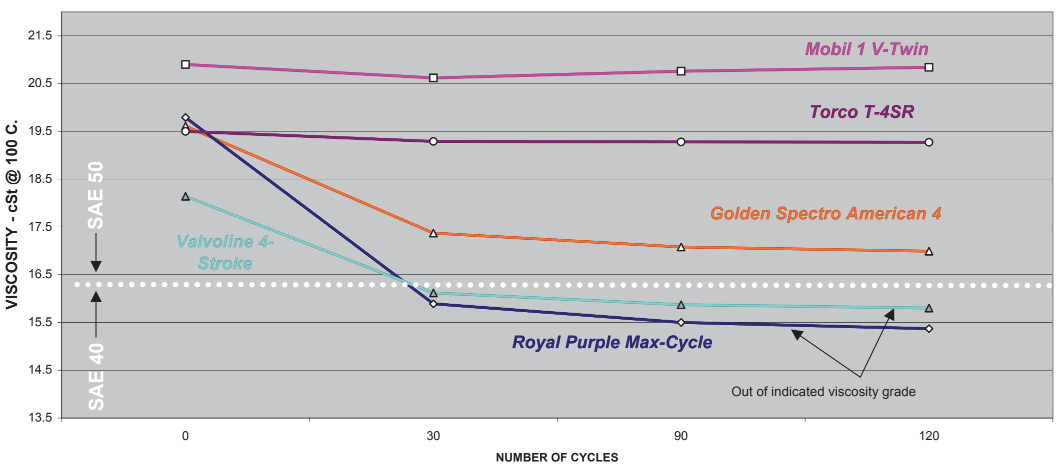
Results, Viscosity Shear Stability, SAE 40 Group 2



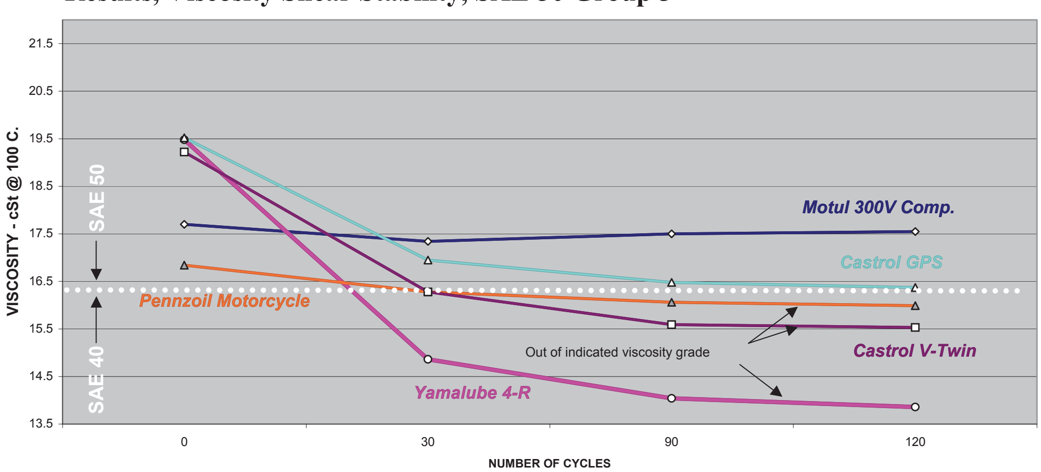
Results, Viscosity Shear Stability, SAE 50 Group 1



Results, Viscosity Shear Stability, SAE 50 Group 2



Results, Viscosity Shear Stability, SAE 50 Group 3



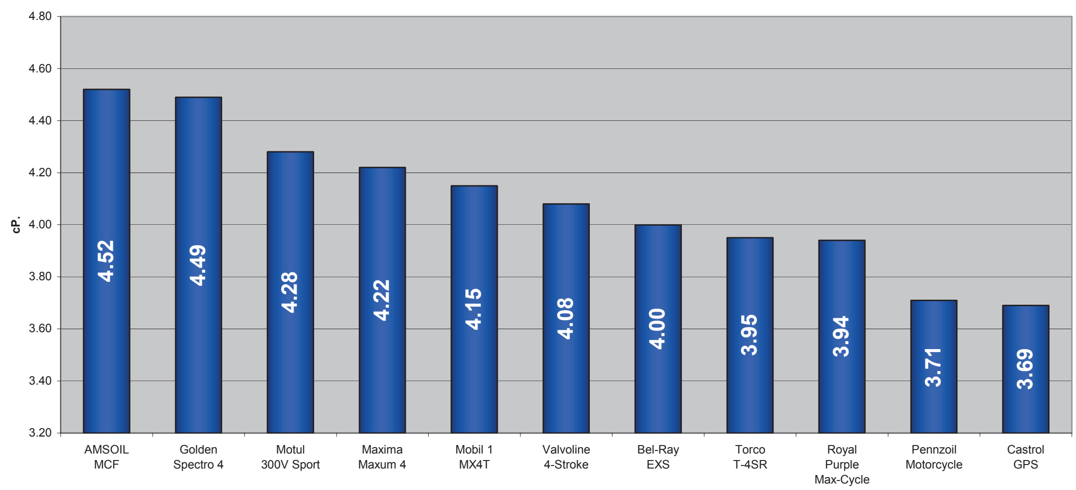
The results point out significant differences between oils and their ability to retain their viscosity. Within the SAE 40 group, 36% of the oils dropped one viscosity grade to an SAE 30. Within the SAE 50 group, 40% dropped one grade to an SAE 40. Most of the oils losing a viscosity grade did so quickly, within the initial 30 cycles of shearing.

It should be noted that both high and low viscosity index oils exhibited significant amounts of shear and viscosity loss. Two of the oils with the highest viscosity index, Torco T-4SR in the SAE 40 group and Yamalube 4R in the SAE 50 group, had the largest drops in viscosity of all the oils in their respective groups. Torco T-4SR sheared to a SAE 30 and Yamalube sheared to a SAE 40. Valvoline 4-Stroke SAE 50 and Castrol V-Twin SAE 50 had a comparatively low viscosity index and they too lost significant viscosity, shearing down to SAE 40.

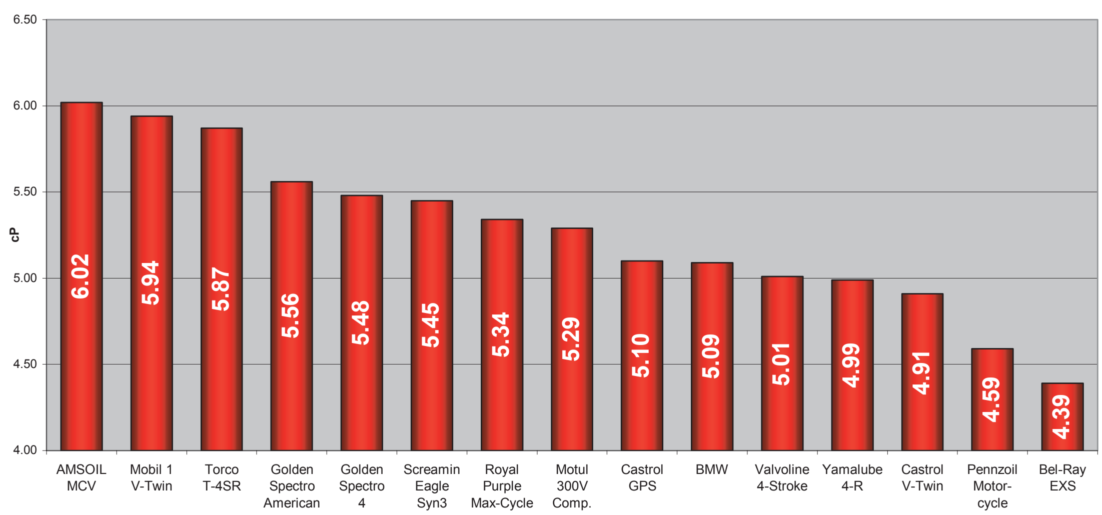
High Temperature / High Shear Viscosity (HT/HS ASTM D-5481)

Shear stability and good high temperature viscosity are critical in motorcycle applications. How these two areas in combination affect the oil is measured using ASTM test methodology D-5481. The test measures an oil's viscosity at high temperature under shearing forces. Shear stable oils that are able to maintain high viscosity at high temperatures perform well in the High Temperature/High Shear Test. The test is revealing as it combines viscosity, shear stability and viscosity index. It is important because bearings require the greatest level of protection during high temperature operation. Test results are indicated in centipoises (cP), which are units of viscosity. The higher the test result, the greater the level of protection offered by the oil.

