



AAA ENGINE OIL RESEARCH:
AAA proprietary research into the differences
between conventional and synthetic engine oil

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Abstract

AAA conducted primary and secondary research to understand the differences between conventional and synthetic engine oils that are readily available for use in gasoline engines. While synthetic oils began to gain prominence on an industrial scale in 1931 [1], they were not significantly used for automotive applications until the 1980s [2].

The majority of vehicles are capable of using either conventional or synthetic engine oil that meets the latest American Petroleum Institute (API) and International Lubricant Standardization and Approval Committee (ILSAC) specifications. However, some automakers mandate that oils used in their vehicles meet proprietary internal specifications as well.

Synthetic oils are generally promoted as having superior performance compared to conventional oils, albeit at a higher cost. The objective of this research is to determine the validity of these claims and to determine the overall cost of switching to a synthetic oil.

Research Questions:

1. Are there differences in performance between oils marketed as conventional versus oils marketed as synthetic?
 - a. Quantitatively determined by analysis of multiple ASTM¹ International (ASTM) standardized tests required for ILSAC GF-5 certification
2. What is the percentage of current model year vehicles that “require” synthetic engine oil?
3. What is the cost increase, if any, associated with switching to a synthetic oil?
4. What are current consumer trends regarding the use of synthetic engine oil?

Key Findings:

1. On average, synthetic oils outperformed conventional oils in the conducted tests by 47 percent. The selected tests evaluated shear stability, deposit formation, volatility, cold-temperature pumpability, oxidation resistance, and oxidation-induced rheological changes.
2. Very few vehicles specifically “require” synthetic oil; however, most vehicle manufacturers require compliance to an internal oil specification for warranty purposes.
3. The average price difference between a conventional and a synthetic oil change is \$32 at a AAA Approved Auto Repair facility.
4. 44 percent of drivers are either not sure if synthetic motor oil is better for their engine, or do not believe synthetic motor oil is better for their engine.



¹ Formerly known as the American Society for Testing and Materials



Contents

1	Introduction	6
2	Background	7
2.1	Defining the Base Oil.....	8
2.1.1	API Base Stock Categories	8
2.2	Engine Oil Ratings	9
2.2.1	API Certification Mark	9
2.2.2	API Service Symbol.....	9
2.2.3	SAE Viscosity Grade.....	10
3	Base Oil and Additive Chemistry.....	11
3.1	Conventional Mineral Base Oil.....	11
3.1.1	Solvent Extraction	11
3.1.2	Dewaxing.....	11
3.1.3	Hydrocracking	11
3.2	Polyalphaolefins (PAOs)	11
3.3	API Group V Base Stocks	12
3.4	Additives	12
3.4.1	Antioxidants	12
3.4.2	Anti-Wear/Extreme Pressure Components (AW/EP Additives).....	13
3.4.3	Detergents.....	13
3.4.4	Dispersants.....	13
3.4.5	Viscosity Modifiers.....	14
3.4.6	Pour Point Depressants.....	14
3.4.7	Foam Inhibitors	14
4	Inquiry #1: Are there differences in performance between oils marketed as conventional versus oils marketed as synthetic?	14
4.1	Objective	14
4.2	Methodology.....	14
4.3	Test Oil Selection.....	15
4.4	Test Results	15
4.4.1	ASTM D6278 Kurt Orbahn Shear Stability Test & ASTM D4683 High Temperature/High Shear (HTHS) Viscosity	15



4.4.2	ASTM D7097 Moderately High Temperature Piston Deposits by Thermo-Oxidation Engine Oil Simulation Test (TEOST MHT).....	21
4.4.3	ASTM D6335 High Temperature Deposits by Thermo-Oxidation Engine Oil Simulation Test (TEOST 33C).....	24
4.4.4	ASTM D5800 Evaporation Loss of Lubricating Oils by the Noack Method (Procedure C) ..	26
4.4.5	ASTM D5133 Low Temperature, Low Shear Rate Viscosity/Temperature Dependence by the Scanning Brookfield Test	29
4.4.6	ASTM D4742 Oxidation Stability by Thin-Film Oxygen Uptake (TFOUT)	32
4.4.7	ASTM D7528 Bench Oxidation by Romaszewski Oil Bench Oxidation (ROBO Apparatus) .	34
4.5	Summary of Findings.....	40
4.6	Secondary Research	40
5	Inquiry #2: What is the percentage of 2016 model year vehicles that “require” synthetic engine oil? 41	
5.1	Objective	41
5.2	Methodology.....	41
5.3	Findings	41
6	Inquiry #3: What is the cost increase associated with switching to a synthetic engine oil?	42
6.1	Objective	42
6.2	Methodology.....	42
6.3	Findings	42
7	Inquiry #4: What are current consumer trends in selection of synthetic engine oil?	43
7.1	Objective	43
7.2	Methodology.....	43
7.3	Test Results	43
8	Key Findings	44
9	Summary Recommendations.....	44
10	Contact Information.....	44
11	References	45
12	Appendices.....	47



1 Introduction

Engine oil is the lifeblood of any engine. Without it, that expensive piece of machinery will quickly turn into a useless pile of scrap metal. Modern automobile engines are usually smaller, operate at higher RPMs, are built to exacting tolerances and produce far more horsepower & torque per cubic inch than engines of decades past – all while delivering better fuel economy. The automobile engines of today cannot run on just any oil, current design philosophies largely owe their feasibility to engine oils tailored to the demands of advanced engine design.

The purpose of this research is to compare the performance of oils marketed as “conventional” versus oils marketed as “full synthetic.” Conventional oils are produced from crude oil through solvent refining or hydrocracking. Synthetic oils can be produced through severe hydrocracking (higher pressure and heat) or through chemical synthesis with tailored starting materials and reaction conditions.

Modern engine oil is a mixture of conventional or synthetic base stock with an additive package that provides a variety of essential functions. The engine oil is part of an overall engine lubrication system that includes the oil pump, oil filter, and various oil passages, or “galleries,” that carry the oil to where it is needed.

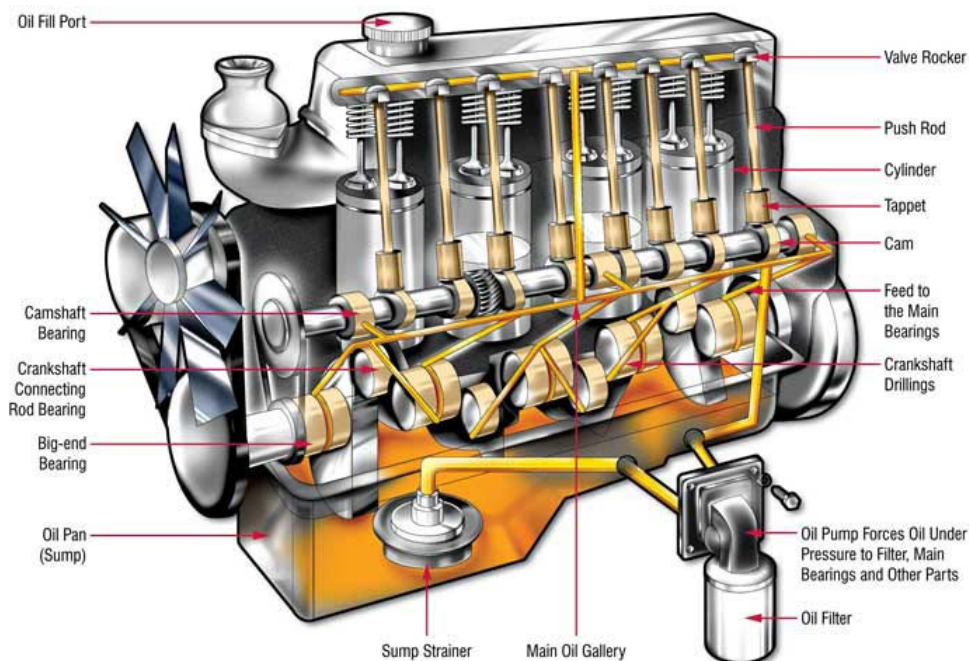


Figure 1: Pushrod engine lubrication system Image Source: Noria Corporation and Machinery Lubrication magazine

Synthetic base oils were more recently introduced to the automotive market. Since their introduction, it has been claimed that synthetic oils have various performance benefits such as high-temperature stability, high film strength and a naturally high viscosity index. These characteristics are beneficial for current engines that tend to operate at higher RPMs and temperatures.

Synthetic oils are commonly represented as an “upgrade” to the motorist and usually come with significant added cost. A survey of AAA Approved Auto Repair facilities across the country found that an



oil change with synthetic engine oil is \$70 on average compared to an average of \$38 for an oil change with conventional oil. For those who change their own engine oil, the average cost of five quarts of synthetic oil is approximately \$45 compared to an approximate cost of \$28 for five quarts of conventional oil.

2 Background

Engine oil performs four basic functions that help engines run smoothly, operate efficiently, and provide a long service life. Some of these functions are properties of the oil itself while other functions are primarily related to additive packages that will be discussed later.

Lubrication – One of the most important properties of engine oil is its viscosity; its resistance to being rapidly squeezed out from between two surfaces pressed together with one moving in relation to the other. Examples would be the piston ring surface against the cylinder or the piston-rod bearing on the crankshaft. By resisting being squeezed out rapidly, the engine oil provides a thin but critical oil layer enabling motion of surfaces in near contact but with little wear. When the viscosity is high enough to keep the two surfaces sufficiently separated to prevent most wear, this is called “hydrodynamic lubrication” [3]. When the oil viscosity is not high enough to keep the two surfaces sufficiently apart to prevent wear, this is descriptively called “boundary lubrication”.

Cleaning – The inside of an engine is a harsh environment subject to contamination from soot, water condensation, combustion gasses and minute airborne particles that make it past the air filter. Without proper preventative measures, these materials will cause deposits and sludge buildup that can make an engine run hotter and restrict oil flow, leading to increased wear or even engine failure. Engine oils capture contaminants, prevent deposits and keep particulates in suspension until they are removed by the filter or an oil change.

Cooling – Several areas of internal combustion engines get extremely hot during operation. Piston rings, cylinder heads near exhaust valves, and turbocharger bearings are just three examples where localized temperatures can exceed 600° F. Engine oil absorbs this excess heat and disperses it into other parts where it is carried away by the engine’s cooling system. The oil is also cooled by outside air passing over the oil pan and, in some cases, an oil cooler.

Protection – Engine oil protects engine components from rust and corrosion by neutralizing acids formed when oil combines with combustion contaminants and water condensation inside the engine. Condensation is especially common during short trips and in cold weather when the engine does not operate long enough at full temperature to evaporate all the moisture. Oil must also be engineered so any burned in the combustion chamber does not produce contaminants that could damage the car’s catalytic converter or other costly emission-control components.

Hydraulics – In modern engines, engine oil acts as a hydraulic fluid to facilitate engine functions like variable cam timing, displacement, compression ratio, and lifter-controlled cylinder deactivation. In these applications, engine oil helps in pushing a pin to a lock/unlock position to achieve these functions.



