

A Study of Automotive Gear Lubes

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Overview

The requirements for automotive gear lubrication have changed over the years, yet vehicle owner awareness has not. Gear lubrication has been commonly considered elementary, but, in fact, it is a dynamic process that requires sophisticated technology. The differentials that house the gears are out of sight, out of mind. They are neglected. But differentials are just as important to the operation of a vehicle as the engine. An engine without a functioning differential will not move the vehicle. Gear lubrication needs to be taken more seriously than before. There are several forces driving the need for better gear lubrication.

First, is improved fuel economy. Modern vehicle aerodynamics, with lower level air dams, is decreasing the air flow over differentials. Fuel economy is improved, but reduced air flow increases differential operating temperatures. Also, lubricant fill volumes in differentials have been reduced in order to lower fluid drag on the gears and bearings for further improvement in fuel economy. However, lubricants cool components, and with less fluid in the sump, operating temperatures rise.

Improvements in vehicle performance have created additional need for more sophisticated gear lubrication. Model-year 2007 turbo diesel pickup trucks, V-10 gasoline pickups and sport utility vehicles (SUVs), and high-horsepower V-8 trucks have more towing and payload capacities than in previous years, yet their differentials have not changed. There has been a 34% increase in engine horsepower over the last decade, while axle gear sizes have remained constant, sump capacities have been lowered and drain intervals extended. In the light truck segment there has been a 93% horsepower increase since 1981.¹ In vehicles such as a fifth-wheel equipped Ford F-350 Super Duty, towing capacities have reached a high of 19,200 lbs.² And testing shows that in new axle applications simulating trailer towing at 88 km/h (55 mph) at a 3.5% grade temperatures can reach as high as 188°C (370°F).³ Stress on differentials has also increased in limousines, conversion vans, and trucks and cars with modified, high-performance engines. More power, more towing capacity and higher hauling limits greatly increase the stress that causes heat and wear.

Improvements in vehicle comfort have also driven the need for better gear lubrication. The demand for greater interior space has forced vehicle manufacturers to lower floor boards, which restricts air flow to the differential. Hot exhaust systems are forced closer to the axle housing, and differential operating temperatures are increased even further.

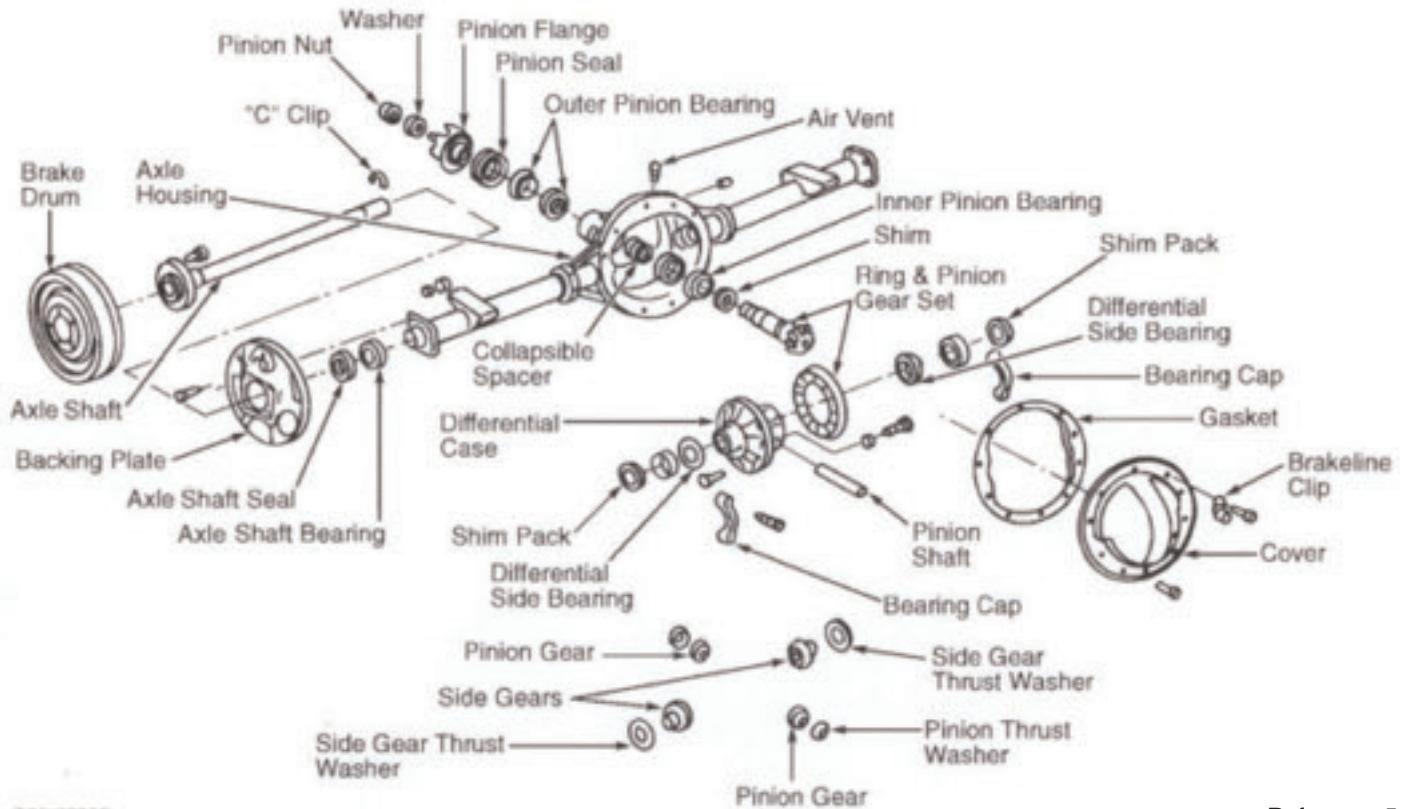
Most vehicles operate under severe service as defined by vehicle manufacturers, but the majority of vehicle owners are unaware of this. Severe service applications include towing, hauling, plowing, off-road use, frequent stop-and-go driving, steep-hill driving and temperature extremes. Severe service applications are on the rise. For example, more than 90 percent of Ford Super Duty pickups are used for towing.⁴ Severe service increases the need for better gear lubrication.

Synthetic gear lubes are recognized as superior to petroleum-based gear lubes by vehicle manufacturers, gear manufacturers and most high-performance automotive experts. Synthetic gear lubes exhibit all-around better performance. There are many synthetic gear lubricants available to consumers, including those marketed by vehicle manufacturers. All position themselves as superior to the rest.

Operating Conditions and Lubrication Requirements

Differentials contain many different components, each having its own requirements for lubrication. The ring and pinion gears operate under extreme pressure and sliding contact that require extreme-pressure additives for protection. The bearings operate under rolling motion where lubricant film strength is particularly important, and limited-slip clutches require special friction additives for proper operation. It is essential, therefore, that gear lube formulations be carefully balanced to protect all components. Too much emphasis on the needs of one component can detract from the needs of another.

The following illustration shows differential components:



Reference 5

Purpose

The purpose of this paper is to inform consumers about the increasingly severe conditions under which differentials operate and to provide data reflecting the quality and cost differences of popular synthetic and petroleum gear lubes. With this information, consumers are better prepared to make informed decisions when purchasing gear lubricants.

Method

The testing by which the gear lubes were evaluated was done in accordance with American Society for Testing and Materials (ASTM) procedures, Society of Automotive Engineers (SAE) J306 requirements and Federal Test Method Standards. Other than the oxidation filter patch procedure, performance testing was conducted by an independent laboratory. Physical-property testing (viscosity, viscosity index, pour point and foaming after oxidation) was conducted in-house. A notarized affidavit certifying that the results are accurately reported is included in Appendix 1. Gear lube pricing was obtained from the manufacturers or distributors, and a notarized affidavit certifying that those prices are reported as obtained is included in Appendix 2.

Scope

The focus of this paper is on American Petroleum Institute (API) GL-5, SAE 75W-90 synthetic gear lubes. Samples of API GL-5, SAE 80W-90 petroleum gear lubes were also included for comparative purposes. The tests were selected to measure the properties consistent with extreme-pressure gear lubricant requirements and are intended to reveal the lubricants' overall performance. The performance characteristics evaluated include each gear lube's ability to:

1. Meet the required viscosity grade of an application
2. Maintain viscosity when subjected to temperature changes
3. Retain viscosity during use
4. Function in cold temperatures
5. Resist high temperatures and oxidation
6. Protect under extreme pressures
7. Protect against wear
8. Resist foaming
9. Prevent copper corrosion.

Review Candidates

The cross-section of gear lubricants tested includes those offered by original equipment manufacturers (OEMs), motor oil companies and specialty companies. All gear lubes, with the exception of Mopar Synthetic and Torco SGO Synthetic, are recommended by their manufacturers for limited-slip differentials and are therefore expected to contain appropriate limited-slip-type additives. Mopar limited-slip additive was added to Mopar Synthetic and Torco Type G limited-slip additive was added to Torco SGO Synthetic at the recommended levels to ensure equal testing. Each gear lube tested is listed in the following chart along with the performance specifications identified on the respective bottles. Batch codes are also listed.

Gear lubricant specifications are established for minimum performance levels. The *active* API gear lubricant specifications are API GL-4, GL-5 and MT-1. API GL-4 designates the type of service characteristics of spiral bevel and hypoid gears in automotive axles operated under moderate speeds and loads. These gear lubes may be used in select manual transmissions and transaxles. API MT-1 designates lubricants for non-synchromesh manual transmissions and transaxles. API MT-1 is independent of API GL-5. API MT-1 calls for a higher level of oxidation stability, copper corrosion resistance and seal compatibility, which is not provided by API GL-4 or GL-5. Not all gear lubes meet API MT-1 performance standards.

API GL-1, GL-2, GL-3 and GL-6 are *inactive*. API GL-6 is identified by Lucas, Red Line and Torco as a performance specification. However, the test equipment is obsolete.

The U.S. military has established separate gear lube specifications. The most current military specification is MIL-PRF-2105E, which supersedes the previous specification, MIL-L-2105D. MIL-PRF-2105E combines the performance requirements of MIL-L-2105D, API GL-5 and all but one parameter of API MT-1, thereby adding improved oxidation stability, copper corrosion resistance and seal compatibility to extreme-pressure axle lubricants. An additional gear lube standard, SAE J2360, mirrors MIL-PRF-2105E and is a global standard used by oil companies in countries where U.S. military standards are not applicable.