Results, HT/HS, SAE 40 Group



Results, HT/HS, SAE 50 Group

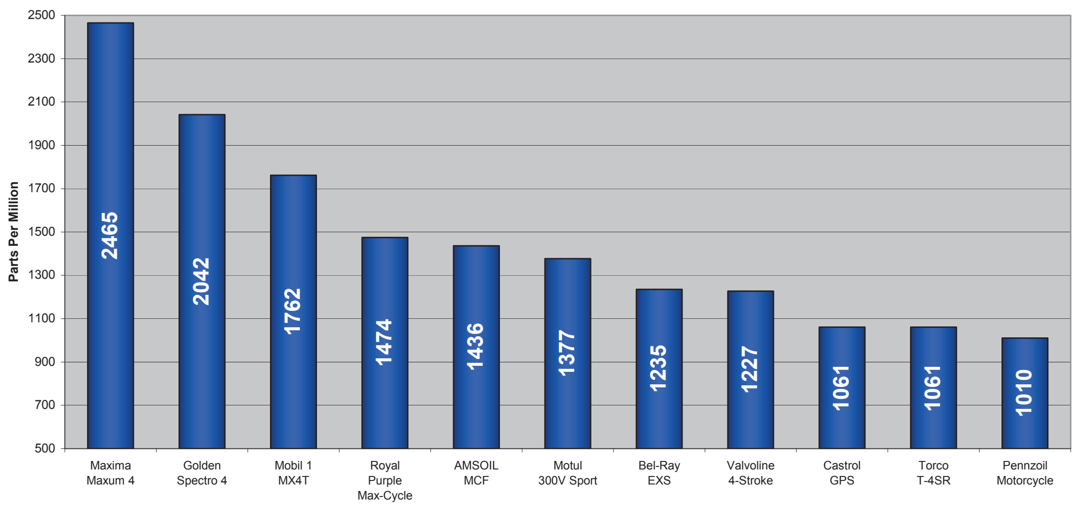


Zinc Concentration (ppm, ICP)

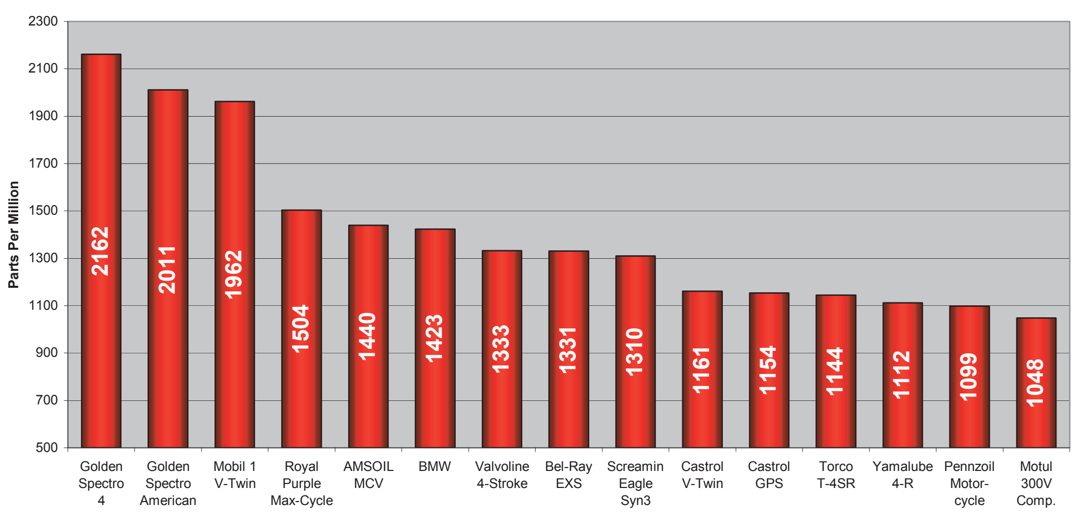
Though viscosity is the most critical variable in terms of wear protection, it does have limitations. Component loading can exceed the load carrying ability of the oil. When that occurs, partial or full contact results between components and wear will occur. Chemical additives are added to the oil as the last line of defense to control wear in these conditions. These additives have an attraction to metal surfaces and create a sacrificial coating on engine parts. If contact occurs the additive coating takes the abuse to minimize component wear. The most common additive used in internal combustion engine oils is zinc dithiophosphate (ZDP). A simple way of reviewing ZDP levels within an oil is to measure the zinc content. It should be noted that ZDP defines a group of zinc-containing compounds that vary in composition, quality and performance. Quantity of zinc content alone does not indicate its performance. Therefore, it cannot be assumed that oils with higher concentrations of zinc provide better wear protection. Additional testing must be reviewed to determine an oil's actual ability to prevent wear. The tables below show the levels of zinc present in each of the oils. Results were determined using an inductively coupled plasma (ICP) machine and are reported in parts per million.

Zinc levels varied widely in both the SAE 40 and 50 groups, ranging from as low as 1,010 ppm to as high as 2,465 ppm.