2.1 Defining the Base Oil

Conventional engine oils are refined petroleum products created from plant and animal remains that became hydrocarbons over eons of exposure to heat and pressure within Earth's crust. Depending on its API Group, either solvent refining or hydrocracking is used to refine the base stock. Quality conventional oils on the market are typically composed of API Group II base stocks. API base stock categories and groups are defined in the following section.

Originally, synthetic oils were produced through the reaction of a few defined reagents in tailored conditions to produce a pure and well-defined base lubricant. One of the first papers dealing with synthetic lubricants was published in 1931 by Sullivan *et al.* [3]; this work described the successful catalytic polymerization of olefins, which resulted in the synthesis of a saturated lubricating oil. Today, oils created in this manner are sometimes called "full synthetic" oils although, as discussed below, the meaning of this term is open to interpretation.

On March 1, 1999, the National Advertising Division (NAD) ruled on case #3526 involving Castrol Synthetic Engine Oil. The ruling found that "severe cracking and reforming processes" to hydroisomerize a mineral base stock is indeed a synthesis and therefore the refined product can be advertised as a synthetic oil. **Because of this ruling, many "synthetic" oils now on the market are composed of highly processed crude oil.**

Semi-synthetic blends are marketed as having some of the same benefits of full synthetic oil at a lower cost than a full synthetic. These blends contain a secondary component consisting of an API Group III or API Group IV oil. Evaluating semi-synthetic blends is outside the scope of this work and oils advertised as such were excluded from testing. Also excluded are oils advertised as being for high-mileage vehicles, which contain non-standardized additive packages.

2.1.1 API Base Stock Categories

Definitions that will be helpful for this section include:

- Base Stock [4]
 - Lubricant component that is produced by a single manufacturer to the same specifications (independent of feed source or manufacturer's location); that meets the same manufacturer's specification; and that is identified by a unique formula, product identification number, or both. Base stocks may be manufactured using a variety of different processes including but not limited to distillation, solvent refining, hydrogen processing, oligomerization, esterification, and rerefining. Rerefined stock shall be substantially free from materials introduced through manufacturing, contamination, or previous use.
- Base Oil [4]
 - The base stock or blend of base stocks used in an API-licensed oil

API 1509 Annex E [4] specifies five general categories for all base stocks:

- Group I base stocks contain less than 90 percent saturates and/or greater than 0.03 percent sulfur and have a viscosity index greater than or equal to 80 and less than 120



- Group II base stocks contain greater than or equal to 90 percent saturates and less than or equal to 0.03 percent sulfur and have a viscosity index greater than or equal to 80 and less than 120
- Group III base stocks contain greater than or equal to 90 percent saturates and less than or equal to 0.03 percent sulfur and have a viscosity index greater than or equal to 120
- Group IV base stocks are polyalphaolefins (PAOs)
- Group V base stocks include all other base stocks not included in Group I, II, III, or IV

Groups I-III are derived from petroleum crude oil. Quality conventional engine oils are typically made from Group II base stocks. They are often manufactured by hydrocracking, a process that saturates the hydrocarbons within the base stock. Due to the saturation of hydrocarbons comprising the base stock, Group II oils have good anti-oxidation properties.

Group III base stocks typically undergo a severe hydrocracking process designed to produce a purer base oil. A significant number of engine oils marketed as “full synthetic” fall into this category.

Group IV base stocks are true “synthetic” base stocks in the technical sense of the word; they are polyalphaolefins (PAOs) synthesized by oligomerization of α -decene or a mixture of α -olefins containing between 6-12 carbon atoms. The resulting oligomers are then hydrogenated and distilled to yield the base stock.

2.2 Engine Oil Ratings

The American Petroleum Institute administers a voluntary engine oil licensing and certification program designed to define, certify, and monitor engine oil performance deemed necessary for satisfactory equipment life and performance by vehicle and engine manufacturers [5]. API licenses two types of Marks to indicate an engine oil has passed certain technical and licensing requirements: the API Certification Mark “Starburst” and the API Service Symbol “Donut” (see figure 2).

2.2.1 API Certification Mark

An API Certification Mark is used to identify engine oils recommended for general application. The API Certification Mark is licensed for use only if an oil satisfies the requirements of the most recent and applicable ILSAC minimum performance standards. ILSAC GF-5 currently defines the minimum oil performance standard [6]. ILSAC consists of U.S and Japanese automakers that have created several engine oil standards over time. ILSAC GF-5 was introduced in 2010; today it is used in conjunction with the API SN service category to identify oils that meet the requirements of most major automakers.

2.2.2 API Service Symbol

Service Categories are used in the upper portion of the API Service Symbol to identify specific engine oil performance levels. These ratings indicate that an oil meets specific performance requirements established by oil companies in conjunction with vehicle and engine manufacturers. API Service Category SN was adopted for use beginning in 2011. These oils are intended for use in gasoline engines in current and earlier passenger cars, sport utility vehicles, vans, and light-duty trucks operating under recommended maintenance procedures.



The first API service category dates back to 1920s and was designated “SA.” The “S” stands for spark ignition. API retrospectively created the “SA” and “SB” service categories in 1972. Subsequent classifications followed in alphabetical order. Today, engine oil with API service classifications SA through SH are obsolete. Current service classifications include SJ for 2001 and older vehicles, SL for 2004 and older vehicles, SM for 2010 and older vehicles and SN for 2017 and older vehicles. Older cars can use oils with newer service categories, but newer cars must, at a minimum, use oils that meet the original service category specified for their model years.

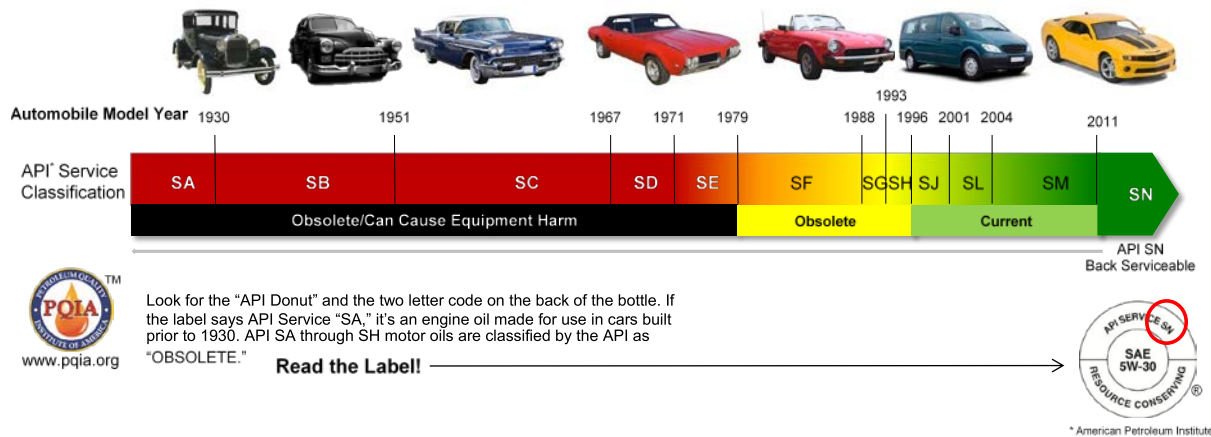


Figure 2: Previous and current API service categories Image Source: Petroleum Quality Institute of America

The API also gives “Energy Conserving” and “Resource Conserving” certifications to oils that meet certain criteria for reducing friction and oil consumption, and improving fuel economy. Current SN oils that qualify as “Resource Conserving” also meet the ILSAC GF-5 standard.

The API has a separate system of service categories for diesel engines that begin with the letter “C,” which stands for compression ignition. Those categories are not described here because diesel motor oils are not addressed in this study.

2.2.3 SAE Viscosity Grade

Viscosity describes how well an oil flows at a given temperature. The Society of Automotive Engineers (SAE International) rating system categorizes engine oils by viscosity grade, sometimes referred to as the weight of an oil. Viscosity grades are based on the time it takes for a given amount of oil to flow through a specified orifice at a standard temperature. The longer it takes, the higher the SAE viscosity grade.

Engine oil viscosity grades are identified by numbers. Lower numbers indicate lighter or thinner oils that flow more easily. Common grades for automotive engine use include 0, 5, 10, 15, 20, 30, 40 and 50. Lower viscosity grades enable easier engine starting in cold winter temperatures and have a “W” added to their numbers: 0W, 5W, 10W, 15W and 20W. Note that 20-weight oil is available in both “W” and high-temperature formulations.

The viscosity ratings for multi-grade engine oil include two numbers. The first number is followed by a “W” and designates how the oil performs in cold temperatures; the exact temperature varies with viscosity grade². The second number designates how the oil performs at 100°C (212°F). For example, SAE

² Defined by SAE standard J300



10W-30 oil flows as easily as a straight 10W oil in cold temperatures, yet maintains the same viscosity as a straight 30-weight oil at high temperatures.

Multi-viscosity oils are made by blending base stocks with pour point depressants that help oil to flow more easily when cold, and viscosity index improvers that enable oil to resist thinning as temperatures increase.

3 Base Oil and Additive Chemistry

3.1 Conventional Mineral Base Oil

Crude oil comes in many varieties. In all cases, they are complex mixtures of hydrocarbons and inorganic compounds. The hydrocarbons typically range in size between C_5 up to C_{200} . Conventional (API Groups I-III) base stocks originate from crude oil fractions collected through vacuum distillation [7]. The vacuum distilled fractions are not suitable as base stock without further refining. Further refining processes include solvent extraction, dewaxing, and hydrocracking. Depending on the API Group of the base stock, further hydrocracking results in the finished product.

3.1.1 Solvent Extraction

Solvent extraction is the first step in refining the raw vacuum distillates. This step removes aromatics to improve the viscosity index and oxidation resistance. Additionally, resistance to the sludge-forming tendency of the distillate is improved.

3.1.2 Dewaxing

Dewaxing improves the cold flow properties of the base oil. Long-chain, high melting point paraffins within the distillate crystallize at low temperatures, resulting in turbidity and an increase in viscosity. Methods of dewaxing currently in use include solvent crystallization, selective hydrocracking, and isomerization. Solvent crystallization involves diluting the distillate with a selected solvent and slowly cooling the mixture. The dilution promotes large crystal growth necessary for good filtration. Selective hydrocracking breaks up the large, waxy molecules into lighter hydrocarbons by catalytic or hydrogenation reactions. Isomerization is a catalytic process that rearranges long, unbranched hydrocarbons into branched hydrocarbons more suitable for base oil stocks.

3.1.3 Hydrocracking

Depending on the API Group of the base stock, hydrocracking is often used as a finishing stage in the refining process. This further improves oxygen stability, ultraviolet stability, acidity, and removes substances that can adversely affect demulsifying properties of the base oil. Severe hydrocracking with heterogeneous catalysts involves pressures in excess of 100 bar and temperatures between 200-350 °C. Severe hydrocracking can cause significant desulfurization and some de-aromatization [7]. Mineral base oils that have undergone severe hydrocracking are often called “synthetic” oils. In most cases, these base oils exhibit performance characteristics greater than or equal to API Group IV & V base stocks.

3.2 Polyalphaolefins (PAOs)

PAO base oils classified as API Group IV base stocks. PAOs are usually derived from α -decene or a mixture of α -olefins containing, in general, a minimum of six and a maximum of 12 carbon atoms [1].