Brand	API		MIL-L-2105D	MIL-PRF-2105E/ SAE J2360	Batch Number
	GL-5	MT-1			
Synthetic Candidates					
AMSOIL® Severe Gear® 75W-90	X	X		X	LN 25902
Castrol® SYNTEC® 75W-90	X	X			MD62597BTW2578
GM® Synthetic Axle 75W-90	X				101006
Lucas® 75/90 Synthetic	X		X		193
Mobil 1® Synthetic 75W-90	X				OEV5J6CO1788#5990
Mopar® Synthetic 75W-90 with Mopar® LS additive	X				MRT081205C
Pennzoil® Synthetic 75W-90	X				Unreadable
Red Line® Synthetic 75W-90	X	X		X	56292/60840001663
Royal Purple® Max-Gear® 75W-90	X			X	ICPH01606
Torco® SGO Synthetic 75W-90 with Torco® Type G LS additive	X				L46680 LNRAGMO
Valvoline® SynPower® 75W-90	X	X		X	F076C
Petroleum Candidates					
Castrol® Hypoy C 80W-90	X		X		PO61165
Pennzoil® Gearplus® 80W-90	X				JDSC 26615512155
Valvoline® High Performance 80W-90	X	X		X	C1860

Viscosity Grade (SAE J306)

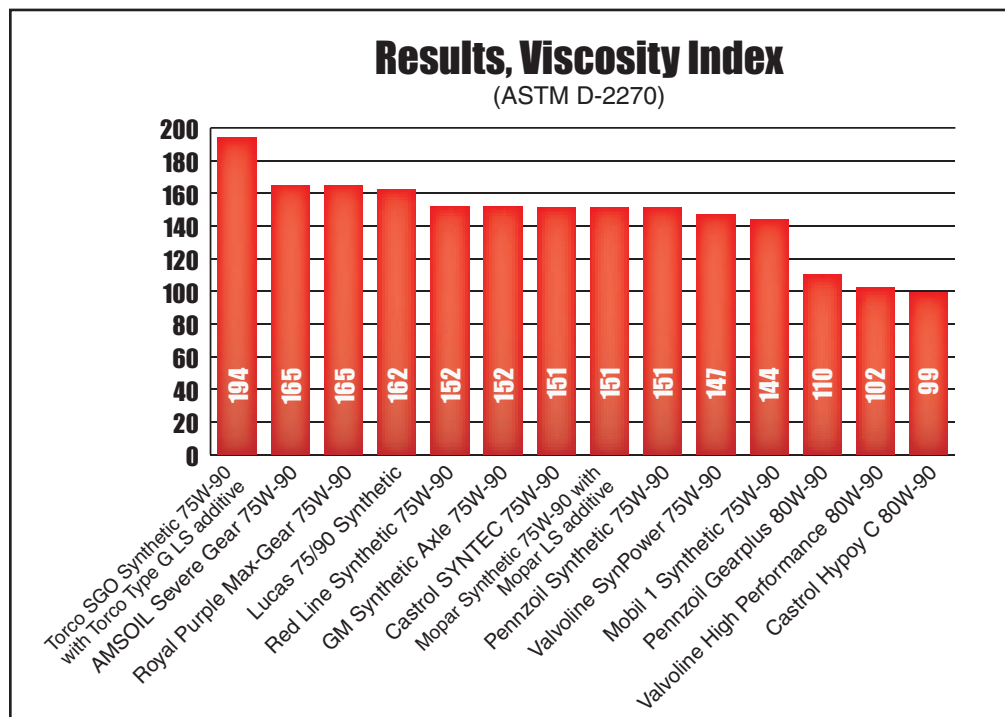
A lubricant's primary function is to reduce friction and wear, and its most important property is its viscosity (thickness/resistance to flow). Lubricants are considered incompressible and under ideal conditions maintain a constant layer of protection, known as film strength, to keep moving parts from contacting each other. With no direct contact, wear is eliminated. There is a point, however, at which heavy loads exceed the oil's ability to separate parts and metal-to-metal contact occurs. This is, in part, a function of viscosity. The higher the viscosity of a lubricant, the greater the load it can carry. Using gear lube that is too thick, however, has disadvantages. Thicker oils are more difficult to circulate, particularly in cold temperatures, and wear protection can be sacrificed. Thicker gear lubricants also require more energy to circulate, which negatively impacts fuel economy. Additionally, thicker gear lubes have higher internal resistance (intra-fluid friction) which causes them to run hotter. There is no advantage to using a gear lube with a viscosity greater than that required by the application. Conversely, gear lube that is too thin will not have sufficient load-carrying ability to meet the equipment requirements.

The SAE has developed a grading system, SAE J306, which categorizes gear lubricants based on their high- and low-temperature viscosities. An additional requirement of SAE J306 is shear stability, which is explained later in this document. The viscosity requirements for SAE 75W-90 gear lubricants are highlighted in green in the following chart.

Automotive Gear Lubricant Viscosity Classifications - SAE J306 - June 14, 2005				
SAE Viscosity Grade	Max. Temperature for Viscosity of 150,000 cP (°C) ^{1,2}		Kinematic Viscosity at 100°C (cSt) ³	
	Min. ⁴	Max.	Min. ⁴	Max.
70W	-55 ⁵		4.1	-
75W	-40		4.1	-
80W	-26		7.0	-
85W	-12		11.0	-
80	-		7.0	<11.0
85	-		11.0	<13.5
90	-		13.5	<18.5
110	-		18.5	<24.0
140	-		24.0	<32.5
190	-		32.5	<41.0
250	-		41.0	-

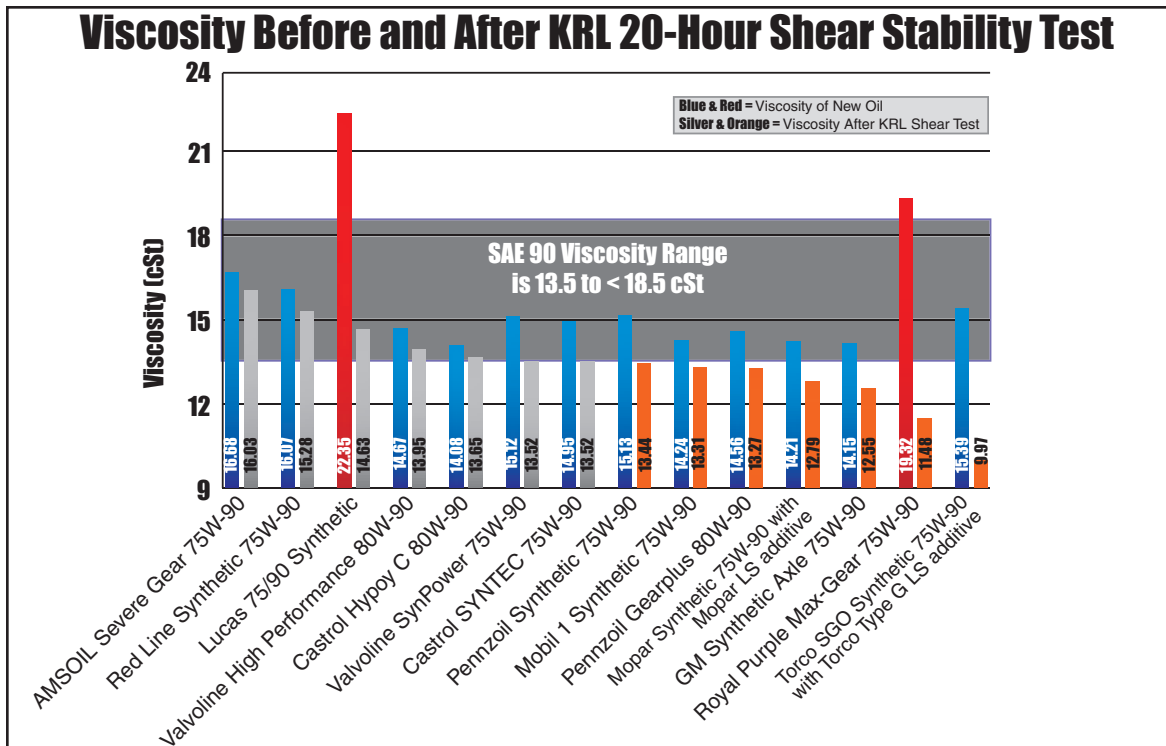
Viscosity Index (ASTM D-2270)

Oil viscosity is affected by temperature changes during use. As a gear lubricant's temperature increases, its viscosity decreases, along with load-carrying ability. The degree of change that occurs is determined by ASTM D-2270 and referred to as the lubricant's viscosity index (VI). ASTM D-2270 examines the viscosity change that occurs between 40°C (104°F) and 100°C (212°F). The higher the VI, the less the viscosity changes with temperature. A high VI is desirable and, in part, indicates higher lubricant quality. It does not, however, represent a lubricant's high-temperature viscosity or its load-carrying ability.



Similar to 5W-30 automotive engine oils, 75W-90 gear lubricants are defined as multi-viscosity. This means the gear lubricant has enough viscosity to protect against wear at high temperatures, as well as good flow properties at cold temperatures. Many gear lubes cannot fulfill both requirements without the use of VI improver additives. VI additives keep lubricants from becoming too thick to flow in cold temperatures and too thin to protect in high temperatures. VI additives have many uses. If used improperly in gear lubricants, however, they can break down and lose viscosity through a process called shearing. Because of this, the SAE incorporated the CEC L-45-A-99 (KRL) 20-Hour Shear Test as a requirement for all automotive gear lubes. This specification requires that gear lubes not shear down and fall below the minimum viscosity for that grade.

The KRL Test utilizes a tapered roller bearing and test cup filled with 40 ml. of gear lube. The test parameters are set at 60°C (140°F), 1475 rpm, 5000 N load for a duration of 1,740,000 motor revolutions (approximately 20 hours). Each gear lube's viscosity was recorded before and after the shear test as seen in the following graph.