Results, Zinc Levels, SAE 40 Group



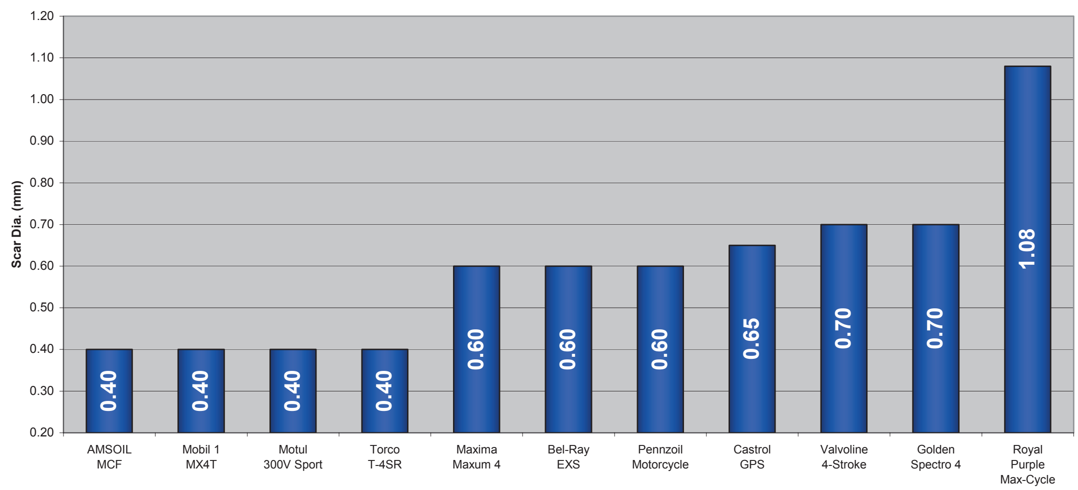
Results, Zinc Levels, SAE 50 Group



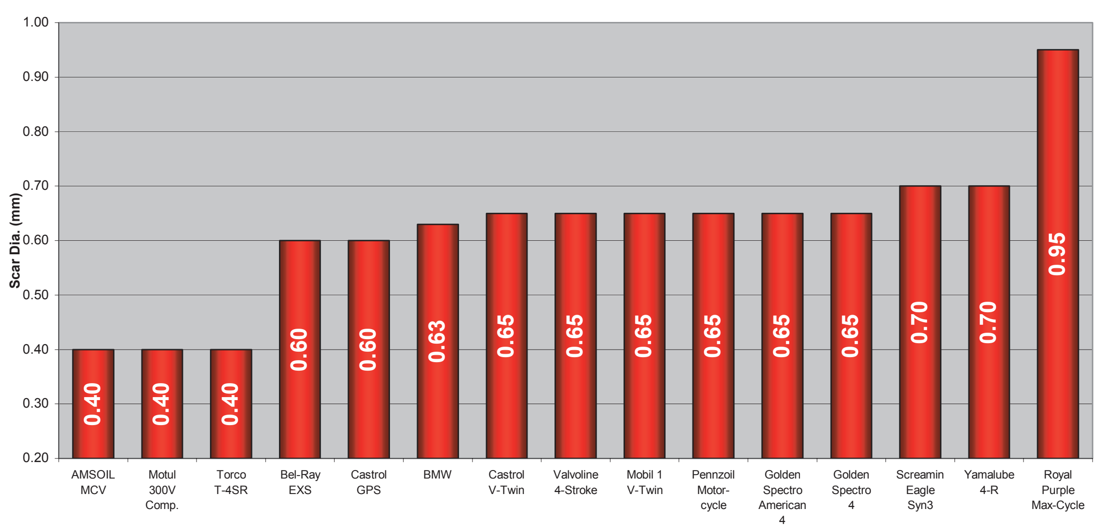
Wear Protection (4-Ball, ASTM D-4172)

The ASTM D-4172 4-Ball Wear Test is a good measure of the existence and robustness of an oil's additive chemistry. It is used to determine an oil's ability to minimize wear in case of metal-to-metal contact. The test consists of a steel ball that sits atop three identical balls that have been placed in a triangular pattern and restrained from moving. All four balls are immersed in the test oil, which is heated and maintained at a constant temperature. The upper ball is then rotated and forced onto the lower three balls with a load measured in kilogram-force (kgf). After a one-hour period of constant load, speed and temperature, the lower three balls are inspected at the point of contact. Any wear will appear as a single scar on each of the lower balls. The diameter of the scar is measured on each of the lower balls and the results are reported as the average of the three scars, expressed in millimeters. The lower the average scar diameter, the better the wear protection of the oil. In this case, the load, speed and temperature used for the test were 40 kg, 1800 RPMs and 150° C respectively.

Results, 4-Ball Wear Test, SAE 40 Group



Results, 4-Ball Wear Test, SAE 50 Group



Interestingly, the SAE 40 oils with the highest and lowest levels of zinc, Maxima Maxum 4 at 2,464 ppm and Pennzoil Motorcycle at 1,010 ppm, had identical results. Royal Purple, with an average level of zinc (1,474 ppm) had the largest wear scar (nearly 55% larger than the next closest wear scar size). Zinc levels for those oils performing the best, AMSOIL MCF, Mobil 1 MX4T, Motul 300V Sport and Torco T-4SR ranged from 1,061 to 1,762 ppm.

The SAE 50 group showed a similar trend. Golden Spectro 4, with the highest zinc level (2,162 ppm), performed less than average in the 4-Ball Wear Test, while the Motul 300 V Competition, with the lowest zinc level (1,048 ppm), tied with AMSOIL MCV and Torco T 4SR with the best test results.

The results strongly suggest that simply having high levels of zinc is not sufficient to effectively minimize wear.

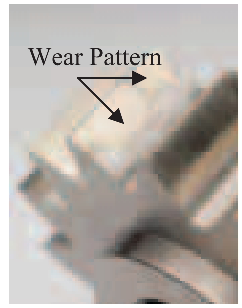
Gear Performance (FZG ASTM D-5182)

Wear protection is provided by both the oil's viscosity and its chemical additives. The greatest need for both is in the motorcycle transmission gear set. High sliding pressures, shock loading and the shearing forces applied by the gears demand a great deal from a lubricant. Motorcycle applications present a unique situation because many motorcycle engines share a common lubrication sump with the transmission. The same oil lubricates both assemblies, yet engines place different demands on the oil than do transmissions. What may work well for one may not work well for the other. In an attempt to meet both needs, a lubricant's performance can be compromised in both areas.

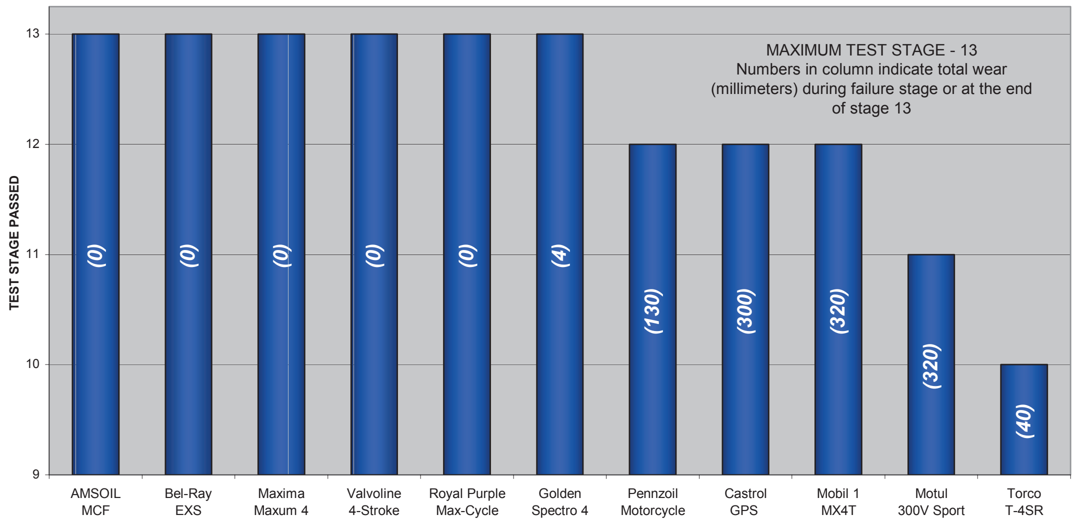
To examine gear oil performance, the ASTM test methodology D-5182 (FZG) is used. In this test, two hardened steel spur gears are partially immersed in the oil to be tested. The oil is maintained at a constant 90°C and a predetermined load is placed on the pinion gear. The gears are then rotated at 1,450 RPM for 21,700 revolutions. Finally, the gears are inspected for scuffing (adhesive wear). If the total width of wear on the pinion gear teeth exceeds 20 mm, the test is ended. If less than 20 mm of wear is noted, additional load is placed on the pinion gear and the test is run for another 21,700 revolutions. Each time additional load is added, the test oil advances to a higher stage. The highest stage is 13. Results indicate the stage passed by each oil. Wear is reported for the stage at which the oil failed.

Results, Gear Wear Test, SAE 40 Group

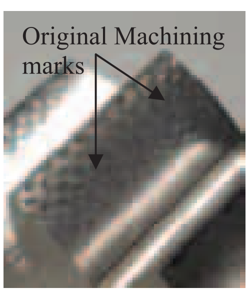
Pass Example:
AMSOIL MCF
Passed Stage 13,
Total Wear 0 mm



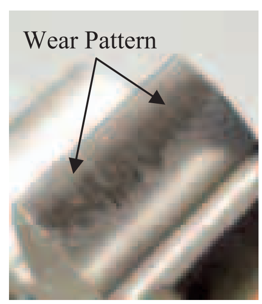
Failure Example:
Castrol GPS
Passed Stage 12,
Failed Stage 13,
Total Wear in Stage 13, 300 mm



Results, Gear Wear Test, SAE 50 Group



Pass Example:
AMSOIL MCV
Stage 13
Total Wear 0 mm



Failure Example:
Motul 300V Comp
Passed Stage 12,
Failed Stage 13
Total Wear in Stage 13, 320 mm