The olefins undergo an oligomerization process via catalysts that vary based upon the desired viscosity of the base oil. The resulting unsaturated oligomers are subjected to catalytic hydrogenation in the next step. Distillation occurs in the final step of the synthesis process. Distillation is necessary because oligomerization of the starting material results in a complex mixture of isomers with significant branching. Ideal hydrocarbons within engine oil should have straight chains, complete saturation, and crystallize at low temperatures.

Distilled PAOs that contain straight chains or long side-chain branching in the middle of the main hydrocarbon chain exhibit favorable narrow boiling ranges and low pour points. For PAOs with kinematic viscosities greater than $4 \text{ mm}^2 \text{ sec}^{-1}$ at $100 \text{ }^\circ\text{C}$, the viscosity index is greater than 135 [1].

3.3 API Group V Base Stocks

As previously discussed, API Group V base stocks include all stocks not covered in API Groups I-IV. Common API Group V base stocks include Neopentyl polyol esters, polyalkylene glycols, and fluorinated polyethers.

3.4 Additives

In addition to base stocks, engine oils contain chemical additive packages to enhance performance in a wide range of areas. As these additives do their jobs, they become depleted over time. Along with thermal and oxidative deterioration of the base oil, additive package depletion is a key factor in establishing oil change intervals.

The following descriptions summarize the most common types of additives; this section is not intended to be an exhaustive description of additives found in engine oil.

3.4.1 Antioxidants

Oxidation of the hydrocarbons within engine oil is initiated by exposure to oxygen and heat. Transition metals such as iron, copper, nickel, etc. can greatly increase the rate of oxidation reactions. Conditions within an internal combustion engine create an optimal environment for oxidation with metal engine parts acting as oxidation catalysts. Oxidation has been identified as the primary cause of oil degradation; harmful species are produced that compromise the functionality of the oil, shortens its service life, and damages the machinery the oil is intended to lubricate [8]. To enhance the oxidative resistance of the base oil, antioxidants are key additives within engine oil.

Common antioxidants include:

- Sulfur Compounds
- Sulfur-Nitrogen Compounds
- Phosphorus Compounds
- Aromatic Amines
- Copper Compounds
- Boron Compounds



3.4.2 Anti-Wear/Extreme Pressure Components (AW/EP Additives)

Zinc dialkyldithiophosphates (ZDDPs) have been used as a multi-functional additive in engine oil for over 50 years [9]. ZDDPs mainly function as an anti-wear additive; however, they also impart oxidative and corrosion resistance to the base oil. ZDDPs also exhibit mild EP characteristics.

As an anti-wear agent, ZDDPs react with surface asperities (surface roughness) to reduce metal-on-metal contact. When applied loads are high enough to collapse the thin-film on the surface, ZDDPs react with the entire metal surface to reduce wear. In a general sense, the anti-wear film can be said to be composed of ZDDP degradation products; the thickness and composition of the products are directly influenced by temperature [9]. The nature of the ZDDP film has been extensively studied; however, no analysis provides a concise description of the film within automotive lubrication regimes.

There is a multitude of AW/EP additives besides the described ZDDPs. Discussion of these additives is outside the scope of this work.

3.4.3 Detergents

One of the primary results of oxidation is the formation of sludge and other products that tend to separate from the bulk lubricant due to differences in polarity. Detergent additives function by suspending polar products of oxidation and by neutralizing oxidation and combustion-derived acids [10]. Because of their dual functionality, detergents control corrosion, rust, and sludge buildup within the engine. Detergents are composed of a metal-containing polar (hydrophilic) head and a hydrocarbon (hydrophobic) tail to enable good solubility within the bulk lubricant.

3.4.4 Dispersants

Dispersants work in conjunction with detergents to suspend polar products of oxidation. One of the main differences between detergents and dispersants is their basicity relative to one another. Detergents are metal salts of organic acids; they usually contain excess basicity in the form of metal hydroxides and metal carbonates. Dispersants have little or no acid-neutralizing ability because they have little or no basic characteristics. However, dispersants are higher in molecular weight than the hydrophobic portion of a detergent. As such, dispersants are more effective in cleaning the internal environment of the engine [11].

Many undesirable products result from oxidative degradation of components making up the bulk lubricant. In addition to the oxidation mechanism previously discussed, fuel combustion is an important cause of lubricant oxidation. Fuel degradation products that are strong oxidizing agents go past the piston rings into the lubricant as *blowby*. These oxidizers attack the hydrocarbon portion of the lubricant [11]. The results include formation of resin, varnish, and sludge. The specific formation is dependent upon the composition of the deposit and the temperature of the engine part experiencing deposit formation.

Dispersants control deposit formation by suspending deposits in a structure called a micelle. This is enabled by the structure of the dispersant, which is characterized as having an oxygen- or nitrogen-based polar head and a large non-polar tail. The polar group associates with the deposit while the non-polar group keeps the micelle suspended in the lubricant.



3.4.5 Viscosity Modifiers

Viscosity Modifiers (VMs) are added to base oil to improve the viscosity index. This type of additive enabled the development of multi-grade engine oils in the 1960s [12]. VMs allow the engine to start at cold temperatures while providing sufficient viscosity to prevent wear at higher temperatures. Most fluids experience a decrease in viscosity as temperature increases. VMs work by exhibiting a temperature-dependent interaction with the base oil. At low temperatures, interaction with the oil is minimal; this interaction is increased at elevated temperatures. The interaction increases the effective volume fraction of the VM; this leads to an increase in lubricant viscosity. To produce a multi-grade oil, a low-viscosity base stock is used to which the VM is added.

3.4.6 Pour Point Depressants

Paraffinic components within a base oil are susceptible to wax formation at lower temperatures. The waxes can conglomerate and prevent lubricant flow. The pour point temperature is defined as the lowest temperature at which the oil is still capable of flowing; this value is used to evaluate the ability of a lubricant to flow at low temperatures. Pour point depressants work by preventing the conglomeration of waxes formed within the lubricant [12].

3.4.7 Foam Inhibitors

Oil that is whipped into froth or foam by spinning engine parts has reduced lubricating and cooling abilities. In engine oil, foams can result in a loss of oil pressure and cavitation. The stability of foams tends to increase as additive packages are added to a base oil. Foam inhibitors work by reducing the surface tension at the air bubble-lubricant interface; this allows the bubbles making up the foam to burst more easily. Foam inhibitors are usually added in very low concentrations (below 20 ppm) [12].

4 Inquiry #1: Are there differences in performance between oils marketed as conventional versus oils marketed as synthetic?

4.1 Objective

To quantify how the base oil composition influences the performance of engine oil. To accomplish this, ASTM standardized tests were used to evaluate several performance characteristics.

4.2 Methodology

Eight ASTM tests were selected to identify differences in engine oil marketed as a conventional versus engine oil marketed as a full synthetic. The selected tests are commonly used to evaluate various performance characteristics of an engine oil. By analyzing the results as a whole, conclusions regarding the overall performance of an engine oil can be made. All ASTM tests with the exception of ASTM D4742 are required for ILSAC GF-5 certification.

AAA engaged the services of two independent (International Standards Organization) ISO 17025 certified testing labs to perform the ASTM International standard tests. ***To avoid complications arising from inter-laboratory reproducibility, one lab conducted an ASTM test in its entirety. All tests with the exception of ASTM D7528 were performed twice on the same test oil and averaged.*** The labs routinely perform the selected ASTM tests for oil companies and engine manufacturers. These capabilities



allowed AAA to compare the effects of base oil composition using back-to-back testing to minimize precision bias.

The selected ASTM bench tests are commonly used to measure various performance characteristics of lubricating oils. This research analyzed high-temperature/high-shear viscosity, shear stability, moderate-temperature deposit formation, high-temperature deposit formation, evaporation loss, low-temperature pumpability, oxidation stability, and oxidation viscosity. In addition to ASTM bench tests, oils are also subjected to multiple engine-fired tests for ILSAC GF-5 certification. Due to the cost of engine-fired dyno testing, the scope of this research was limited to ASTM bench tests used within oil certification testing.

4.3 Test Oil Selection

For this research, AAA selected five oil brands by first identifying brands commonly available throughout the United States. Only brands that produced both conventional and full synthetic oils were considered. This was done to minimize variables resulting from different brands under test. Oils were required to meet ILSAC GF-5 and API SN specifications to be eligible for testing. The oil was categorized as conventional or synthetic based on the manufacturers labeling. Once the eligible brands were identified, a random number generator program was used to randomly select five oil brands. An SAE 5W-20 conventional and synthetic oil from each of the five selected brands was sourced for evaluation. SAE 5W-20 oil was selected for testing because this viscosity is common in newer vehicles. Additionally, low viscosity oils will be increasingly popular in the future. Each oil was purchased in the form of five (5) one-quart bottles with identical lot numbers. All oils were purchased from auto part retailers in the greater Orlando area and sent to the testing labs without modification or being opened.

4.4 Test Results

All measurements specified by the selected ASTM tests were reported to AAA in unprocessed form.

4.4.1 ASTM D6278 Kurt Orbahn Shear Stability Test & ASTM D4683 High Temperature/High Shear (HTHS) Viscosity

A critical aspect of an engine oil is to provide protection in high-shear environments. The shear rate and temperature specified in ASTM D4683 (10^6 sec^{-1} & 150°C) are similar to the hydrodynamic flow environment of a crankshaft journal bearing at steady state [13]. If only the viscosity modifier is varied between identical engine oils, the HTHS viscosity can correlate to wear in regions subject to hydrodynamic lubrication [14]. HTHS viscosity is relevant to wear in these regions because this viscometric property relates to oil film thickness. In hydrodynamic lubrication regions, the oil film thickness is a critical factor influencing wear. For this reason, SAE J300 specifies a minimum HTHS viscosity for each viscosity grade [15]. This is because the oil film thickness is primarily responsible for preventing asperities on opposing surfaces from making contact. Within the ILSAC GF-5 specification, the minimum HTHS viscosity for a SAE 20 Viscosity Grade as measured by ASTM D4683 is 2.6 cP [5].

The Kurt Orbahn shear stability test (ASTM D6278) breaks apart molecules above a threshold molecular weight. Viscosity modifiers (VMs) are added to the base oil to improve the viscosity index. These additives are typically high-molecular weight polymers susceptible to mechanical shearing. Once the VMs are sheared, the oil is subject to permanent thinning at high temperatures. This permanent



viscosity loss can adversely influence the oil film thickness in hydrodynamic lubrication regions, leading to increased wear.



Figure 3: ASTM D4683 Tapered Bearing Simulator viscometer Image Source: AAA

ASTM D4683 and ASTM D6278 were combined to evaluate the ability of an engine oil to maintain HTHS viscosity after being subjected to high shear. To accomplish this, the HTHS viscosity of new oil was measured as specified by ASTM D4683 [16]. The test was performed twice on each sample. The same oil was subjected to mechanical shear via thirty passes through a diesel injector nozzle as specified by ASTM D6278 [17]. After shear, the HTHS viscosity was again measured twice and the un-sheared and sheared HTHS viscosities were compared. The kinematic viscosities at 100°C before and after shearing were also measured twice and compared.