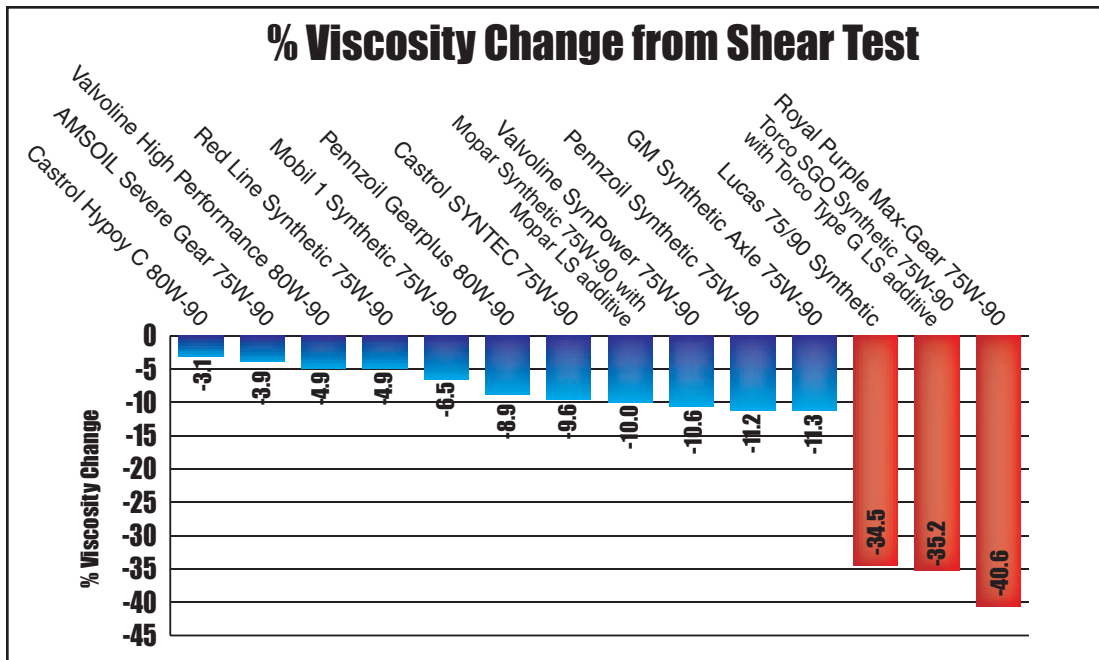


This graph shows the initial oil viscosity and the viscosity after the shear test. The SAE J306 high-temperature viscosity requirements (shaded area) for SAE 90 gear lubes are between 13.5 centistokes (a unit of measure for viscosity designated as cSt) and 18.49 cSt @ 100°C (212°F) maximum.

Lucas 75/90 Synthetic, at 22.35 cSt, and Royal Purple Max-Gear 75W-90, at 19.32 cSt, both exceed the maximum 18.49 cSt initial viscosity (red), failing the SAE J306 requirements for SAE 90 gear lubricants. All other gear lubricants were within the required high-temperature viscosity range prior to the KRL Shear Stability Test.

Viscosity measurements following the KRL Shear Stability Test revealed that seven gear lubes sheared down below the minimum viscosity requirements (orange), failing the shear stability requirements of the SAE J306. The two gear lubes with the largest viscosity loss, as reflected in the following graph, were Royal Purple, losing 40.6% of its viscosity, and Torco SGO Synthetic, losing 35.2% of its viscosity. Royal Purple was the only gear lube to fail both the initial viscosity requirements and the shear stability requirements. It started out too thick and ended up too thin. Torco SGO Synthetic, which had the highest VI in the previous graph, finished the shear stability test as the thinnest of all the oils at 9.97 cSt, far below the minimum 13.5 cSt requirement. Lucas 75/90 Synthetic, with an initial viscosity that exceeded the maximum requirements by 20.8%, passed the shear stability test, but lost 34.5% of its viscosity, the third largest loss of viscosity. Both OEM gear lubes, GM and Mopar, failed the minimum viscosity requirements after the shear test. Of all the gear lubes tested, half did not meet the SAE J306 shear stability requirements.

AMSOIL Severe Gear 75W-90 was in the proper initial viscosity range and retained the highest viscosity after the shear test with a viscosity of 16.03 cSt – the mid-point of the SAE 90 viscosity grade.



Low-Temperature Viscosity - Brookfield Viscosity Test (ASTM D-2983)

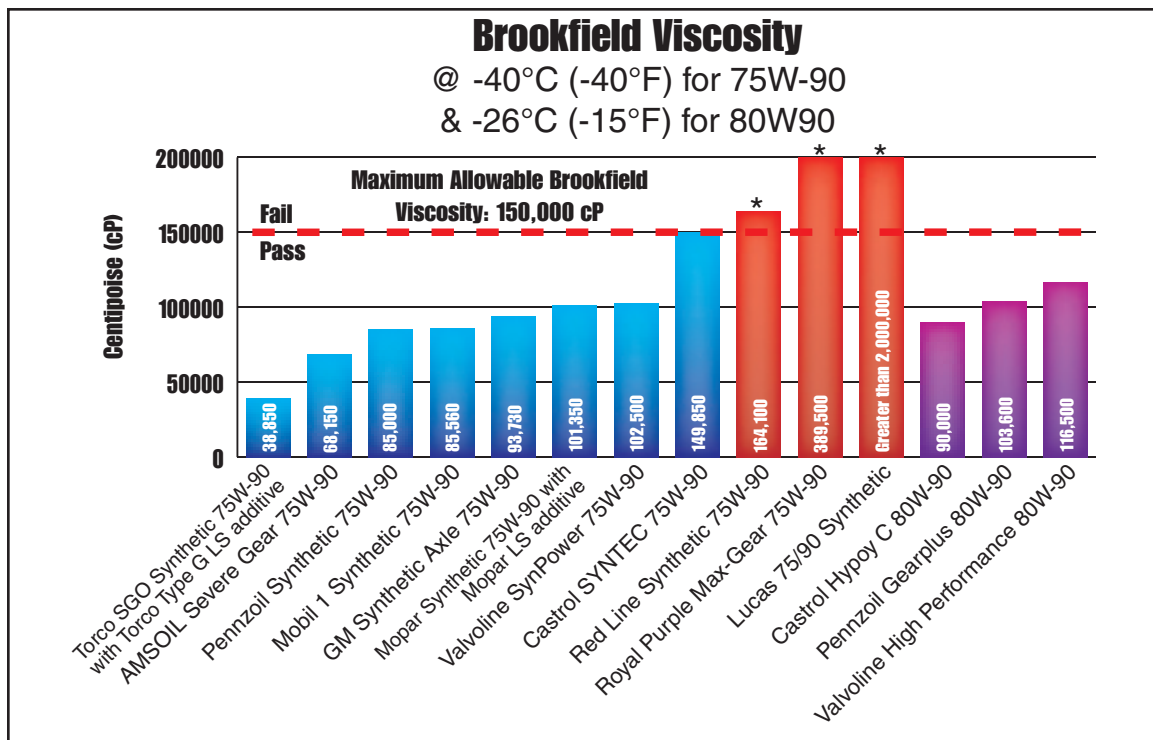
As temperature decreases, the viscosity of oil increases. Gear lubricants with high viscosity at cold temperatures are less efficient, and the gears require more energy to turn. Gears and bearings in the differential and axle housing are splash-lubricated, and gear lubricants that are too thick at cold temperatures can starve internal components of lubrication, which can cause failure.

The cold-temperature viscosity of gear lubricants is indicated by the first number in the SAE viscosity grade (75W of a 75W-90 gear lube). The SAE J306 standard utilizes the Brookfield Viscosity Test, recorded in centipoises (cP), to determine cold-temperature performance. The maximum viscosity is 150,000 cP at the given temperature for the SAE viscosity grade. For example, SAE 75W must be less than 150,000 cP at -40°C (-40°F), while SAE 80W must be less than 150,000 cP at -26°C (-15°F).

In the Brookfield Viscosity Test, a glass test tube is filled with gear lube and cooled to the appropriate temperature. A small spindle is inserted into the lubricant and the maximum torque required to rotate the spindle is recorded. The torque reading is used to calculate the viscosity in cP.

Brookfield Viscosity Measurement Example





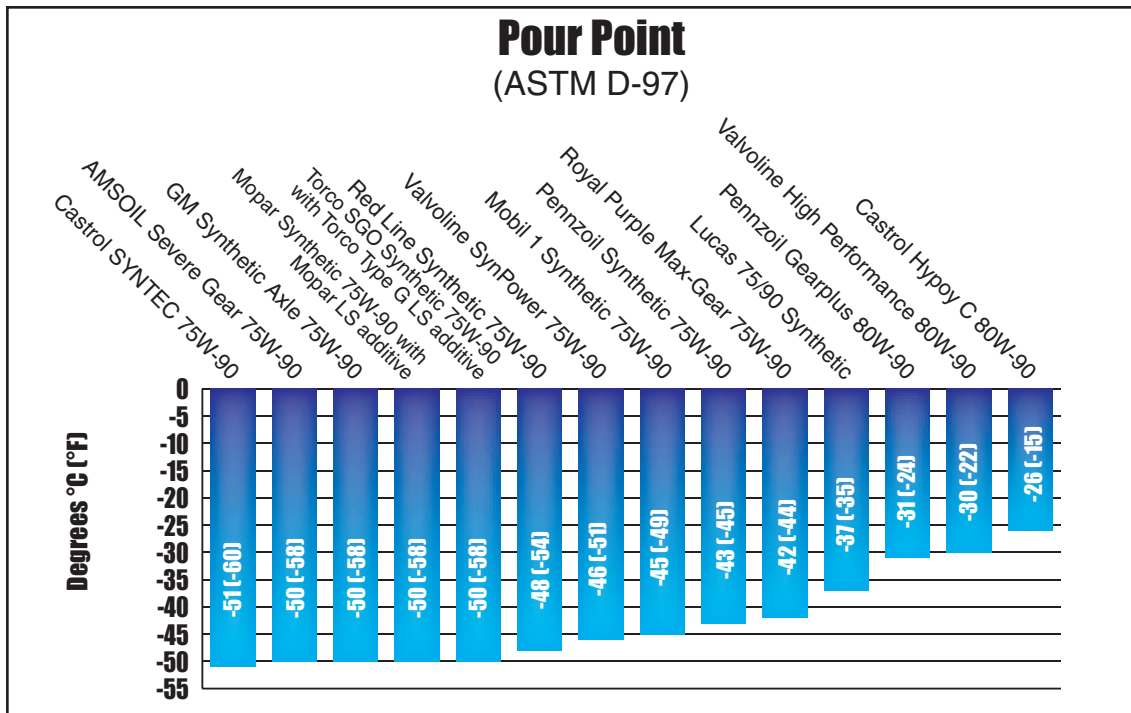
Cold-temperature performance is impacted by a lubricant’s high-temperature viscosity. High-viscosity gear lubes tend to have worse cold-temperature performance than low-viscosity gear lubes. AMSOIL Severe Gear, however, with the highest after-shear viscosity, exhibited the best cold-temperature properties of all gear lubes, except for Torco SGO, which thinned out of grade in the shear test. Royal Purple and Lucas failed the cold-temperature Brookfield requirements for 75W gear lubes, as well as the high-temperature requirements for SAE 90 gear lubes, effectively disqualifying them entirely from the SAE 75W-90 category. Royal Purple Max-Gear, having also failed the Shear Stability Test, was the only gear lube to fail every parameter of the SAE J306 requirements. Red Line was 14,100 cP over the maximum allowable viscosity at 164,100 cP, and Castrol SYNTEC 75W-90 had a borderline pass at 149,850 cP. As noted, SAE 80W-90 gear lubes are measured at -26°C (-15°F) and all test candidates passed.