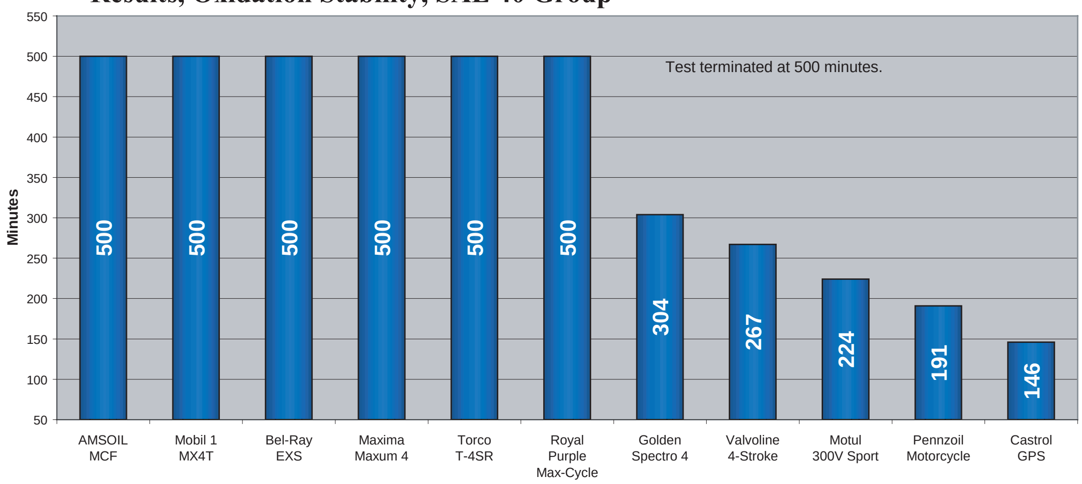
The test shows that 54.5% of the SAE 40 grade oils and 73.3% of the SAE 50 grade oils passed stage 13. Note that in the SAE 40 group, Mobil 1 MX4T, Motul 300V Sport and Torco T-4SR tied with AMSOIL MCF for the best 4-ball result but scored among the lowest in the FZG gear test. In the SAE 50 group, Motul 300V Competition and Torco T-4SR tied with AMSOIL MCV for the best 4-ball result, yet scored among the lowest at 26.7%. FZG and 4-ball wear tests measure wear protection differently. High scores in both tests indicate superior wear protection in a variety of applications and conditions. Only AMSOIL MCF (SAE 40) and MCV (SAE 50) placed on top in both wear tests.

Oxidation Stability (TFOUT ASTM D-4742)

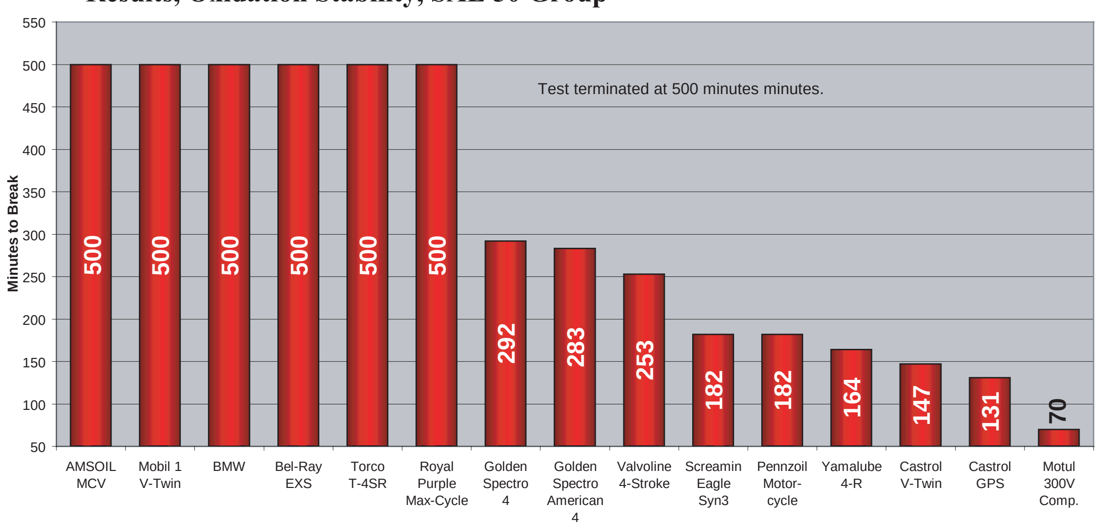
Heat can destroy lubricants. High temperatures accelerate oxidation, which shortens the oil life and promotes carbon deposits. Oxidized lubricants can create and react with contaminates such as fuel and water to produce corrosive by-products. Oxidation stability is critical in air-cooled and high performance motorcycles.

ASTM test methodology D-4742 is used to determine an oil's ability to resist oxidation by exposing the oil to common conditions found in gasoline fueled engines. These conditions include the presence of fuel; metal catalysts such as iron, lead and copper; water; oxygen and heat. Typically, the initial rate of oxidation is slow and increases with time. At a certain point, the rate of oxidation will increase significantly. The length of time it takes to reach that level of rapid oxidation is measured in minutes.

Results, Oxidation Stability, SAE 40 Group



Results, Oxidation Stability, SAE 50 Group



The test shows that 54.5% of the SAE 40 group oils and 40% of the SAE 50 group oils achieved the maximum obtainable results of 500 minutes. The results of the remaining oils suggest a faster rate of degradation and shorter service life.

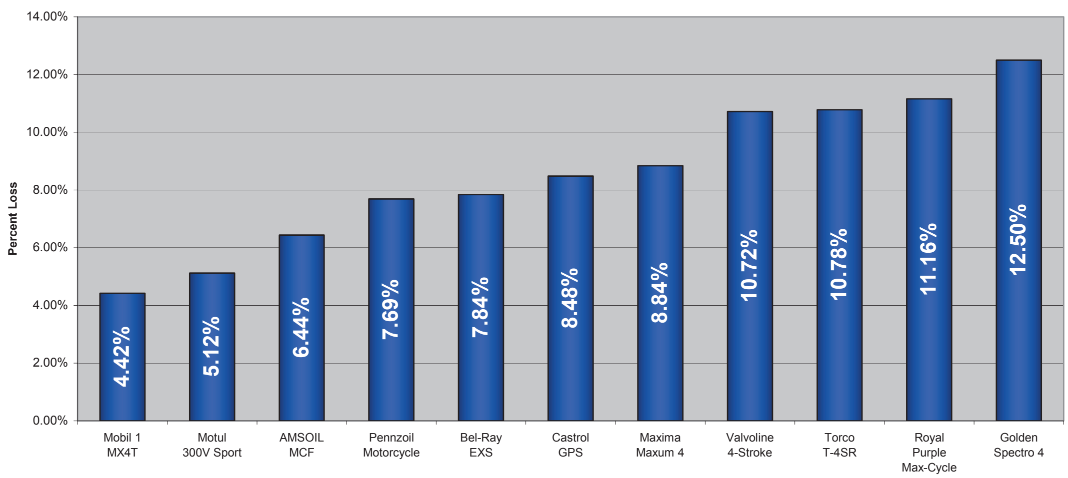
Superior oxidation stability is obtained through a combination of oil base stock and additive technology. In addition to being an anti-wear agent, zinc dithiophosphate (ZDP) is also an oxidation inhibitor. Similar to the discussion on wear, one might assume that oils with higher levels of zinc would provide improved oxidation stability. However, the results show that high ZDP levels were not consistent with good oxidation stability in the TFOUT test.