Since the VMs are changed after shear, the HTHS stability can correlate to wear. This methodology is representative of real-world use because engine oils are subjected to comparable shear rates throughout its service life.



■ ASTM D6278 Kinematic Viscosity Stability

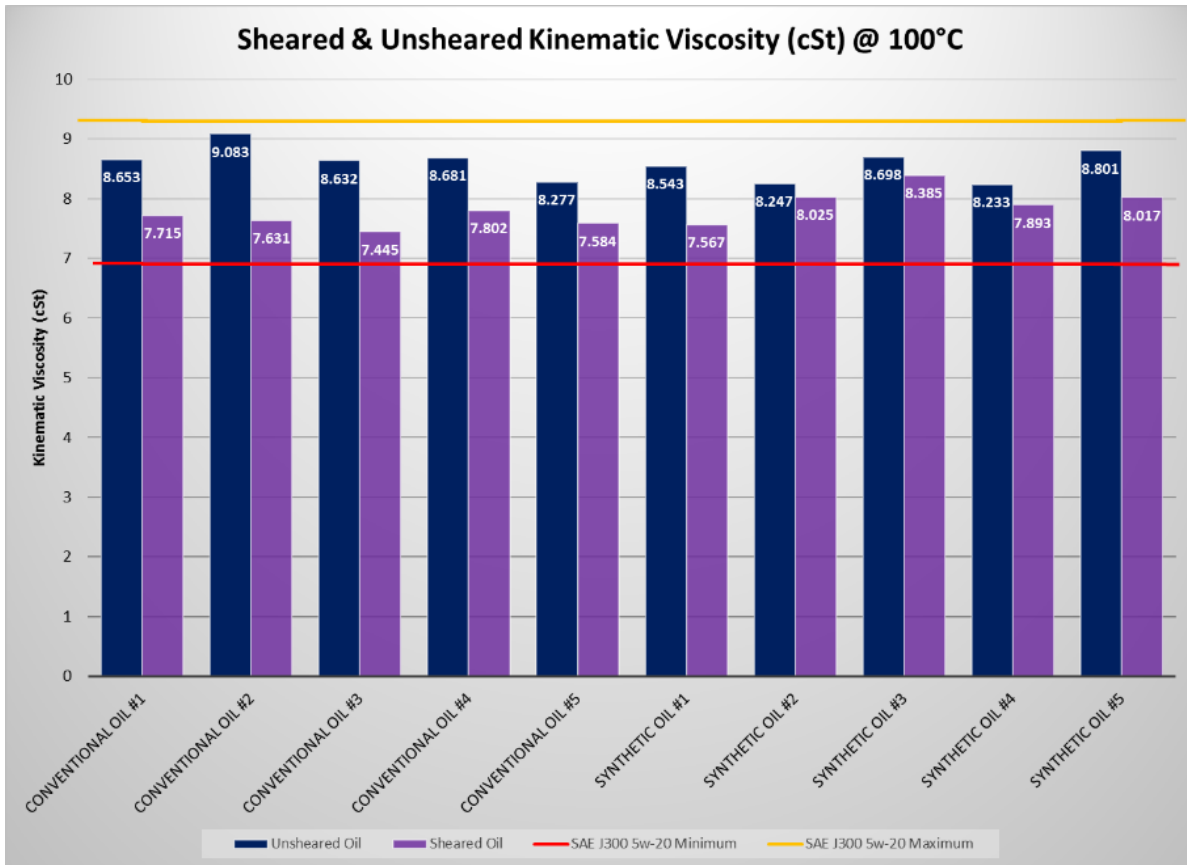


Figure 4: ASTM D6278 Sheared & unsheared kinematic viscosity (reported as the average of two replicate measurements)

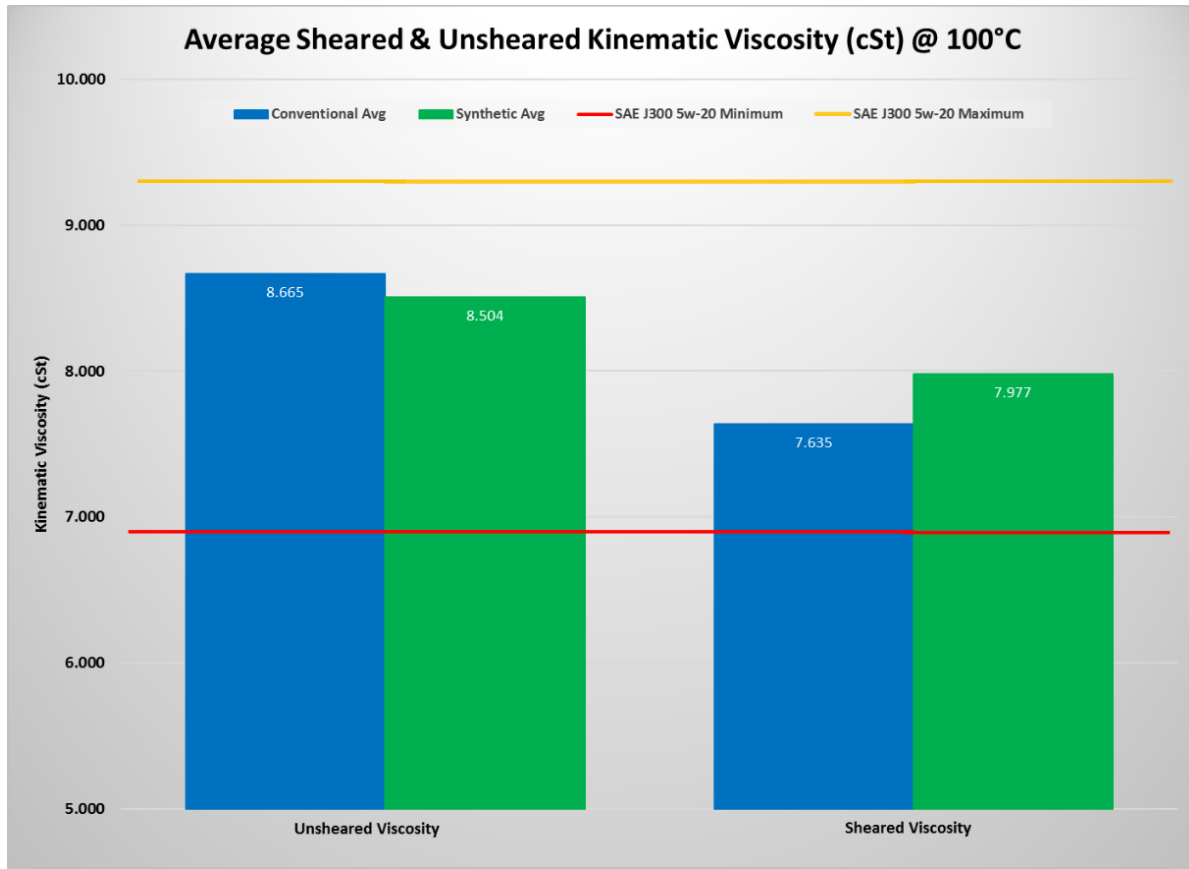


Figure 5: ASTM D6278 average sheared & unsheared kinematic viscosity

The graphs above show the maximum and minimum kinematic viscosities defined for SAE 5W-20 oil. These values are specified in SAE J300. Figure 4 shows that all tested conventional and synthetic oils stay within the SAE 5W-20 Viscosity Grade after shear. On average, the kinematic viscosities of tested synthetic oils are more shear stable than tested conventional oils as shown in figure 5.



■ ASTM D4683 High Temperature/High Shear Stability

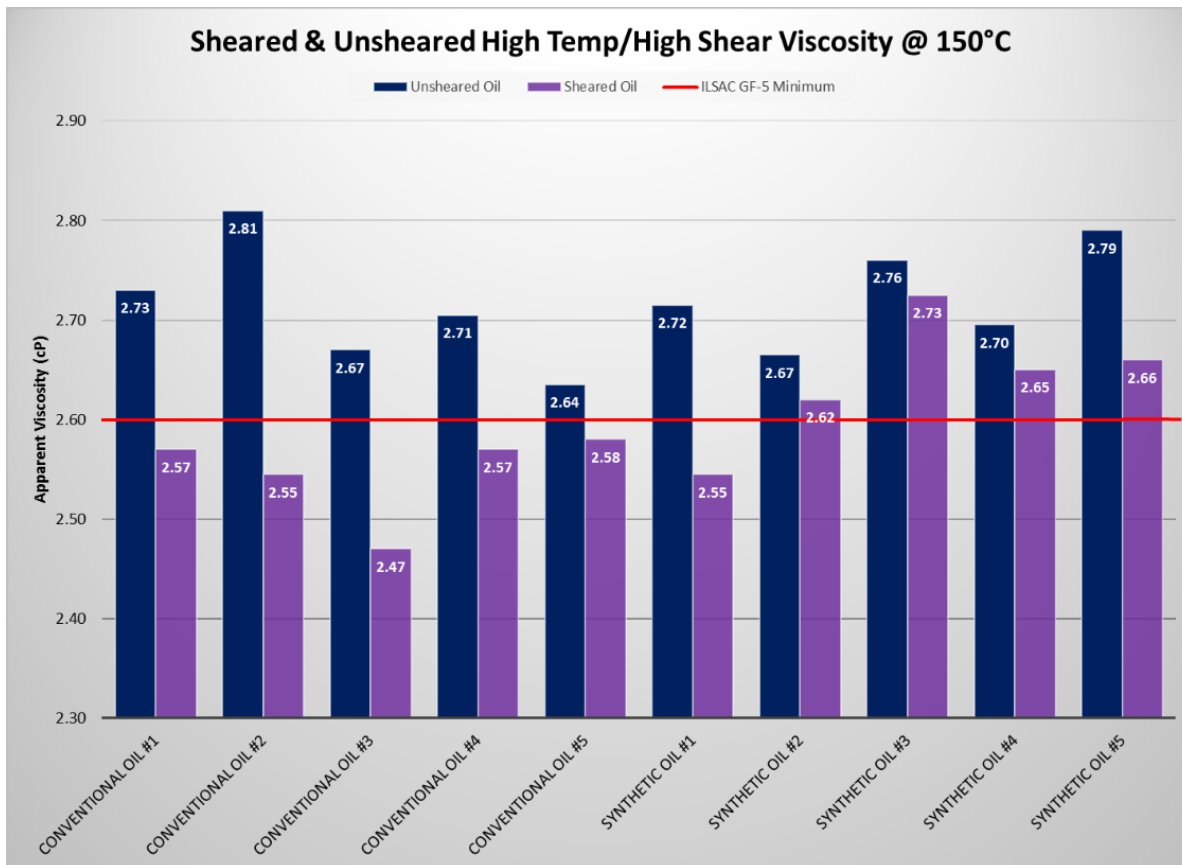


Figure 6: ASTM D4683 sheared & unsheared HTHS viscosity (reported as the average of two replicate measurements)