*Red Line, Royal Purple and Lucas, having failed the viscosity requirement for SAE 75W, were then tested at the SAE 80W parameters for comparison purposes. Red Line scored 18,250 cP and Royal Purple scored 24,700 cP, showing better performance than the SAE 80W-90 gear lubes. Lucas, however, at 98,050 cP, showed worse cold-temperature properties than Castrol 80W-90, which is reflected in the overall score on page 19.

Standard Pour Point Test Method (ASTM D-97)

Pour point can vary greatly depending on the construction of the product. Pour point and Brookfield viscosity both measure the cold-temperature properties of gear lube, but are very different. Pour point is defined as the coldest temperature at which oil will flow before solidifying. The Pour Point Test consists of a glass jar filled with gear lube which is cooled to a temperature close to its pour point. The gear lube is checked at intervals of 3°C (5°F) for fluidity. When the gear lube no longer flows, the pour point is recorded at the last temperature of fluidity.





The SAE 80W-90 gear lube test results were between -26°C (-15°F) and -31°C (-24°F). SAE 75W-90 gear lubes have better cold-temperature properties and therefore better pour points. It is important to have a low pour point combined with a low Brookfield viscosity value since it is possible to have a good low pour point but only a marginal Brookfield viscosity. Castrol SYNTEC is a good example of this. SYNTEC had the best pour point of the gear lubes tested, but a borderline Brookfield viscosity pass at 149,850 cP. Lucas 75/90 Synthetic, on the other hand, did not perform well in either area. It showed a pour point of -37°C (-35°F) and a Brookfield viscosity of greater than 2,000,000 cP. AMSOIL Severe Gear 75W-90 and Torco SGO Synthetic had the best combined Brookfield and pour point scores.

Channel Point - Federal Test Method Standard (FTMS 791C) No. 3456

MIL-PRF-2105E is an extreme-pressure, hypoid gear lubricant specification established by the U.S. military. It is more stringent than API GL-5. An additional requirement of MIL-PRF-2105E is the lubricant's ability to pass the Channel Point Test. While not all gear lubes claim MIL-PRF-2105E, the channel point requirement is important because channeling during cold-temperature operation may cause catastrophic gear and bearing failure. A test sample container with 650 ml of oil is run through a warming cycle before being placed in a temperature-controlled bath at -45°C (-49°F) for SAE 75W-90 gear lubes and -35°C (-31°F) for SAE 80W-90 gear lubes. The test is run for 18 hours +/- 2 hours. A groove 2 cm wide is then made in the gear lubricant down to the bottom of the container. The gear lubes must completely fill the groove and cover the bottom of the container in less than 10 seconds to pass the test. Lucas 75/90 Synthetic and Valvoline High Performance 80W-90 were the only gear lubes to fail the channel point test.

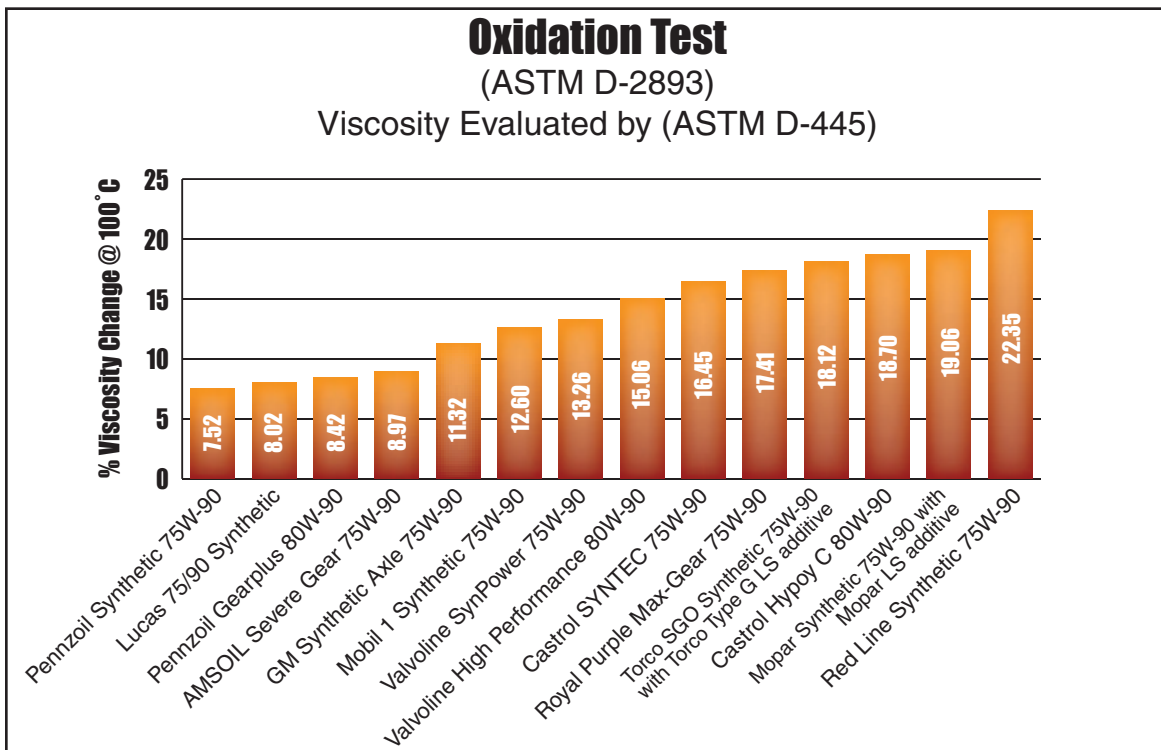
Federal Test Method Standard (FTMS 791C) No. 3456	
Channeling Point	
AMSOIL Severe Gear 75W-90	Non-Channeling - Pass
Castrol SYNTEC 75W-90	Non-Channeling - Pass
GM Synthetic Axle 75W-90	Non-Channeling - Pass
Lucas 75/90 Synthetic	Channeling - FAIL
Mobil Synthetic 75W-90	Non-Channeling - Pass
Mopar Synthetic 75W-90 plus Mopar LS additive	Non-Channeling - Pass
Pennzoil Synthetic 75W-90	Non-Channeling - Pass
Red Line Synthetic 75W-90	Non-Channeling - Pass
Royal Purple Max-Gear 75W-90	Non-Channeling - Pass
Torco SGO Synthetic 75W-90 plus Torco Type G LS additive	Non-Channeling - Pass
Valvoline SynPower 75W-90	Non-Channeling - Pass
Castrol Hypoy C 80W-90	Non-Channeling - Pass
Pennzoil Gearplus 80W-90	Non-Channeling - Pass
Valvoline High Performance 80W-90	Channeling - FAIL

High Temperature Oxidation Resistance

Standard Test Method for Oxidation Characteristics of Extreme-Pressure Lubrication Oils (ASTM D-2893 Method B)

Heat can destroy lubricants. High temperatures accelerate oxidation, which causes acid development, corrosion, sludge and varnish deposits, lubricant thickening and shortened gear lube life. Oxidized gear lubes lose lubricating effectiveness. Energy efficiency goes down, wear goes up and cold-temperature flow properties are greatly reduced. Heat and oxidation resistance are critical for proper gear lubrication and long lubricant life.

ASTM D-2893 Method B test methodology measures the oxidation-resistance characteristics of extreme-pressure lubricants. The test utilizes 41 mm x 600 mm test tubes filled with 300 ml of gear lube, heated to 121°C (250°F) and aerated at 10 liters per hour. The test is run for 312 hours (13 days). The gear lubes are then evaluated for viscosity increase and precipitation of solids. Large increases in viscosity and deposit formation indicate greater gear lube deterioration. In addition, 50 ml of each tested gear lube was filtered through an 8 micron filter patch to show discoloration. Filtering the lubricant for visual inspection is not a test requirement. The test parameters simulate the severe conditions inside a differential.



Solids Precipitation (measured in ml)

All gear lubes measured at <0.05 ml with the exception of Mopar Synthetic 75W-90 with Mopar LS additive, which measured at 0.08 ml, and Lucas 75/90 Synthetic, which measured at 0.25 ml.

Filter Patch Results



AMSOIL Severe Gear 75W-90



Castrol SYNTEC 75W-90



Pennzoil Synthetic 75W-90



Valvoline SynPower 75W-90



GM Synthetic Axle 75W-90



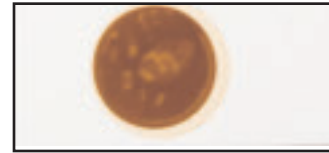
Castrol Hypoy C 80W-90



Mobil 1 Synthetic 75W-90



**Valvoline High
Performance 80W-90**



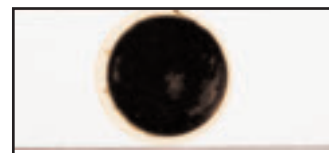
Red Line Synthetic 75W-90



**Torco SGO Synthetic 75W-90
with Torco Typs G LS Additive**



Pennzoil Gearplus 80W-90



Royal Purple Max-Gear 75W-90



**Mopar Synthetic 75W-90
with Mopar LS Additive**



Lucas 75/90 Synthetic

Pennzoil Synthetic 75W-90 and AMSOIL Severe Gear 75W-90 had the best overall performance in both categories, indicating high resistance to oxidation and extended lubricant life. Pennzoil Synthetic 75W-90 showed the lowest viscosity increase, and AMSOIL Severe Gear had the cleanest high-temperature deposit properties. While petroleum-based Pennzoil Gearplus 80W-90 and Lucas 75/90 Synthetic showed limited viscosity increase, they both left significant deposits on the filter patches. Castrol SYNTEC 75W-90 thickened by 16.45%, yet had clean performance.

Wear Reduction

In automotive differentials the ring and pinion are spiral-cut, hypoid gears. They slide more on each other than other types of gears. Although spiral-cut gears allow for quieter operation, under load their extreme sliding action can wipe the lubricant film from between the gears. High levels of extreme-pressure additives are used to protect these gears when the lubricant film is wiped away or ruptured.