Volatility (Evaporation) (ASTM D-5800)

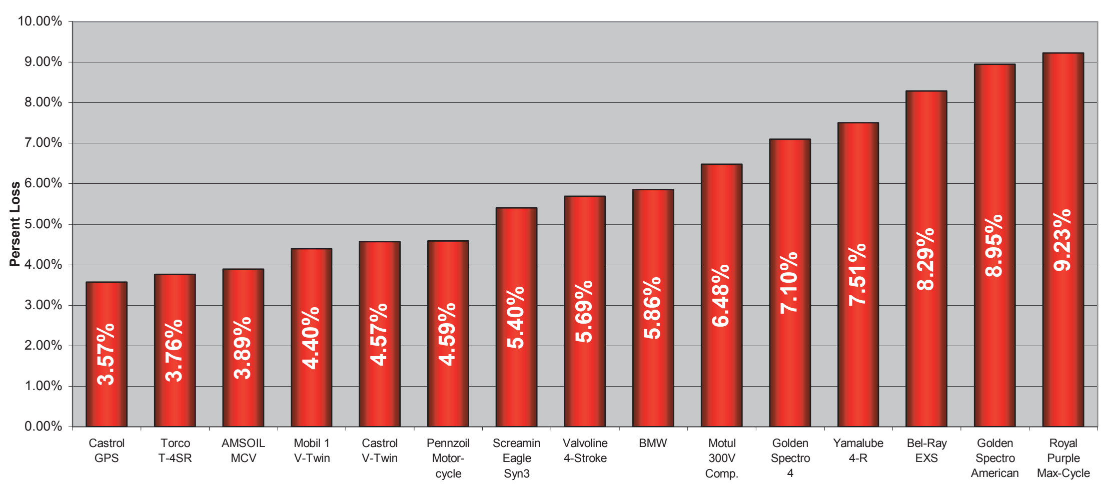
When oil is heated, lighter fractions in the oil volatilize (evaporate). This leads to increased oil consumption, emissions and viscosity increase. Higher operating temperatures produce greater volatility.

To determine an oil's resistance to volatility, ASTM test methodology D-5800 is used. In this test, a specific volume of oil is heated to a temperature of 250° C for a period of 60 minutes. Air is drawn through the container holding the oil sample, removing oil that has turned into vapor. At the end of the 60-minute period, the remaining oil volume is weighed and compared to the original weight of the sample. The difference is reported as the percentage of weight lost.

Results, Volatility, SAE 40 Group



Results, Volatility, SAE 50 Group



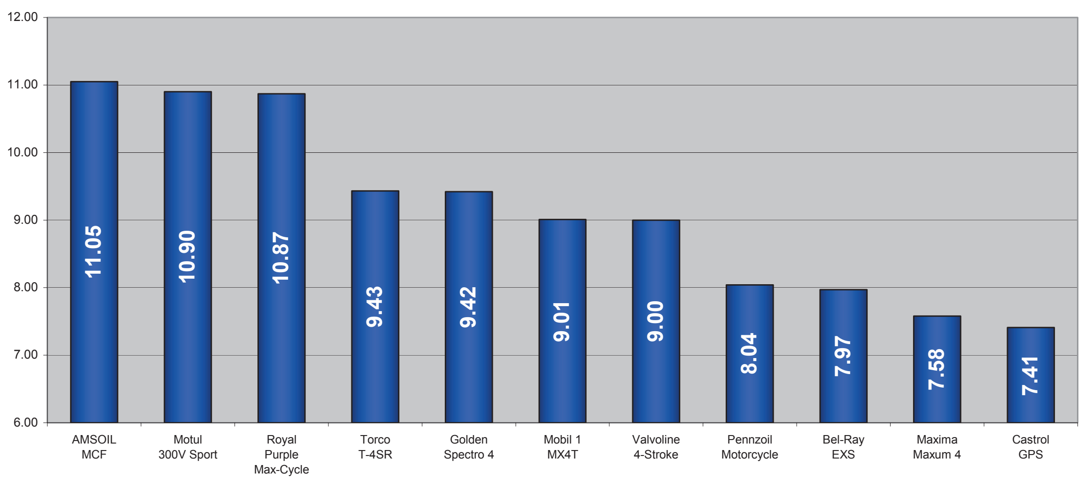
The results show a significant difference between those oils with low volatility and those with higher volatility. Low volatility is of particular benefit in hot running, air-cooled engines.

Acid Neutralization and Engine Cleanliness (TBN ASTM D-2896)

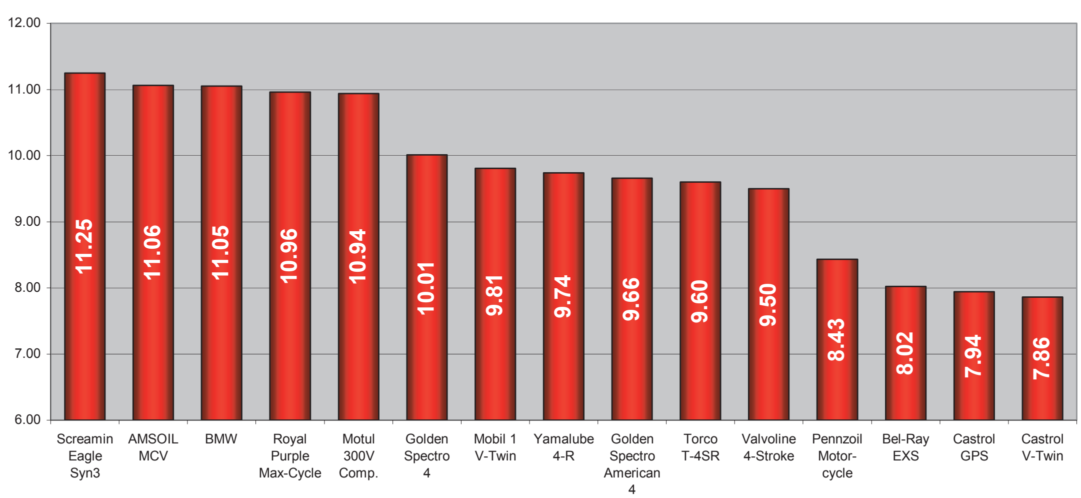
Motor oils are designed to neutralize acids and keep engines clean. Both tasks can be accomplished, in part, through the use of detergent additives, as they are often alkaline in nature. The extent to which alkalinity exists within an oil can be measured using ASTM D-2896. Reported as a Total Base Number (TBN), the test determines the amount of acid required to neutralize the oil's alkaline properties. The higher the result, the greater amount of acid the oil can withstand.

Detergent additives are sacrificial and are depleted as they neutralize acids. Therefore, oils with a higher TBN should provide benefits over a longer period of time.

Results, TBN and Cleanliness, SAE 40 Group



Results, TBN and Cleanliness, SAE 50 Group



Foaming Tendency (ASTM D-892)

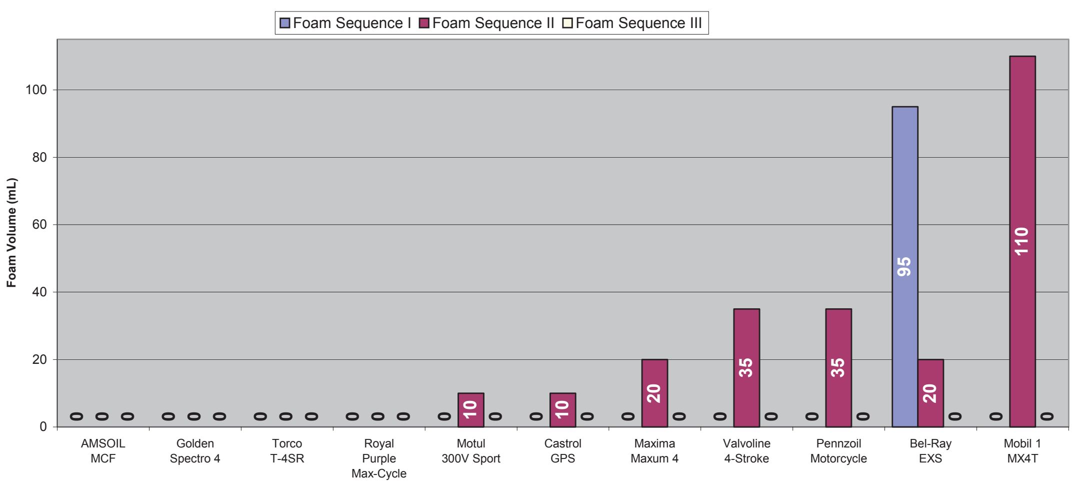
During engine and transmission operation, air is introduced into the lubricating oil, which may produce foam. In severe cases, foam can increase wear, operating temperatures and oxidation. Oil is non-compressible, but when air passes through loaded areas, the bubbles can collapse and allow the metal surfaces to contact each other. In addition, the oil has a larger surface area exposed to oxygen when air is trapped in the oil, which promotes increased oxidation.