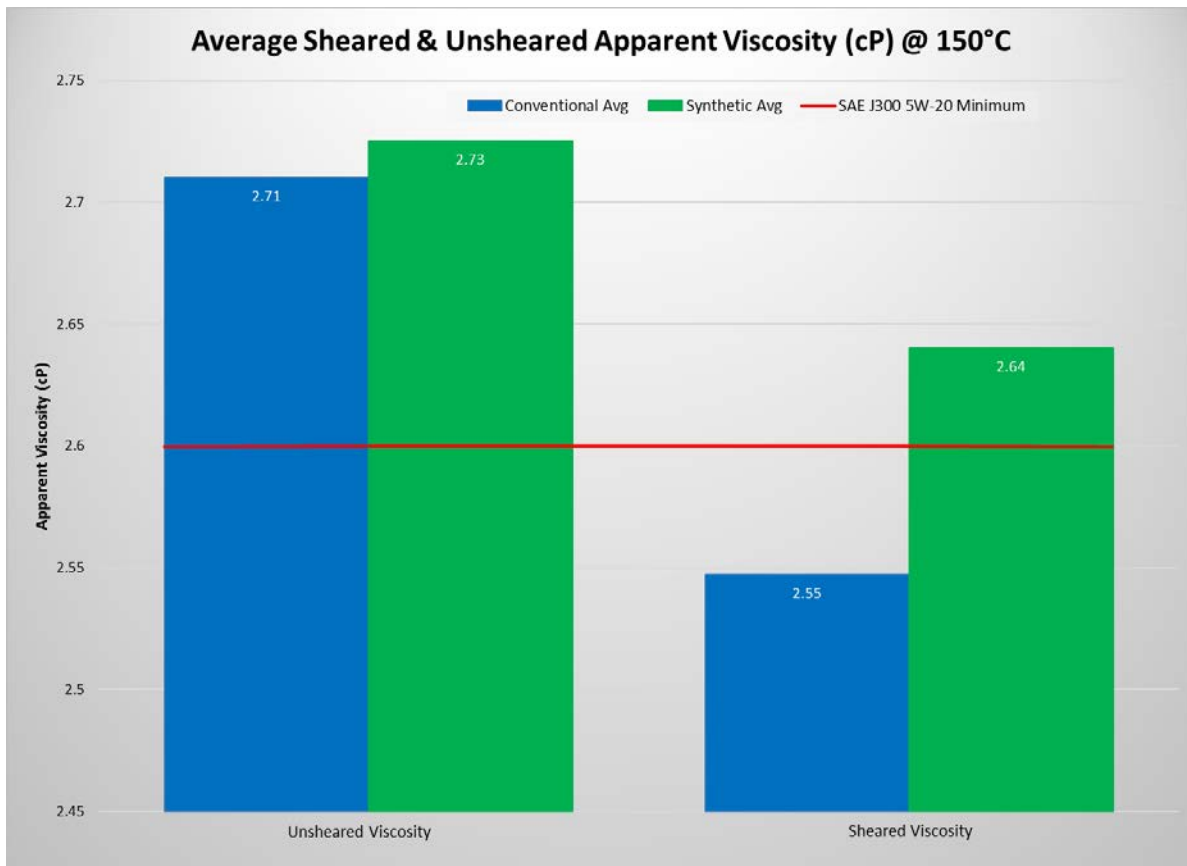


Figure 7: ASTM D4683 average sheared & unsheared HTHS viscosity

No tested conventional oils met the minimum SAE J300 specified HTHS viscosity of 2.6 cP after shear.³ It should be noted that this specified HTHS viscosity is for fresh oil; however, this is irrelevant when evaluating the HTHS shear stability of engine oil. As the oil film thickness is influenced by the HTHS viscosity [15], engine wear can be adversely affected if an engine oil exhibits poor HTHS stability throughout its service life.

Synthetic oil #1 failed to meet the minimum HTHS viscosity specification after shear; however, the synthetic oils exhibited better HTHS stability than conventional oils on average (Figure 7). This is likely due to the naturally high viscosity index of synthetic based engine oils. These oils tend to need less viscosity improvers that are prone to shear [18].

³ Results could vary due to test or batch variations.

▪ Average Percent Viscosity Losses

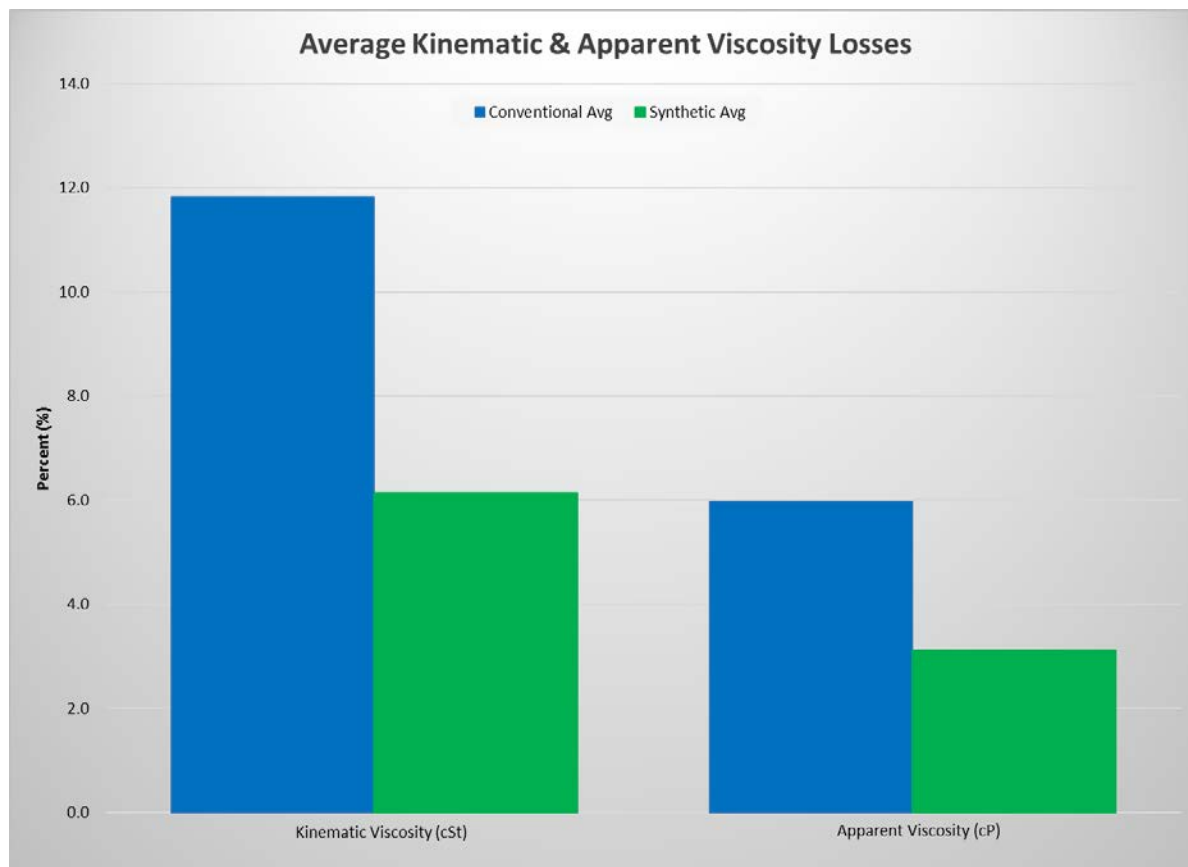


Figure 8: Average percent kinematic & apparent viscosity losses

On average, the percent kinematic viscosity loss of tested conventional oils was 93 percent greater than that of tested synthetic oils. The percent apparent viscosity loss of tested conventional oils was 92 percent greater than tested synthetic oils. The combination of ASTM D6278 & ASTM D4683 demonstrates that tested synthetic oils have significantly greater shear stability than tested conventional oils in terms of kinematic & apparent viscosity.

4.4.2 ASTM D7097 Moderately High Temperature Piston Deposits by Thermo-Oxidation Engine Oil Simulation Test (TEOST MHT)

The piston ring/cylinder liner interface is subjected to temperatures that can cause engine oils to form deposits. Approximately ten years ago, engine manufacturers began moving piston rings higher on the piston to improve emissions [19]. As a result, piston ring temperatures are generally increasing. When evaluating the performance of an engine oil, it is essential that deposit-forming tendencies be evaluated. It has been known that engine oil deposits have a negative effect on engine performance in regards to drivability, durability, and emissions [20]. When deposits form on and/or behind piston rings, ring sticking can occur. This results in a poor seal and poor heat transfer from the cylinder to the wall. If not controlled, this will result in loss of compression and ultimately engine failure [11].



Figure 9: ASTM D7097 TEOST MHT instrument Image Source: AAA

Deposits formed in the TEOST MHT test are primarily due to the stability of the base oil [21]. ILSAC GF-5 specifies the maximum mass of deposits in ASTM D7097 to be 35 mg [5]. Oils under test were mixed with a catalytic amount of organo-metallic catalyst and circulated for 24 hours under steady-state airflow in the TEOST MHT instrument. The instrument contains a depositor rod; the hottest location on the depositor rod is regulated to 285°C. The depositor rod was weighed before and after the test; the mass of deposits on the rod and any deposits collected from the filter were determined. The test was carried out twice on each oil as specified by ASTM D7097 [22]. Post-test photos of MHT depositor rods are included in the Appendix.

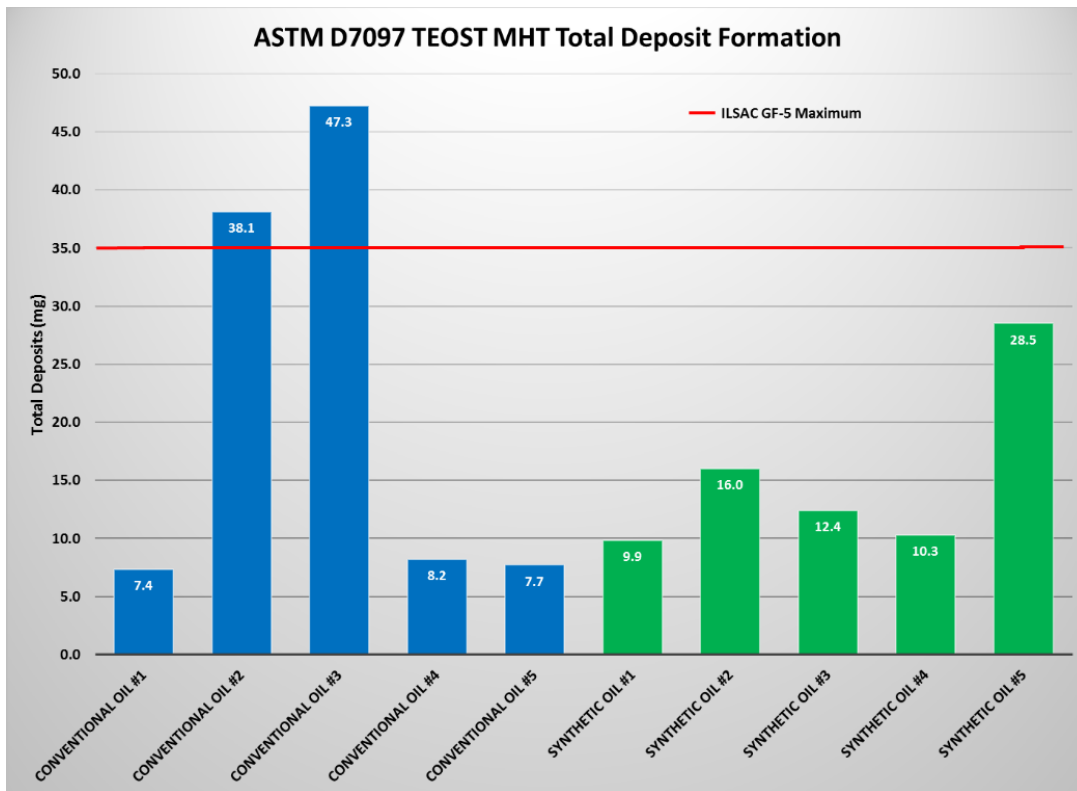


Figure 10: ASTM D7097 total MHT deposit formation (reported as the average of two replicate measurements)