Ring and Pinion Hypoid Gears



Many different tests are used to measure the extreme-pressure and anti-wear performance of lubricants. Three ASTM laboratory tests were selected that operate under different extreme-pressure and anti-wear conditions. These tests include the 4-Ball Extreme Pressure Test, the Falex Pin and V-Block Test and the 4-Ball Wear Test. Good performance in all of the tests indicates good anti-wear and extreme-pressure protection.

Extreme-Pressure (EP) Property Measurements (4-Ball EP Test ASTM D-2783)

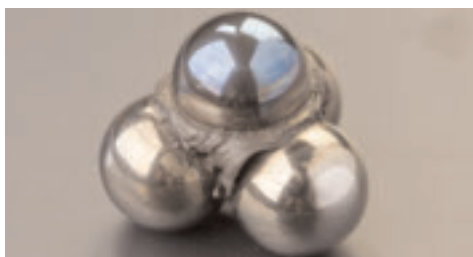
The 4-Ball Extreme-Pressure Test evaluates extreme-pressure properties and high-load, anti-wear protection properties. High reported values indicate the gear lube provides better protection against wear and galling when the lubricant film is ruptured under heavy loads. Towing, hauling, racing and high-horsepower/torque applications are examples of severe service where the lubricant film is commonly ruptured and metal-to-metal contact occurs.

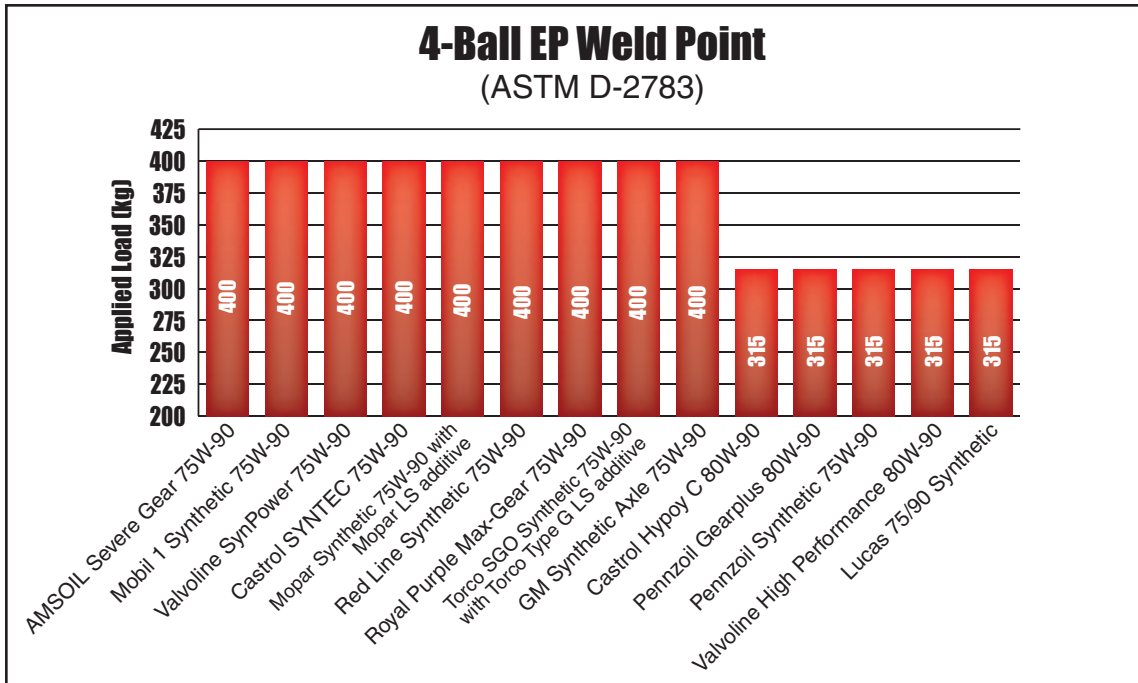
The 4-Ball EP Test is operated with one steel ball under load rotating at 1760 rpm against three steel balls submerged in oil and held stationary in a cradle. The temperature of the gear lube is brought to 18.33 to 35.0°C (65 to 95°F). Weld point and load-wear index are determined from a series of 4-Ball EP Test runs.

Weld Point

A series of tests with increasing loads, measured in kilograms (kg) are performed until the fourth loaded ball seizes (welds) to the three stationary balls. The weld point is the lowest (first) extreme-pressure point which exceeds the lubricant's load-carrying ability. It is a good indicator of a lubricant's extreme-pressure properties. Gear lubes with weld points of 400kg indicate better EP properties than those with weld points of 315kg.

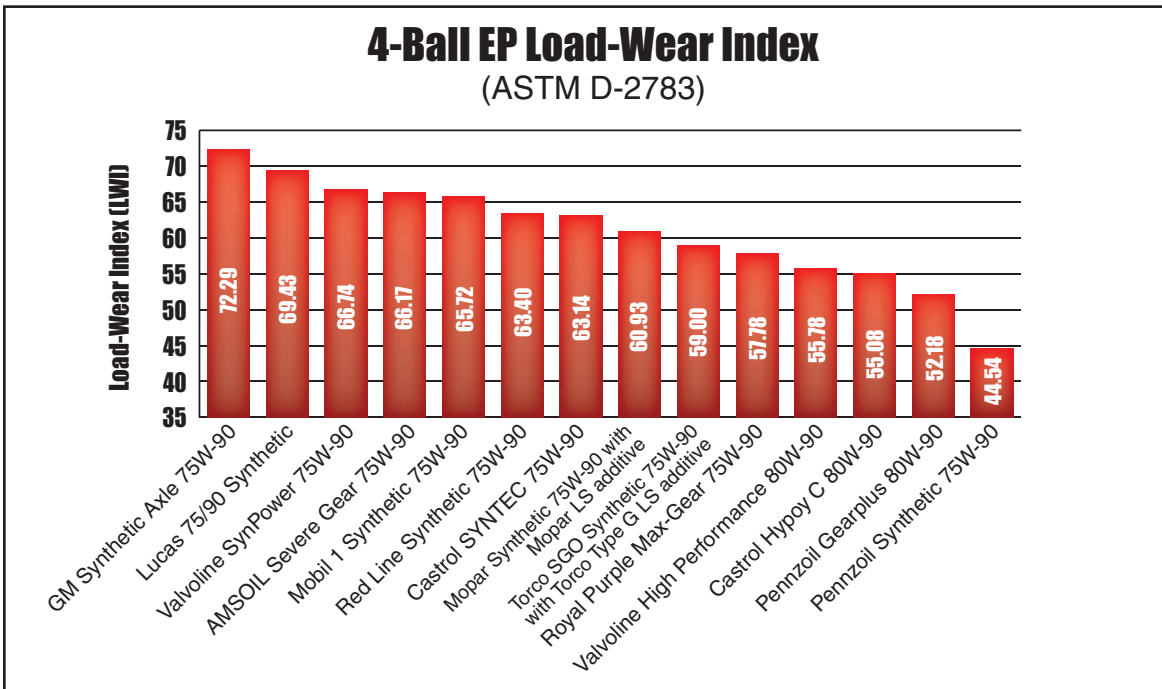
Example of welded test balls





Load-Wear Index

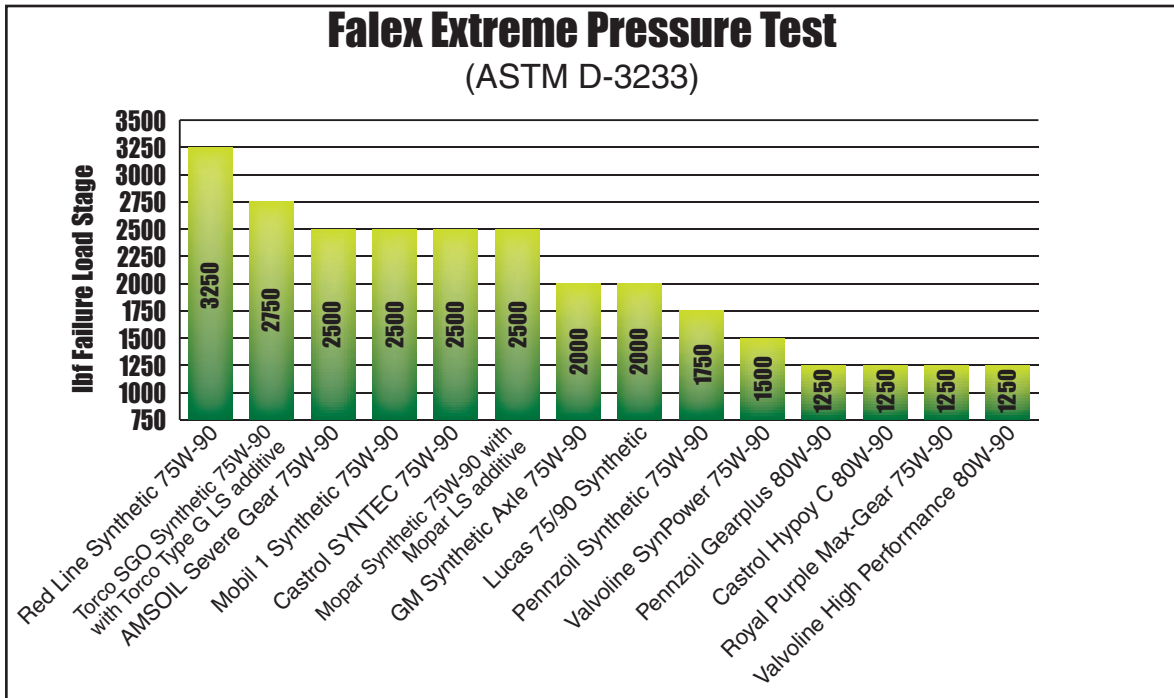
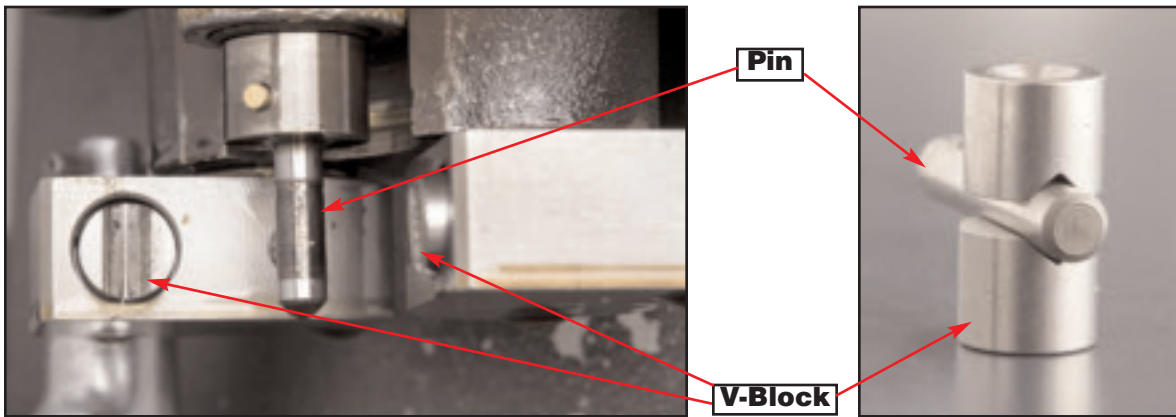
The load-wear index (LWI) represents the ability of the lubricant to minimize wear at applied loads. The LWI is determined by conducting ten 10-second tests below a lubricant's weld point. The LWI is the average of the loads determined by those tests. Gear lubes with high test values indicate good anti-wear properties under heavy loads.