Higher operating speeds and gear systems in motorcycles increase the need for good foam control. While oil cannot prevent the introduction of air, it can control foaming through the use of anti-foam additives.

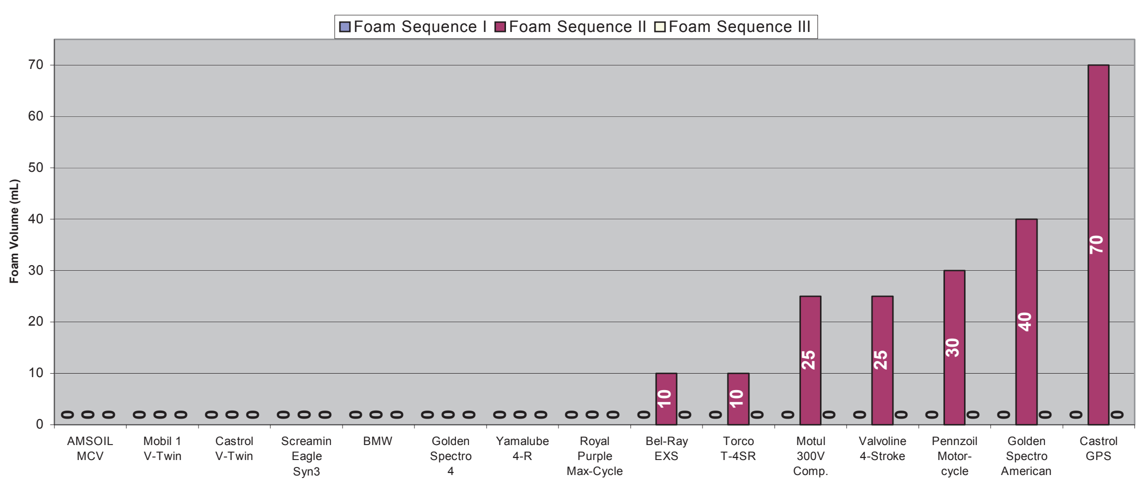
To determine foaming characteristics, ASTM test methodology D-892 is used. The testing is divided into three individual sequences. In each sequence, air is bubbled through the oil for five minutes and the foam generated is measured in millimeters immediately following the test. At the end of the sequence, the oil is allowed to settle for 10 minutes and the remaining foam is measured again. Both results are reported. The temperature is altered for each sequence. Sequence I is conducted at 24° C, Sequence II at 93.5° C and Sequence III after allowing the oil to cool back to 24° C.

The amount of foam after the 10 minute settling period for all oils in all sequences was zero. The results shown are the levels of foam present for each sequence immediately following the five-minute bubbling process.

Results, Foaming Tendency, SAE 40 Group



Results, Foaming Tendency, SAE 50 Group



Rust Protection (Humidity Cabinet ASTM D-1748)

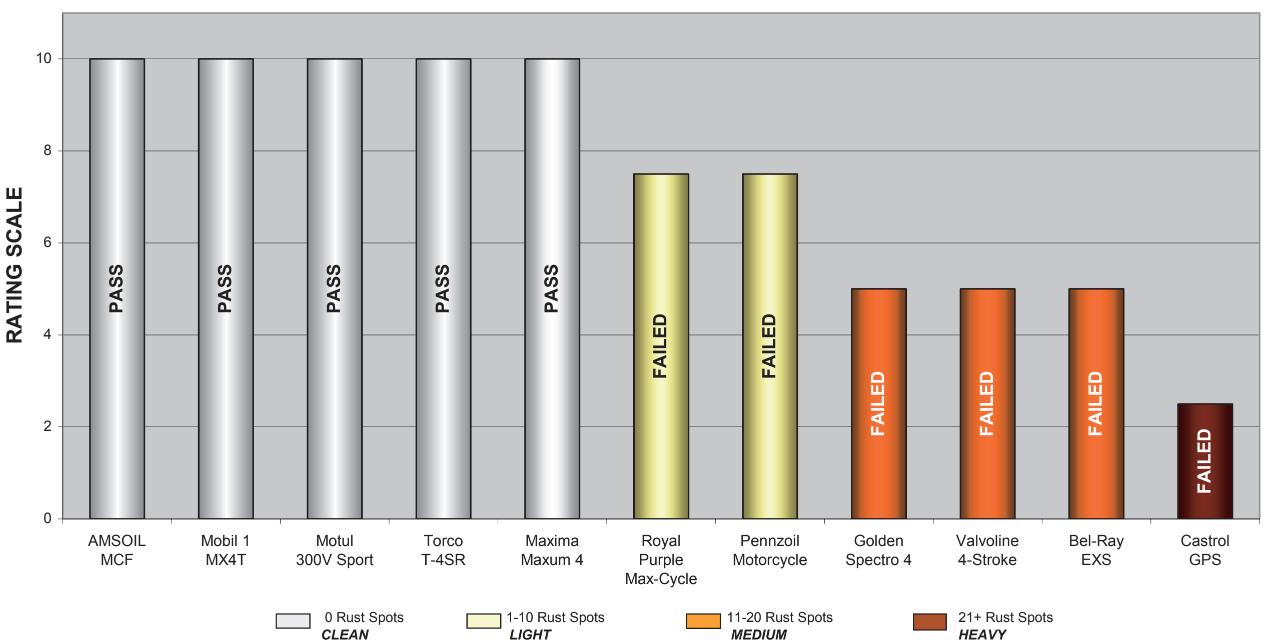
Rust protection is of particular importance in motorcycle applications. Motorcycles are typically not used every day and are often stored during the off-season. Condensation and moisture within the engine can cause rust. Rust is very abrasive and leaves pits in metal surfaces. Rust rapidly accelerates wear and can cause catastrophic failure. Roller bearings are especially sensitive to rust. Oil, however, has little or no natural ability to prevent rust. General engine oil additives may provide some degree of rust protection, but for superior anti-rust properties, rust inhibitors must be added.

Rust protection is measured using the ASTM D-1748 humidity cabinet test. The procedure calls for metal coupons to be dipped in the test oil, then placed in a humidity cabinet for 24 hours at 48.9° C. After 24 hours, the coupons are removed and inspected for rust. Oils allowing no rust or no more than three rust spots less than or equal to 1 mm in diameter are determined to have passed. Oils allowing more than three rust spots or one rust spot greater than 1 mm in diameter are determined to have failed. The degree of failure has been divided into three additional categories: 1-10 spots, 11-20 spots and 21 or more spots.