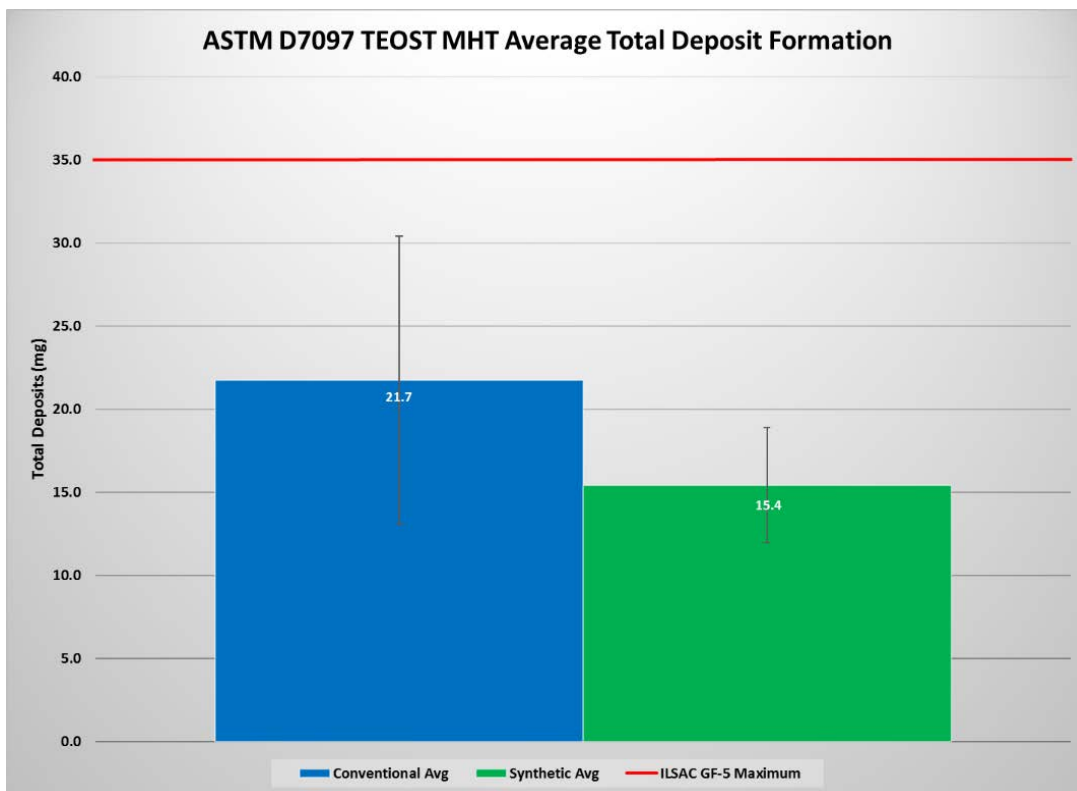


Figure 11: ASTM D7097 average total MHT deposit formation



Three out of five conventional oils performed very well in the MHT test; these three oils even outperformed all synthetic oils tested. However, the remaining two conventional oils failed the ILSAC GF-5 specification by a significant margin. This resulted in a large standard deviation among conventional oils. With only five oil brands tested, it is not possible to definitively state that conventional oils as a whole will exhibit large variation in MHT deposit-forming performance. However, these data suggest that significant variations in deposit formation exist between conventional oils.

A smaller standard deviation was found between the five synthetic oils tested. All synthetic oils passed the ILSAC GF-5 specification; however, synthetic oil #5 formed nearly twice the amount of deposits as the second worst performing synthetic oil.

Although within the standard deviation, tested conventional oils formed 41 percent more deposits in the MHT test than tested synthetic oils, on average.

4.4.3 ASTM D6335 High Temperature Deposits by Thermo-Oxidation Engine Oil Simulation Test (TEOST 33C)

The TEOST 33C test is designed to evaluate the ability of engine oils to control turbocharger deposits [21]. The test operates at up to 485°C to simulate temperatures found on the turbocharger impeller shaft. Additionally, when the engine is shut down, oil in contact with the exhaust side of the impeller shaft is exposed to a static temperature of more than 500°C. At these temperatures, organic and carbonaceous material from the base oil is volatilized. As a result, deposits formed in the 33C test and within the turbocharger are predominately from organometallic additive packages [21].



Figure 12: ASTM D6335 TEOST 33C instrument Image Source: AAA



ILSAC GF-5 specifies the maximum mass of deposits in ASTM D6335 to be 30 mg [5]. Oils under test were mixed with a catalytic amount of ferric naphthenate, heated, and stirred at 100°C. Nitrous oxide and moist air was introduced to the oil to simulate conditions encountered within the engine. The catalyzed oil was pumped past a tared depositor rod that cycles between 200°C to 480°C. Deposits on the depositor rod and any deposits collected from the filter were weighed. The test was carried out twice on each oil as specified by ASTM D6335 [23]. Post-test photos of 33C depositor rods are included in the Appendix.

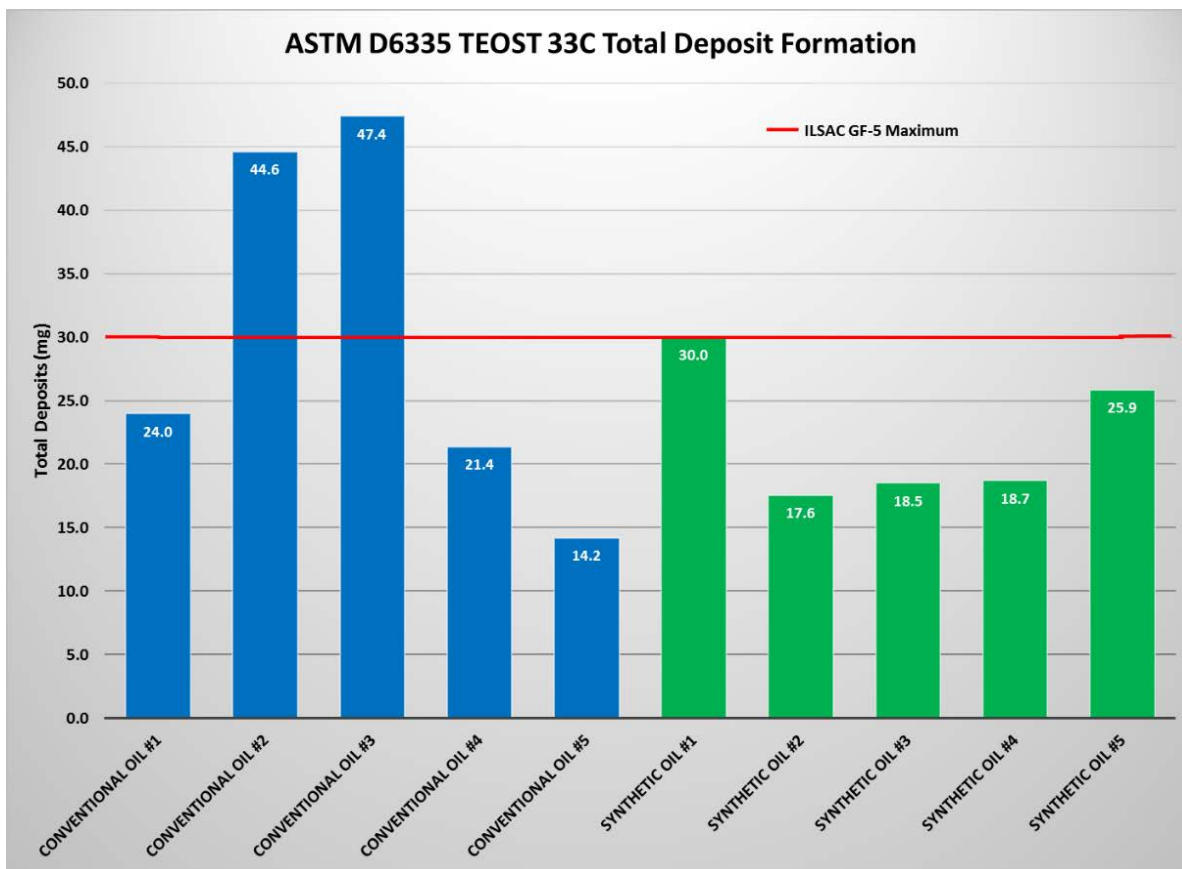


Figure 13: ASTM D6335 total deposit formation (reported as the average of two replicate measurements)