It should be noted that good performance in one test does not necessarily mean good performance in both tests. An example of mixed performance is Lucas 75/90 Synthetic, which had a high load-wear index value but a low score in the weld parameter. Pennzoil Synthetic 75W-90 had low scores in both test parameters.

Extreme-Pressure Property Measurements Falex Pin and V-Block One Minute Step Test (ASTM D-3233B)

The Falex Extreme Pressure Test differentiates between lubricants having low, medium and high levels of extreme-pressure properties by measuring their load-carrying capacities. The Falex Test consists of a steel pin that rotates at 290 rpm against two stationary V-blocks in 250-lb. increments. Each 250-lb. increment is applied for 60 seconds and failure is recorded when either the pin seizes to the V-blocks or the wear between the pin and V-blocks is so rapid that the loading gear cannot keep the applied load constant.

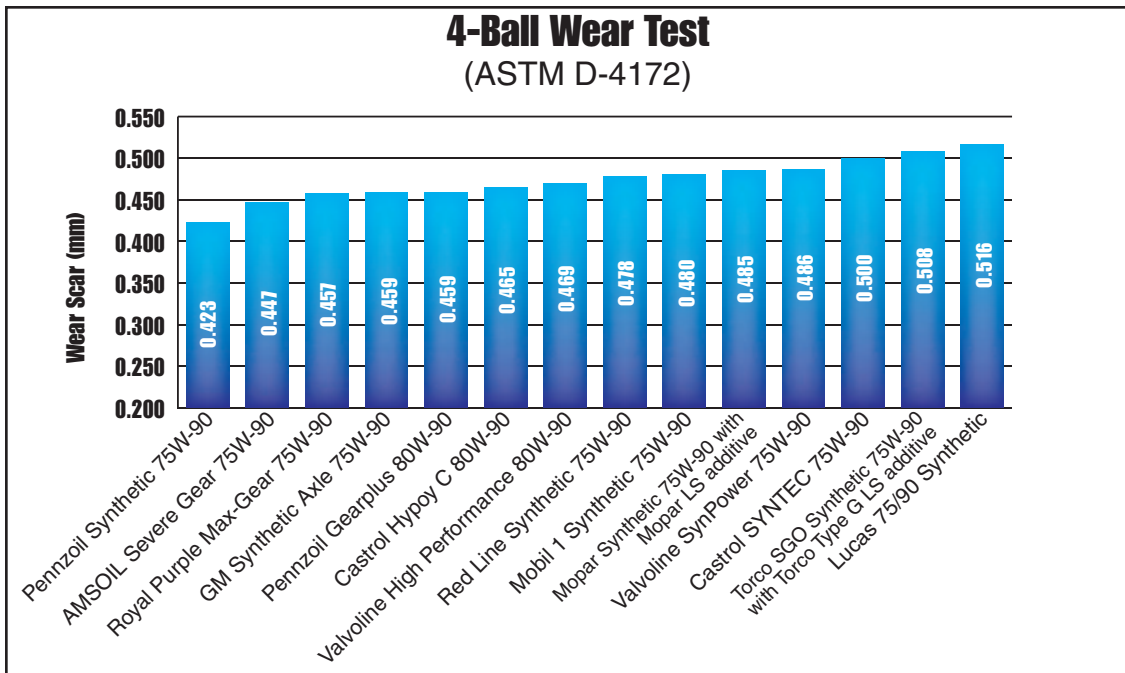


High numerical values represent better extreme-pressure properties. Six of the gear lubes scored 2500 lbf (pounds force) or greater, indicating a higher level of protection compared to the remaining eight lubricants. When looking at the combined Falex Test results and 4-Ball EP Test results, it is noted that all three petroleum SAE 80W-90 gear lubes consistently scored lower than most of the other oils. When evaluating the top six gear lubes in the Falex Test, only AMSOIL, Red Line and Mobil placed in the top six in both categories of the 4-Ball EP Test, ahead of GM, Lucas and Valvoline which had good 4-ball EP load-wear index scores.

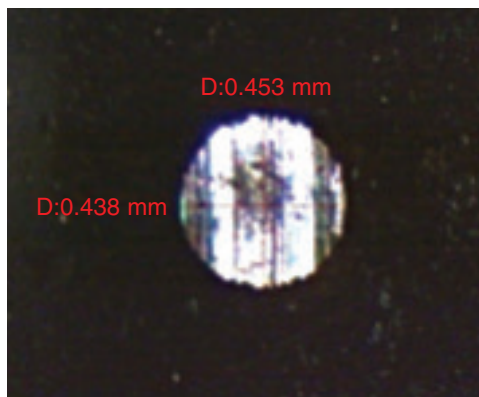
Wear Preventative Characteristics of Lubricants (4-Ball Wear Test ASTM D-4172)

This test evaluates the anti-wear properties of fluid lubricants in sliding contact and under lighter loads than those used in the 4-Ball EP Test. It is conducted using the 4-Ball Anti-Wear Test procedure and measurements, which are different than the 4-Ball EP Test procedure. The standard test parameters of the 4-Ball Wear Test are 75°C (167°F), 40kg load, 1200 rpm for 1 hour. The wear scar diameter of the three stationary balls is measured and the average is reported as the wear scar in mm.

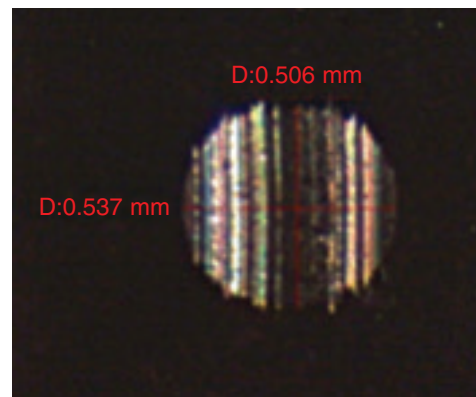




The anti-wear 4-Ball Test results were much closer than in the higher-loaded tests. Note: Although in some cases the test results are negligible between oils, results were taken as recorded for scoring purposes. There are, however, some interesting observations when comparing the data to the other extreme-pressure and anti-wear testing. Pennzoil Synthetic 75W-90 scored worst in the 4-Ball EP LWI, yet scored best in the 4-Ball Wear Test. And out of all the extreme-pressure and anti-wear testing, AMSOIL Severe Gear consistently scored in the top four in all categories, which indicates that the AMSOIL lubricant offers superior protection under widely varying operating conditions. Examples of wear scars from one of the three stationary balls from 4-ball wear testing performed on AMSOIL Severe Gear 75W-90 and Lucas 75/90 synthetic gear lubes are shown below.



AMSOIL Severe Gear 75W-90



Lucas 75/90 Synthetic

Foam Resistance

During differential operation, gears and bearings turn at high speeds which churn the lubricant. When air is introduced, foaming can occur. While gear lube is considered incompressible, air is compressible and when bubbles pass between loaded areas, the bubbles collapse and metal-to-metal contact occurs, causing wear. Foam can also increase friction and act as an insulator, which increases heat and oxidation. Good foam control is important in gear lubricants. In most cases, anti-foam additives are needed. The API has established maximum foam limits for GL-5 gear lubricants.

Foaming Tendencies (ASTM D-892)

This test measures the foaming characteristics of lubricating oils. It consists of a 1,000-ml graduated cylinder fitted with an air diffuser in the bottom. The cylinder is filled with 190 ml of gear lube and heated to 24°C (75°F) (Sequence I). The air passing through the diffuser is adjusted to 94ml/min and percolates up through the test lubricant. The test is run for five minutes and the air is shut off. Any foam that forms on the surface of the lubricant is then measured. After 10 minutes of settling time, foam levels are measured again. The procedure is repeated for Sequence II with 180 ml of lubricant at 93.5°C (200°F), then back down to 24°C (75°F) and 190 ml of lubricant for Sequence III. The test results are reported as \bar{x}/\bar{x} for each of the three sequences; the first number indicates foam immediately after the test, and the second number indicates foam after settling. In addition to testing fresh gear lubes, testing was done on the “aged” gear lubes after oxidation testing.

Oxidation can change a lubricant's properties and negatively impact foam performance. Note that API GL-5 does not require a foam test on aged, oxidized oils. This was done strictly to simulate in-service operation.

The API GL-5 specification has established a maximum limit of 20/0 in Sequence I, 50/0 in Sequence II and 20/0 in Sequence III.

Gear lubes failing the GL-5 requirements are marked in red under the New Oil heading. Gear lubes in the right column report foam results on the aged, oxidized oils. GM Synthetic 75W-90 passed the API GL-5 requirement but generated significant amounts of foam after oxidation. Pennzoil Synthetic 75W-90 and Lucas 75/90 Synthetic, on the other hand, failed the initial API GL-5 requirement but passed after oxidation testing.



Example of Non-Foaming Oil.