Results, Rust Protection, SAE 40 Group

Pass example: AMSOIL MCF

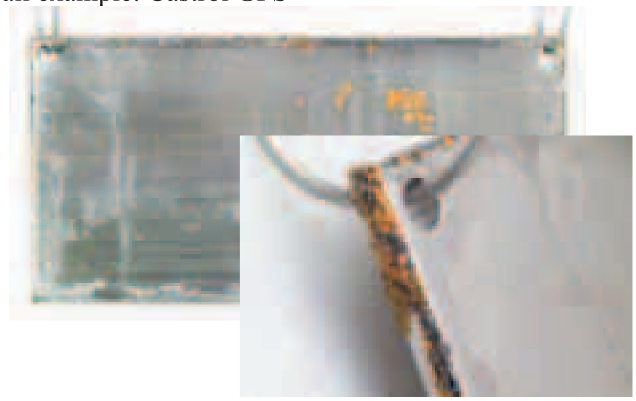
Fail example: Castrol GPS

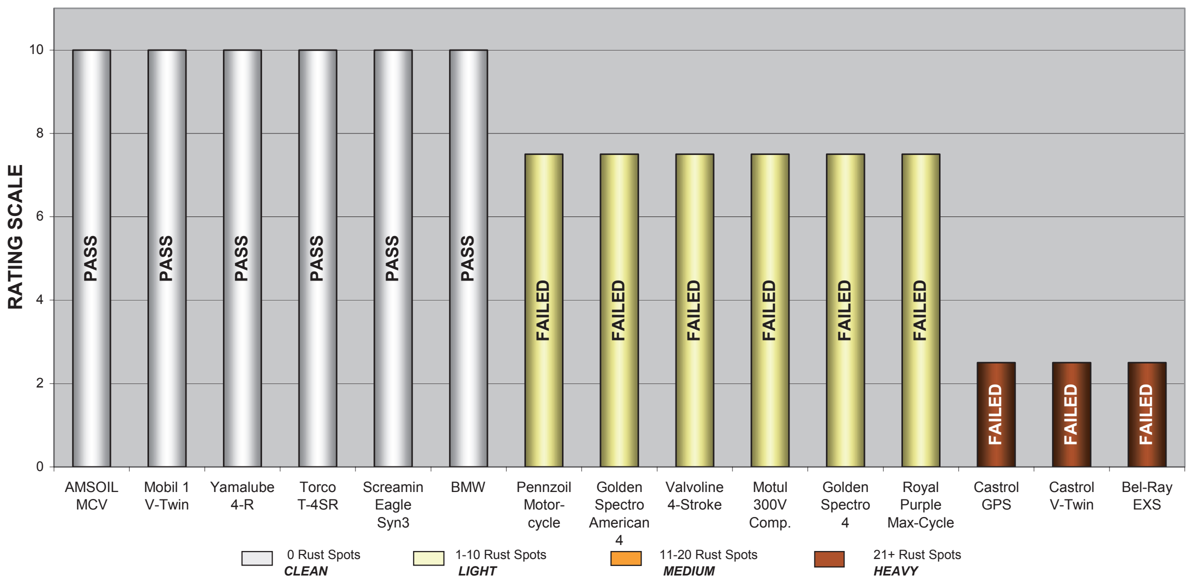


Results, Rust Protection, SAE 50 Group

Pass example: AMSOIL MCV

Fail example: Castrol GPS

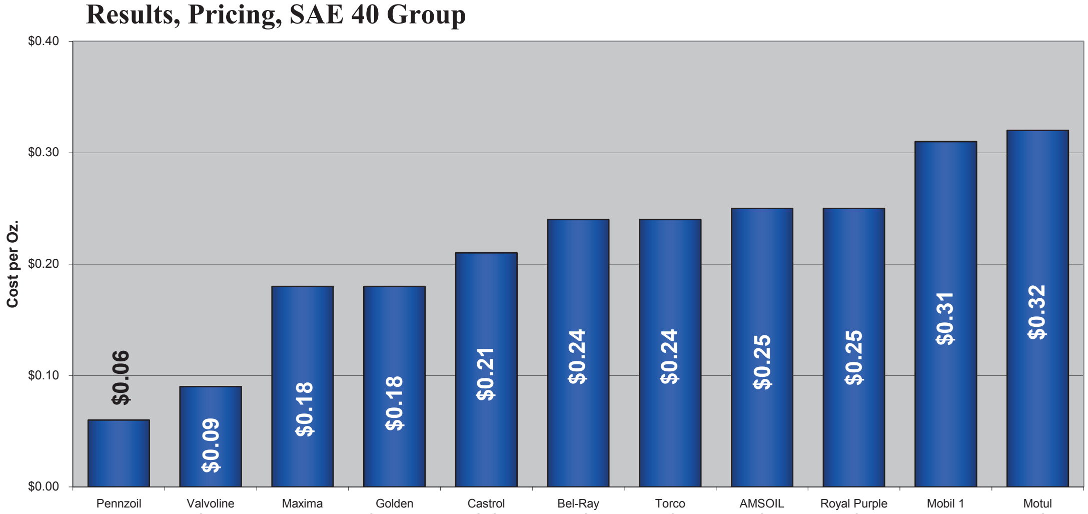




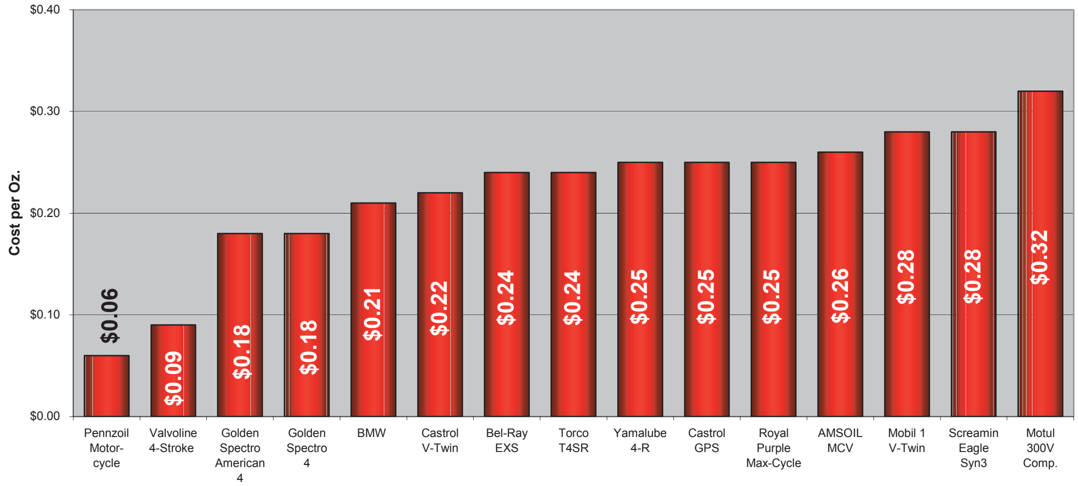
Pricing

Performance is not all that is considered when making a motorcycle oil purchase. The consumer will wish to optimize the performance of the product as compared to the price. In this evaluation the price of the candidate oils were compared on a cost per ounce basis, equalizing the differences between quart and liter volumes. Prices are based on the actual cost paid for the product when purchased in case lots.

Results, Pricing, SAE 40 Group



Results, Pricing, SAE 50 Group



Although the initial price of a product is a primary concern, it does not reflect the actual cost of using the product. Less expensive oils may save money initially but can cost more in the end if they compromise performance. The additional benefits offered by a more expensive oil can offset the difference in price. For example, oils that last longer cost less over time, and oils that offer superior anti-wear performance and rust protection can increase equipment life, reducing expensive repairs. High quality motorcycle oil is an inexpensive way to protect an expensive investment.

Wet-Clutch Compatibility (JASO T 904-98, limited review)

It has been noted that motorcycle oils must be multi-functional, meeting the needs of both the engine and transmission. An additional concern is in those applications in which the clutch is immersed in the oil occupying the transmission. As the clutch is a frictional devise and oils are by design used to minimize friction, concern arises over the impact the oil may have on the operation of the clutch. How an oil performs in a wet-clutch application is, in part, a function of its additive system. An oil should be free of additives such as friction modifiers that can dramatically alter the dynamic and static frictional properties of the clutch and result in clutch plate slippage.

Wet-clutch compatibility is determined using JASO T 904-98 test methodology. This procedure determines the frictional characteristics of an oil and allows for comparison against a standard. That standard has two categories: JASO MA and MB. For motorcycle applications, the best performance is generally obtained when oils meeting the JASO MA specifications are used.

The scope of this paper did not allow for the evaluation of all oils in this area. As such, results of the oils tested were not included in the overall product summary. The results provided are for interest only.