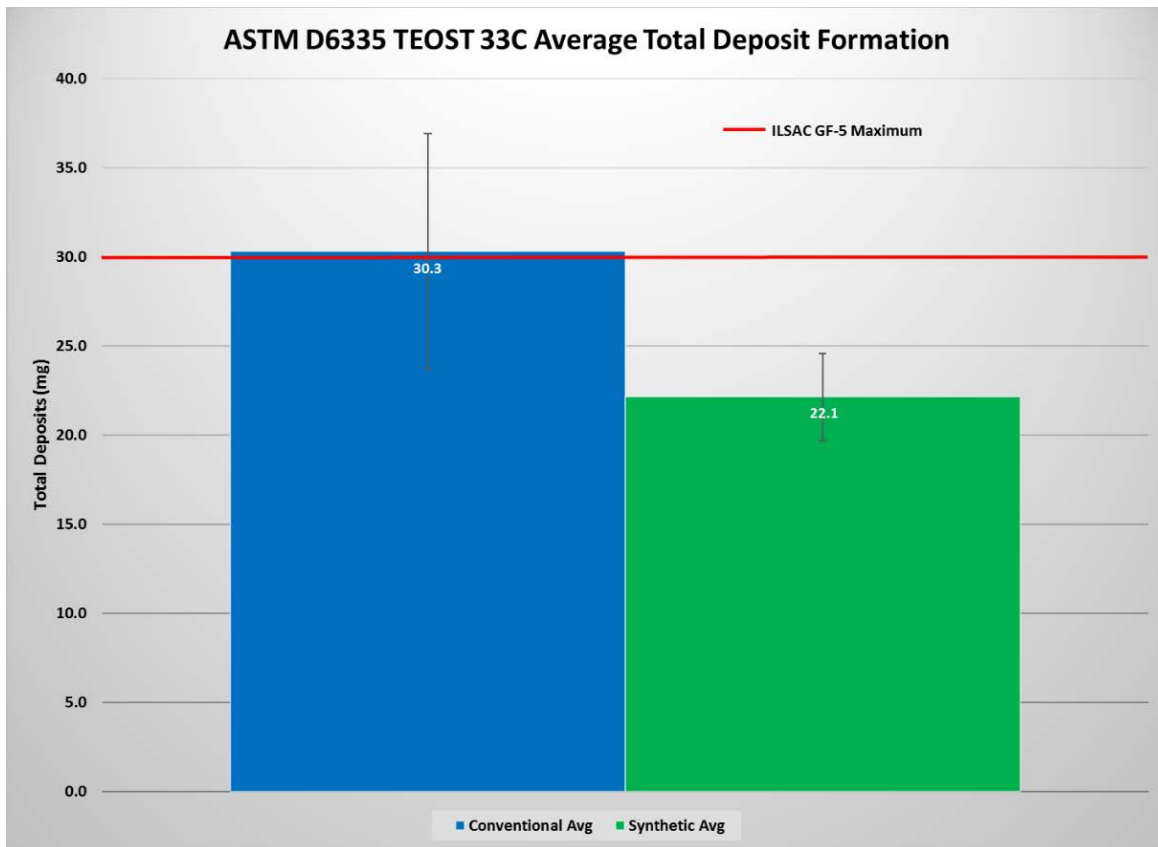


Figure 14: ASTM D6335 average total 33C deposit formation

The results from the 33C test are similar to results obtained from the MHT test. Three out of five conventional oils passed the 33C test while the remaining two conventional oils failed the ILSAC GF-5 specification by a significant margin. The two failing oils in the 33C test were the same two oils that failed the MHT test. These oils performed significantly worse than the remaining three conventional oils, resulting in a large standard deviation.

Synthetic oil #1 just met the ILSAC GF-5 specification.

On average, tested conventional oils formed 37 percent more deposits in the 33C test than tested synthetic oils.

4.4.4 ASTM D5800 Evaporation Loss of Lubricating Oils by the Noack Method (Procedure C)

Oil volatility is a parameter that is believed to have a major impact on total oil consumption because this directly governs the oil evaporation rate from hot surfaces. When engine oil components evaporate, they mix with exhaust gases and contribute to hydrocarbon and particulate emissions. Some volatile components such as phosphorus containing compounds can also damage the catalytic converter.

It has been found that the relation between oil volatility and oil consumption is magnified at increased engine speed and load [24]. This finding is especially pertinent for towing and/or aggressive driving scenarios.



ILSAC GF-5 specifies the maximum volatility found by ASTM D5800 to be 15 percent volatilization by mass. A sample of test oil was placed in an evaporation crucible and heated to 250°C with constant airflow for 1 hour. The loss in mass of the oil was measured to determine evaporative loss. The test was carried out twice on each oil as specified by ASTM D5800 Procedure C [25].

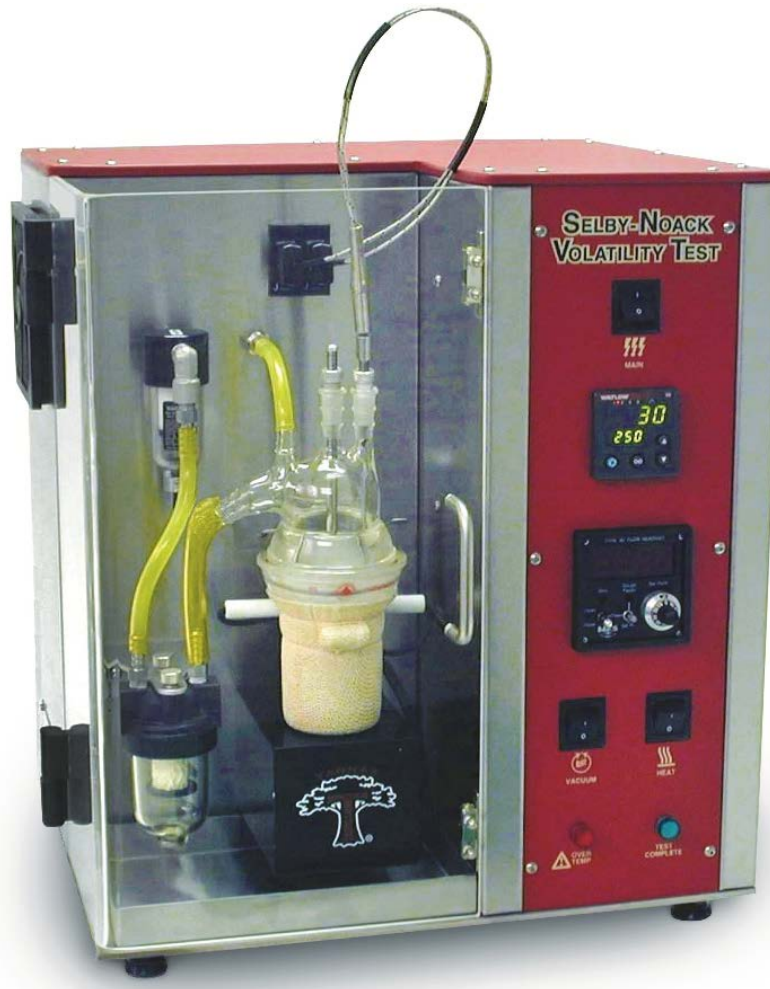


Figure 15: ASTM D5800 Selby-Noack volatility instrument Image Source: AAA

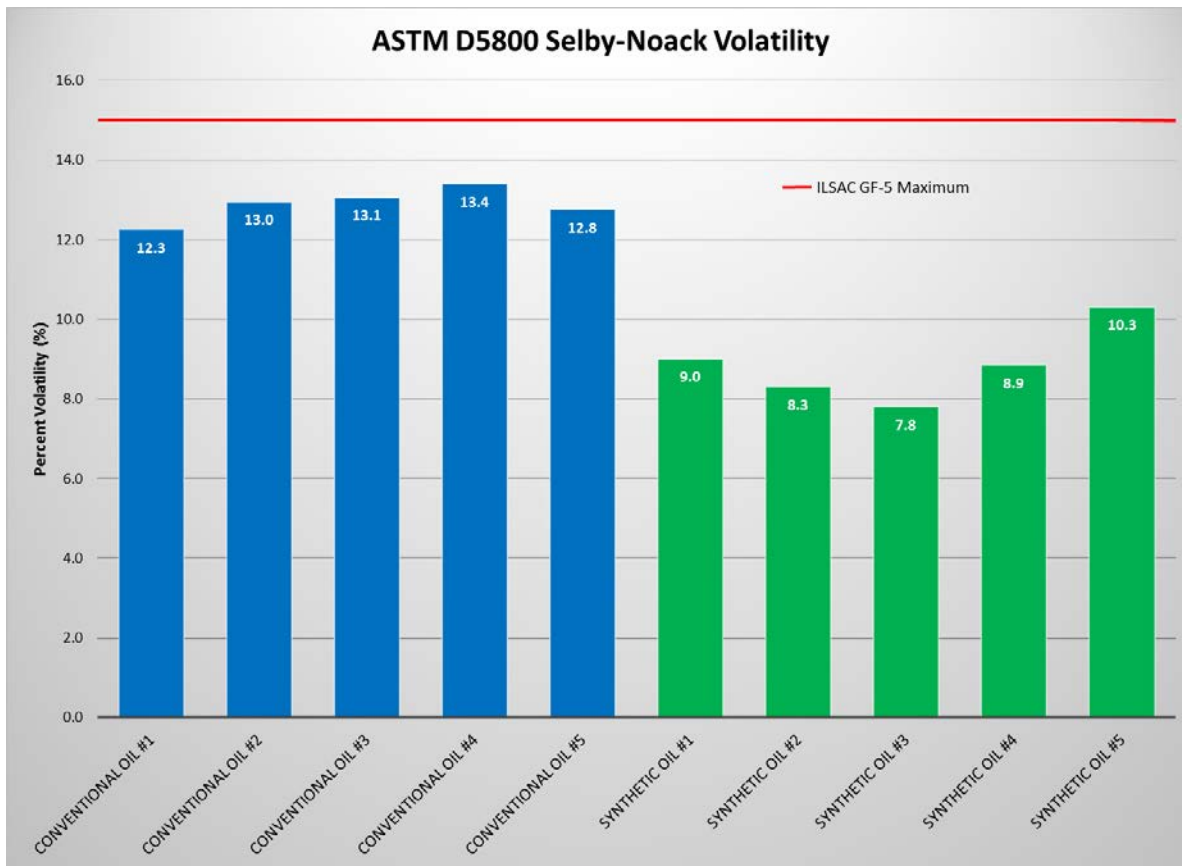


Figure 16: ASTM D5800 Selby-Noack volatility (reported as the average of two replicate measurements)

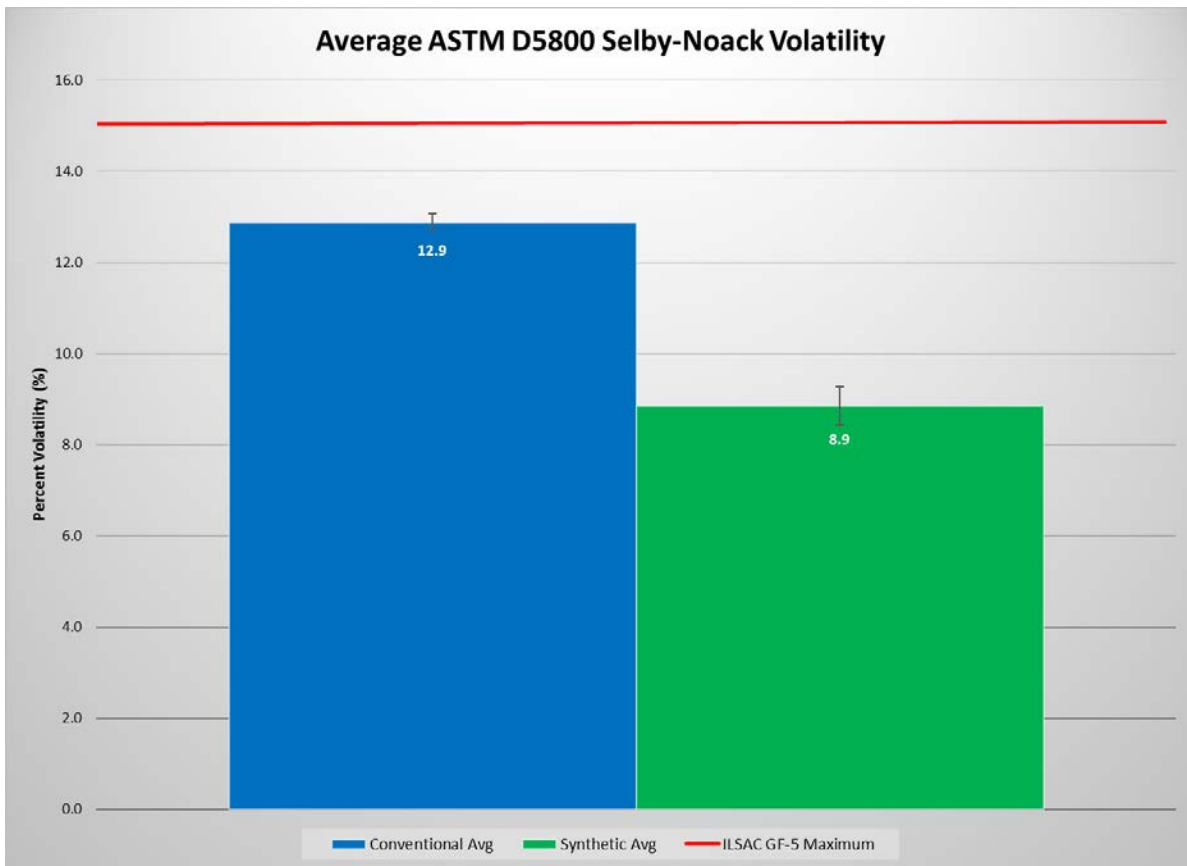


Figure 17: ASTM D5800 average Selby-Noack volatility

All tested conventional and synthetic oils passed the Selby-Noack volatility test as specified by ILSAC GF-5. The standard deviation for both groups was low, indicating little variation within each group. All tested conventional oils exhibited higher volatility than all tested synthetic oils. This is likely due to the greater presence of lower molecular weight compounds within conventional base stocks.