	Foam Tendency							
	New Oil				Aged after Heat Oxidation Testing			
	Seq. I	Seq. II	Seq. III		Seq. I	Seq. II	Seq. III	
AMSOIL Severe Gear 75W-90	0/0	0/0	0/0	PASS	0/0	25/0	0/0	PASS
Castrol Hypoy C 80W-90	0/0	0/0	0/0	PASS	0/0	0/0	0/0	PASS
Valvoline High Performance 80W-90	0/0	0/0	0/0	PASS	0/0	0/0	0/0	PASS
Mobil 1 Synthetic 75W-90	0/0	10/0	0/0	PASS	10/0	45/0	10/0	PASS
Royal Purple Max-Gear 75W-90	0/0	25/0	0/0	PASS	0/0	0/0	0/0	PASS
GM Synthetic Axle 75W-90	0/0	40/0	0/0	PASS	575/15	290/0	410/0	FAIL
Pennzoil Synthetic 75W-90	50/0	25/0	35/0	FAIL	0/0	35/0	15/0	PASS
Mopar Synthetic 75W-90 with Mopar LS additive	30/0	120/0	10/0	FAIL	445/0	25/0	400/0	FAIL
Red Line Synthetic 75W-90	0/0	155/0	0/0	FAIL	225/0	0/0	145/0	FAIL
Castrol SYNTEC 75W-90	0/0	200/0	0/0	FAIL	295/0	200/0	240/0	FAIL
Pennzoil Gearplus 80W-90	0/0	230/0	0/0	FAIL	0/0	375/0	0/0	FAIL
Torco SGO Synthetic 75W-90 with Torco Type G LS additive	25/0	230/0	20/0	FAIL	540/0	280/0	370/0	FAIL
Lucas 75/90 Synthetic	125/0	50/0	30/0	FAIL	0/0	20/0	10/0	PASS
Valvoline SynPower 75W-90	125/0	20/0	130/0	FAIL	30/0	10/0	30/0	FAIL

Copper Corrosion Resistance

Extreme-pressure additives in gear lubricants become more chemically active when subjected to heat. Copper and brass are soft metals and are subject to attack from acids, sulfur compounds and other chemicals in gear lubricants. When corrosion attacks these components it can be seen as a discoloration and occasionally forms buildup on the surface of the component. Acidic corrosion results in wear, which can lead to component failure.

Copper Corrosion (ASTM D-130)

The standard Copper Corrosion Test is designed to assess the corrosive characteristics of lubricants. In this test a polished copper strip is immersed in a test tube with a given quantity of sample fluid. The entire test tube is then immersed into a bath which is heated to either 100°C (212°F) or 121°C (250°F) for three hours. The hotter temperature is more severe. The copper strip is then removed, washed and evaluated according to ASTM Copper Strip Corrosion Standards (shown below). Corrosion is evident from discoloration. The test results are reported in a range from 1a to 4c.

API GL-5, MT-1 and MIL-PRF-2105E all require the hotter 121°C (250°F) test temperature. However, API MT-1 and MIL-PRF-2105E have a tighter specification limit for a pass, requiring 2a as opposed to 3a for GL-5.



ASTM D-130 Copper Corrosion Classifications, Limits and Results

	API MT-1& ML-PRF-2105E (2a max @ 121°C, 3 hrs)						API GL-5 (3a max @ 121°C, 3 hrs)					
	Slight Tarnish		Moderate Tarnish				Dark Tarnish		Corrosion			
	Classification	1a	1b	2a	2b	2c	2d	2e	3a	3b	4a	4b
AMSOIL Severe Gear 75W-90	Pass	Pass										
Mobil 1 Synthetic 75W-90	Pass	Pass										
Red Line Synthetic 75W-90	Pass	Pass										
GM Synthetic Axle 75W-90	Pass	Pass										
Torco SGO Synthetic 75W-90 with Torco Type G LS additive	Pass	Pass										
Pennzoil Gearplus 80W-90	Pass	Pass										
Pennzoil Synthetic 75W-90	Pass	Pass										
Castrol Hypoy C 80W-90	Pass	Pass										
Castrol SYNTEC 75W-90	Pass	Pass										
Valvoline High Performance 80W-90	Pass	Pass										
Valvoline SynPower 75W-90	Pass	Pass										
Mopar Synthetic 75W-90 with Mopar LS additive											Fail	
Royal Purple Max-Gear 75W-90											Fail	
Lucas 75/90 Synthetic												Fail



AMSOIL Severe Gear 75W-90 (1b)



Mobil 1 Synthetic 75W-90 (1b)



Red Line Synthetic 75W-90 (1b)



GM Synthetic Axle 75W-90 (1b)



Torco SGO Synthetic 75W-90 with Torco Type G LS Additive (1b)



Pennzoil Gearplus 80W-90 (1b)



Pennzoil Synthetic 75W-90 (1b)



Castrol Hypoy C 80W-90 (1b)



Castrol SYNTEC 75W-90 (1b)



Valvoline High Performance 80W-90 (1b)



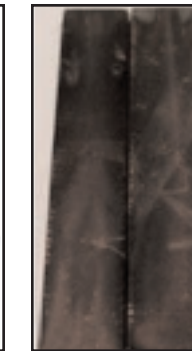
Valvoline SynPower 75W-90 (1b)



Mopar 75W-90 with Mopar LS Additive (4a)



Royal Purple Max-Gear 75W-90 (4a)



Lucas 75/90 Synthetic (4b)

To determine test results, a technician rates the components by comparing them to the copper corrosion standard. Mopar 75W-90 and Royal Purple Max-Gear 75W-90 each displayed black streaks and received 4a ratings. Lucas 75/90 Synthetic was clearly corroded and was given a 4b rating.

Pricing

The price of a product is most often a consumer's first concern when selecting a gear lube. Price, however, does not reflect the actual *cost* of a product. Less expensive oils may save money initially, but may cost more in the end if the products compromise performance or require more frequent oil changes. Ford, for example, requires petroleum gear lubes to be changed every 3,000 miles under severe service but waives that requirement for synthetic gear lubes, extending the service life.⁶ In this study, the three lower-priced petroleum SAE 80W-90 gear lubes had consistently lower test scores in the 4-Ball EP and Falex Tests. Generally, lower performance is associated with lower price. There are, however, exceptions. Lucas 75/90 Synthetic and Royal Purple Max-Gear Synthetic 75W-90 demonstrated that price is not necessarily consistent with performance.

The benefits provided by a well-engineered, although higher-priced gear lube, can easily offset that higher price. Paying a little more for a quality lube that delivers the right performance is a low-cost investment to protect high-priced equipment. In this study, the pricing was obtained by purchasing a 12-quart case of each product from the manufacturers or distributors and calculating the cost per quart.

Price Comparison	
Product	Quart Price
Valvoline High Performance 80W-90	\$3.99
Pennzoil Gearplus 80W-90	\$4.99
Castrol Hypoy C 80W-90	\$5.99
Mobil 1 Synthetic 75W-90	\$7.99
Castrol SYNTEC 75W-90	\$8.99
Lucas 75/90 Synthetic	\$8.99
Valvoline SynPower 75W-90	\$10.49
Pennzoil Synthetic 75W-90	\$10.99
AMSOIL Severe Gear 75W-90	\$11.75
Red Line Synthetic 75W-90	\$11.95
Royal Purple Max-Gear 75W-90	\$13.95
Torco SGO Synthetic 75W-90 with Torco Type G LS additive	\$17.04
Mopar Synthetic 75W-90 with Mopar LS additive	\$20.94
GM Synthetic Axle 75W-90	\$28.11

Scoring and Summary of Results

Each gear lubricant was assigned a score for each test result. The gear lube with the best test result was assigned a 1. The gear lube with the second best result was assigned a 2, and so on. If two or more oils tied, the next best score was ranked according to the number of oils preceding it. In pass/fail testing, passing gear lubes were given scores of 1. Failing gear lubes were given scores dependent on the number of gear lubes that passed. For example, of the 14 gear lubes tested, 12 passed the Channel Point Test and received scores of 1. With 12 gear lubes passing, the two failing gear lubes received scores of 13. In the Solids Precipitation evaluation, differentiation was immeasurable in the 12 gear lubes with values of .05 ml. Differentiation was measurable in those gear lubes that scored greater than .05 ml, and they received scores of 13 and 14 respectively. Note that the results of each test have not been weighted to suggest the degree of significance it represents. The degree of significance is left to the consumer to decide. The results in all categories were added to produce an overall total for each gear lube. The gear lube with the lowest total demonstrated the best overall performance. Red scores did not meet either API GL-5 performance requirements or SAE J306 viscosity requirements.

The filter patch results from the oxidation test were not considered in the final evaluation because the measurement was visual and not quantified.

	Page Number	AMSOIL Severe Gear 75W-90	Mobil 1 Synthetic 75W-90	GM Synthetic Axle 75W-90	Castrol SYNTEC 75W-90	Red Line Synthetic 75W-90	Pennzoil Synthetic 75W-90	Valvoline SynPower 75W-90	Castrol Hypoyn C 80W-90	Torco SGO Synthetic 75W-90 with Torco Type G LS Additive	Valvoline High Performance 80W-90	Pennzoil Gearplus 80W-90	Royal Purple Max-Gear 75W-90	Mopar Synthetic 75W-90 with Mopar LS Additive	Lucas 75/90 Synthetic
SAE J306 Initial Viscosity	5	1	1	1	1	1	1	1	1	1	1	1	13	1	14
Viscosity Index	5	2	11	5	7	5	7	10	14	1	13	12	4	7	2
Viscosity After KRL Shear Test	6	1	9	12	1	1	8	1	1	14	1	10	13	11	1
%Viscosity Decrease from Shear Test	7	2	5	11	7	3	10	9	1	13	3	6	14	8	12
Brookfield Viscosity	8	2	4	5	8	9	3	7	13	1	14	11	10	6	12
Pour Point	9	2	8	2	1	6	9	7	14	2	13	12	10	2	11
Channel Point	9	1	1	1	1	1	1	1	1	1	13	1	1	1	13
Oxidation Test															
Percent Viscosity Increase	10	4	6	5	9	14	1	7	12	11	8	3	10	13	2
Solids Precipitation (ml)	11	1	1	1	1	1	1	1	1	1	1	1	1	13	14
4-Ball EP Weld Point	13	1	1	1	1	1	10	1	10	1	10	10	1	1	10
4-Ball EP Load-Wear Index	13	4	5	1	7	6	14	3	12	9	11	13	10	8	2
Falex Extreme Pressure Test	14	3	3	7	3	1	9	10	11	2	11	11	11	3	7
4-Ball Wear Test	15	2	9	4	12	8	1	11	6	13	7	4	3	10	14
Foam New Oil	16	1	1	1	11	9	7	14	1	13	1	12	1	8	10
Foam Aged Oil After Oxidation Test	16	1	1	14	11	10	1	8	1	13	1	9	1	12	1
Copper Corrosion	17	1	1	1	1	1	1	1	1	1	1	1	12	12	14
Price	18	9	4	14	5	10	8	7	3	12	1	2	11	13	6
Total Score		38	71	86	87	87	92	99	103	109	110	119	126	129	145

Conclusion

As the testing indicates, AMSOIL Severe Gear ranked highest among all gear lubes tested. It was the only gear lube to score a 4 or better in all performance categories. The high ranking of AMSOIL Severe Gear clearly points to a well-balanced formulation capable of delivering effective, long-lasting lubrication protection to all differential components. Most notable is the superior performance of AMSOIL Severe Gear in the critical areas of extreme-pressure protection and viscosity and oxidation stability. Based on the performance testing, the slightly higher than average price of AMSOIL Severe Gear would be offset by the cost savings achieved through reduced maintenance, longer lasting differentials and extended lubricant life.