Results, Wet-Clutch Compatibility

	Dynamic Friction Index	Static Friction Index	Stop Time Index	Meets JASO MA Requirements
JASO MA Requirements	∅1.45	∅1.15	∅1.55	
AMSOIL MCF 10W-40	1.93	1.81	1.95	YES
AMSOIL MCV 20W-50	1.93	1.8	1.93	YES
Mobil 1 MX4T 10W-40	1.66	1.64	1.75	YES
Castrol GPS 10W-40	2.05	1.97	1.96	YES
Motul 300V Sport 10W-40	2.02	1.41	1.94	YES
Motul 300V Comp. 15W-50	2.07	1.35	1.99	YES

Scoring and Summary of Results

Each oil was assigned a score for each test result. The oil with the best test result was assigned a 1. The oil with the second best result was assigned a 2, and so on. Oils demonstrating the same level of performance were assigned the same number. Note that the results of each test have not been weighted to reflect or suggest the degree of significance it represents in a motorcycle application. The degree of significance will vary between individual applications and by consumer perception. As oils must perform a number of tasks, results in all categories were added together to produce an overall total for each oil. The oil with the lowest total is the overall highest performer.

Results, Scoring Summary, SAE 40 Group

SAE 40 - PRODUCT COMPARISON RESULTS (Motorcycle)	AMSOIL MCF	Motul 300V Sport	Mobil 1 MX4T	Golden Spectro 4	Maxima Maxum 4	Bel-Ray EXS	Royal Purple Max-Cycle	Torco T-4SR	Valvoline 4-Stroke	Pennzoil Motorcycle	Castrol GPS
Wear Protection (4-Ball ASTM D-4172)	1	1	1	4	2	2	5	1	4	2	3
High Temperature / High Shear Viscosity (HT/HS ASTM D-4683)	1	3	5	2	4	7	9	8	6	10	11
Gear Performance (FZG ASTM D-5182)	1	3	2	1	1	1	1	4	1	2	2
Oxidation Stability (TFOUT ASTM D-4742)	1	4	1	2	1	1	1	1	3	5	6
Rust Protection (Humidity Cabinet ASTM D-1748)	1	1	1	3	1	3	2	1	3	2	4
Foam Control (ASTM D-892)	1	2	7	1	3	6	1	1	4	5	2
Volatility (NOACK ASTM D-5800)	3	2	1	11	7	5	10	9	8	4	6
Viscosity Shear Stability (% Viscosity Retention after 90 cycles, ASTM D-6278)	1	4	2	7	6	5	9	11	10	3	8
Viscosity Index (ASTM D-2270)	8	3	9	5	11	2	4	1	6	10	7
Acid Neutralization (TBN ASTM D-2896)	1	2	6	5	10	9	3	4	7	8	11
Zinc Levels (ppm ICP)	5	6	3	2	1	7	4	9	8	10	9
Pricing	6	8	7	3	3	5	6	5	2	1	4
OVERALL TOTALS	30	38	45	46	50	53	55	55	62	62	73
Ranking	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7**	**8**	**8**	**9**

AMSOIL MCF | Motul 300V Sport | Mobil 1 MX4T | Golden Spectro 4 | Maxima Maxum 4 | Bel-Ray EXS | Royal Purple Max-Cycle | Torco T-4SR | Valvoline 4-Stroke | Pennzoil Motorcycle | Castrol GPS

Results, Scoring Summary, SAE 50 Group

SAE 50 - PRODUCT COMPARISON RESULTS (Motorcycle)	AMSOIL MCV	Mobil 1 V-Twin	BMW	Torco T 4SR	Golden Spectro 4	Screamin' Eagle Syn3	Golden Spectro American 4	Royal Purple Max-Cycle	Motul 300V Comp.	Bel-Ray EXS	Valvoline 4-Stroke	Pennzoil Motorcycle	Yamalube 4-R	Castrol GPS	Castrol V-Twin
Wear Protection (4-Ball ASTM D-4172)	1	4	3	1	4	5	4	6	4	2	4	4	5	2	4
High Temperature / High Shear Viscosity (HT/HS ASTM D-4683)	1	2	10	3	5	6	4	7	8	15	11	14	12	9	13
Gear Performance (FZG ASTM D-5182)	1	1	1	3	1	1	1	1	2	1	1	3	3	1	1
Oxidation Stability (TFOUT ASTM D-4742)	1	1	1	1	2	5	3	1	10	1	4	6	7	9	8
Rust Protection (Humidity Cabinet ASTM D-1748)	1	1	1	1	2	1	2	2	2	4	2	2	1	4	4
Foam Control (ASTM D-892)	1	1	1	2	1	1	5	1	3	2	3	4	1	6	1
Volatility (NOACK ASTM D-5800)	3	4	9	2	11	7	14	15	10	13	8	6	12	1	5
Viscosity Shear Stability (% Viscosity Retention after 90 Cycles, ASTM D-6278	1	2	6	4	8	11	10	14	3	7	9	5	15	12	13
Viscosity Index (ASTM D-2270)	5	7	4	6	9	2	9	8	3	1	12	13	1	10	11
Acid Neutralization (TBN ASTM D-2896)	2	7	3	10	6	1	9	4	5	13	11	12	8	14	15
Zinc Levels (ppm ICP)	5	3	6	12	1	9	2	4	15	8	7	14	13	11	10
Pricing	8	9	4	6	3	9	3	7	10	6	2	1	7	7	5
OVERALL TOTALS	30	42	49	51	53	58	66	70	72	73	74	84	85	86	90
Ranking	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**

AMSOIL MCV | Mobil 1 V-Twin | BMW | Torco T 4SR | Golden Spectro 4 | Screamin' Eagle Syn3 | Golden Spectro American 4 | Royal Purple Max-Cycle | Motul 300V Comp. | Bel-Ray EXS | Valvoline 4-Stroke | Pennzoil Motorcycle | Yamalube 4-R | Castrol GPS | Castrol V-Twin

Conclusion

The intent of this document is to provide scientific data on the performance of motorcycle oils and information on their intended applications. The document also attempts to dismiss several rumors or mistruths common to motorcycle oils. In doing so, it will assist the reader in making an informed decision when selecting a motorcycle oil.

The tests conducted are intended to measure variables of lubrication critical to motorcycles, with some having much greater value than others. Gear and general anti-wear protection, oxidation stability and rust protection are the most important, with zinc content being among the least important. The results were not weighted based on importance. The value of each test is to be determined by the reader.

The data presented serves as predictors of actual service; the better the score, the better the performance. AMSOIL MCF and MCV demonstrated superior performance, particularly in the most important areas, and each ranked first overall in its respective category. It should be noted that the performance of a given manufacturer's oils was not always consistent between viscosities. For example, Motul 300V Sport scored second within the SAE 40 group while Motul 300V Competition scored ninth in the SAE 50 group.

The results suggest a relationship between the cost of an oil and its level of performance. Generally, higher priced oils tend to perform better, although price alone is not a guarantee of performance. Motul 300V Competition was the most costly oil tested, yet lower priced oils showed better performance. Price must be put into perspective. The cost of oil compared to the cost of a motorcycle is minimal. The cost difference between the average price for motorcycle oils and the most expensive oils is about $10 per oil change. If the performance of an oil can support an extended oil change interval, that cost is reduced. The consumer must consider the performance and benefits offered by an oil and how those benefits affect their motorcycle investment to determine the oil's value.

In conclusion, maximum performance and cost effectiveness are obtained when one looks beyond marketing claims and selects a product based on the data that supports it.

Affidavit

I hereby affirm to the best of my knowledge that all of the test results reported in the document entitled "A Study of Motorcycle Specific Oils" prepared for the AMSOIL Power Sports Group in August of 2005 are correct. I further affirm that the tests results were obtained following procedures approved by the American Society of Testing and Materials (ASTM) or other recognized organizations as referenced in the paper. Written documentation of test results are on file at AMSOIL INC.

David E. Leitten

STATE OF Wisconsin
COUNTY OF Douglas

Subscribed and sworn to before me this 16th day of Sept 2005

NOTARY PUBLIC

[SEAL]

Name: Judith A. Greeley
My commission expires: 10-14-07

JUDITH GREELY
NOTARY PUBLIC
STATE OF WISCONSIN

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