Some gear lubes tested well in some areas but scored low marks in others. Torco SGO Synthetic scored highest in viscosity index and cold-temperature Brookfield viscosity but sheared out of grade, failing the SAE J306 requirements for SAE 75W-90 gear lubes. Mopar and Royal Purple scored well in the 4-Ball EP Weld Test, but failed the Copper Corrosion Test and GM, with a good 4-ball EP score, foamed badly after oxidation. This would indicate that too much emphasis in one area of formulation can detract from performance in others. A gear lube is only as good as its weakest link.

A well-balanced gear lube formulation, therefore, is critical for differentials in all types of vehicles, both standard and high-performance. With more horsepower, more towing capacity, higher hauling limits and changes in vehicle design, more stress than ever is placed on differential gears. High-quality lubrication is essential, and awareness is now necessary to ensure maximum differential performance and to avoid costly repairs. When purchasing gear lube the decision is left to the consumer, yet based on the facts reported in this document, AMSOIL Severe Gear is the logical choice.

Note: To further verify the findings, additional testing was performed on AMSOIL Severe Gear. The L-37 Axle Rig Test evaluates load-carrying, wear protection and extreme-pressure properties of gear lubricants. The severity of the test was increased to challenge AMSOIL Severe Gear to the absolute limits in gear lube performance. See Appendix C for test parameters and results.

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1. Richardson, Robert; Marsic, Vera; Tarrant, Simon: "Driveline Fluids - Thermal Management Challenges and Impacts on Base Oil and Additive Technologies," National Petrochemical & Refiners Association Annual Meeting, Paper AM-05-32, March, 2005.
 2. 2007 Trailer Life Towing Guide.
 3. O'Conner, B.M.; Schenkenberger, C.: "The Effect of Heavy Loads on Light Duty Vehicle Axle Operating Temperature," Powertrain & Fluid Systems Conference and Exhibition, SAE Paper #2005-01-3893, October, 2005.
 4. Tocci, Lisa: "Torque Spark." Lubes 'N' Greases, September 2007.
 5. Mitchell Repair Information Company, LLC.
 6. Motor Information Systems
Check Chart 2007 Quick
Lubrication Guide.

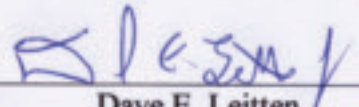
Additional Sources:
Lubrizol website.

Lubrizol Ready Reference Manual
for Lubricants and Fuels, 2005.

Appendix 1

Affidavit

I hereby affirm that to the best of my knowledge all of the test results reported in the document entitled "A Study in Automotive Gear Lubes" prepared for the AMSOIL Drivetrain Division in September of 2007 are correct. I further affirm that the tests requested followed procedures approved by the American Society of Testing and Materials (ASTM), Society of Automotive Engineers (SAE) and Federal Test Method Standards that are referenced in the paper. Written documentation of test results are on file at AMSOIL INC.



Dave E. Leitten

STATE OF Wisconsin
COUNTY OF Douglas

Subscribed and sworn to before me this 19 day of September 2007.

[SEAL]




NOTARY PUBLIC

Name: Donna E. Mrozik
My commission expires: 2-20-2011

Appendix 2

Affidavit

I hereby affirm that I personally obtained the prices quoted in the document entitled "A Study in Automotive Gear Lubes" prepared for the AMSOIL Drivetrain Division in September of 2007. I further affirm that the pricing in this paper was correct and was quoted to me by the manufacturers and distributors of the products. Written support of this information is on file at AMSOIL INC.


Kevin L. Dinwiddie

STATE OF Wisconsin
COUNTY OF Douglas

Subscribed and sworn to before me this 19 day of September 2007

[SEAL]



NOTARY PUBLIC

Name: Donna E. Mrozik
My commission expires: 2-20-2011

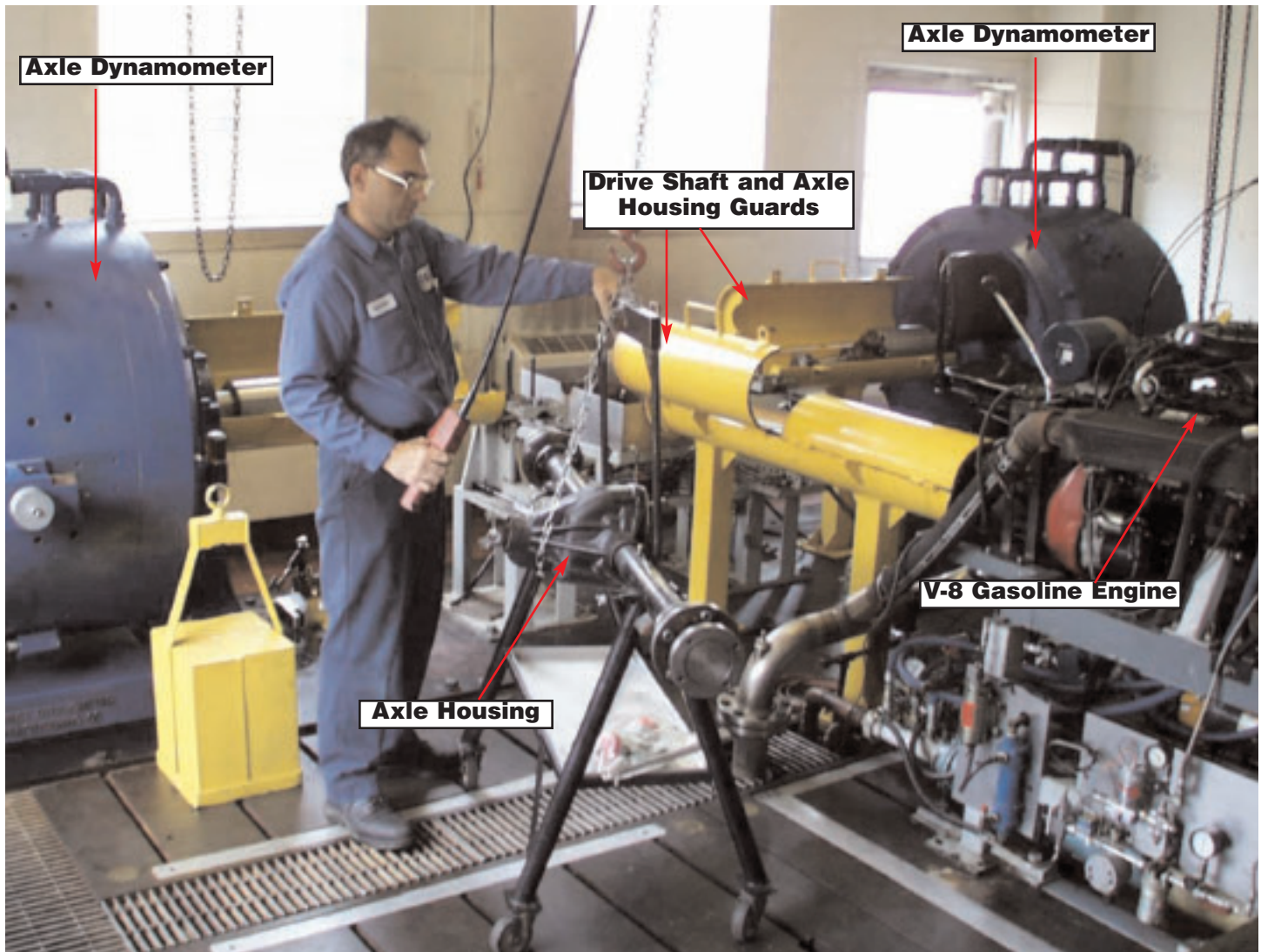
Appendix 3

Extreme-Pressure Gear Testing (ASTM D-6121-06) Final Verification

Laboratory extreme-pressure and anti-wear tests are reliable predictors of in-service performance. To demonstrate that the testing conducted for this study accurately predicted the performance of the top-rated gear lube, AMSOIL Severe Gear, an industry-standard Axle Rig Test was used. Commonly referred to as the L-37 Axle Rig Test, the ASTM D-6121-06 is used to evaluate the load-carrying, wear and extreme-pressure properties of a gear lubricant in a hypoid axle under conditions of low-speed, high-torque operation. The L-37 Test consists of a Dana Model 60 with 5.86-to-1 ratio gears connected to a V-8 gasoline-powered engine with a transmission capable of maintaining test conditions. The load is controlled by two large dynamometers connected to each axle. Following a gear conditioning phase, the test is conducted for 24 grueling hours at 80 wheel rpm, 1740 lbf-ft (2359 N-m) torque per wheel with an axle sump temperature maintained at a constant 135°C (275°F). At the end of the test, the ring and pinion gears are inspected for abrasive wear, adhesive wear, plastic deformation and surface fatigue.

Under standard operating test conditions, the L-37 is considered a severe test that accurately discriminates between gear lubes capable of protecting gears and those that cannot. To further challenge the integrity of AMSOIL Severe Gear Synthetic 75W-90, the test severity was increased by adding 20% greater load. Under these test conditions, AMSOIL Severe Gear was tested at 2088 lbf-ft (2831 N-m) per wheel for a total combined load of 4176 lbf-ft (5662 N-m). This is equivalent to a Duramax 6.6 liter engine connected to an Allison transmission in second gear (1.81 to 1) with a differential gear ratio of 3.55 to 1, going up-hill, pulling a loaded trailer heavy enough for the engine to develop and maintain a maximum 650 ft-lb of torque under full-throttle operation for 24 straight hours.

The gears are evaluated and assigned a pass or fail rating. At the end of the test, AMSOIL Severe Gear *passed* all the requirements, even with 20% greater load. The following gear photos are from the actual test rating. Note the original machining marks on the pinion gear are still intact after the test.





Ring gear exhibits very low wear.



Pinion gear - original machine marks still present.



Pinion tapered roller bearing in like-new condition.