On average, the percent volatility of tested conventional oils was 46 percent higher than that of tested synthetic oils.

4.4.5 ASTM D5133 Low Temperature, Low Shear Rate Viscosity/Temperature Dependence by the Scanning Brookfield Test

Low-temperature pumpability is influenced by the base oil composition, viscosity modifiers, and pour-point depressants [12]. Paraffinic components within the base oil have a tendency to form wax crystals that can agglomerate if the oil is undisturbed and slowly cooled. The agglomerated wax crystals form a matrix within the oil that can impede pumpability, this tendency is known as gelation. Oils subject to gelation and/or excessive viscosity can starve the engine of lubrication during start-up at low temperatures, leading to increased wear and possible engine failure.

ASTM D5133 provides a realistic simulation of conditions encountered in cold climates. Once a vehicle is parked, the oil will drain back to the oil pan and slowly cool to ambient temperature. ASTM D5133 specifies that the test oil be pre-heated to 90°C for 90 to 120 minutes before being cooled at a rate of



1°C per hour over the temperature range of -5° to -40°C. The shear rate is approximately 0.2 sec⁻¹; the slow cooling rate and low shear rate allow the growth of wax crystals responsible for gelation.

While the oil is cooled, the apparent viscosity is continuously measured. This allows viscometric and gelation response to be analyzed with one test. An important parameter obtained from ASTM D5133 is the gelation index. This dimensionless value pertains to the maximum rate of viscosity increase at a specific temperature. The temperature at which the gelation index occurs is also reported. ILSAC GF-5 specifies the maximum gelation index found by ASTM D5133 to be 12. The test was carried out twice on each oil as specified by ASTM D5133 [26].



Figure 18: ASTM D5133 Scanning Brookfield instrument Image Source: AAA

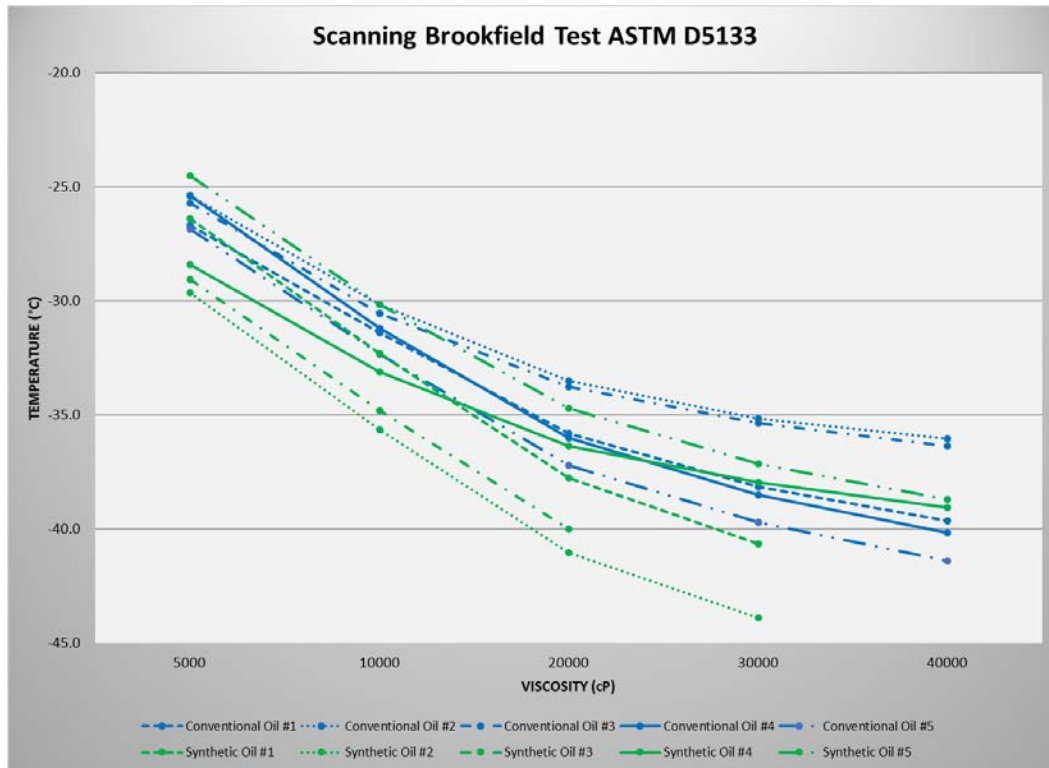


Figure 19: ASTM D5133 temperature/viscosity dependence (reported as the average of two replicate measurements)

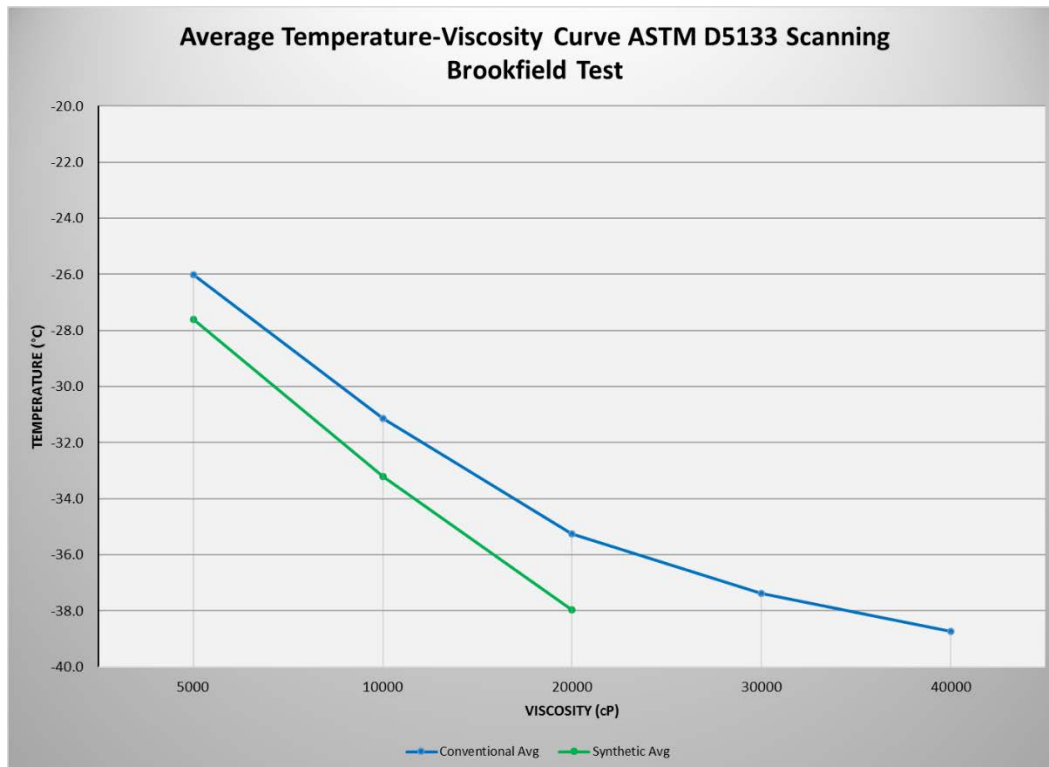


Figure 20: ASTM D5133 average temperature/viscosity dependence



ASTM D5133 specifies that the apparent viscosity be continually measured at a low shear rate as the oil is cooled. This allows for the calculation of gelation index. In figures 19 and 20, viscosity was plotted on the x-axis and temperature was plotted on the y-axis. The temperature was recorded when the viscosity equaled 5,000 cP, 10,000 cP, 20,000 cP, 30,000 cP, and 40,000 cP

Some synthetic oils are missing data points because they did not reach the specified viscosities of 30000 cP and/or 40000 cP within the temperature range of the test. These oils performed the best in ASTM D5133 because their viscosities remained low throughout the temperature range relative to the other tested oils.

Figure 20 was used to estimate the average apparent viscosity difference between tested conventional and synthetic oils at specific temperatures. At -28°C, tested conventional oils were an estimated 30 percent more viscous than tested synthetic oils. At -34°C and -38°C, tested conventional oils were an estimated 45 and 73 percent more viscous, respectively.

Estimated Viscosity (cP)	-28°C	-34°C	-38°C
Conventional	6943	16966	34667
Synthetic	5357	11677	20000

Figure 21: ASTM D5133 estimated viscosities

Depending on the specific characteristics of the sump inlet screen, oil pump annulus and rotor, and oil galleries, a high low-temperature/low-shear viscosity may result in flow-limited behavior and subsequent engine damage. Flow-limited behavior is associated with viscosity and is not dependent on gelation [26]. All oils passed the ILSAC GF-5 maximum specified gelation index of 12. However, on average the tested conventional oils were significantly more viscous at a given temperature than the tested synthetic oils.

4.4.6 ASTM D4742 Oxidation Stability by Thin-Film Oxygen Uptake (TFOUT)

Oxidation is the primary cause of oil degradation and is initiated by exposing hydrocarbons within the engine oil to oxygen and heat. ASTM D4742 evaluates the oxidation stability of gasoline engine oils. The test uses a rotating reactor pressurized with oxygen and heated to 160°C. A metal catalyst package, fuel catalyst, and water are added to the test oil to partially simulate conditions found in a gasoline engine [27]. When oxygen pressure in the reactor rapidly drops, the anti-oxidant properties of the oil have been overwhelmed. The results are reported in minutes of resistance up to 500 minutes; higher results are better.

ASTM D4742 was originally developed to monitor batch-to-batch variations in the oxidative stability of re-refined base stocks [8]. Since this technique was adopted as an ASTM standard method, the TFOUT test has been widely utilized to screen base stocks, additives, and finished oils before engine testing.

ASTM D4742 was carried out twice on each oil as specified by ASTM D4742 [27]. Results from this test are compared to results obtained from ASTM D7528.



Figure 22: ASTM D4742 TFOUT instrument Image Source: AAA

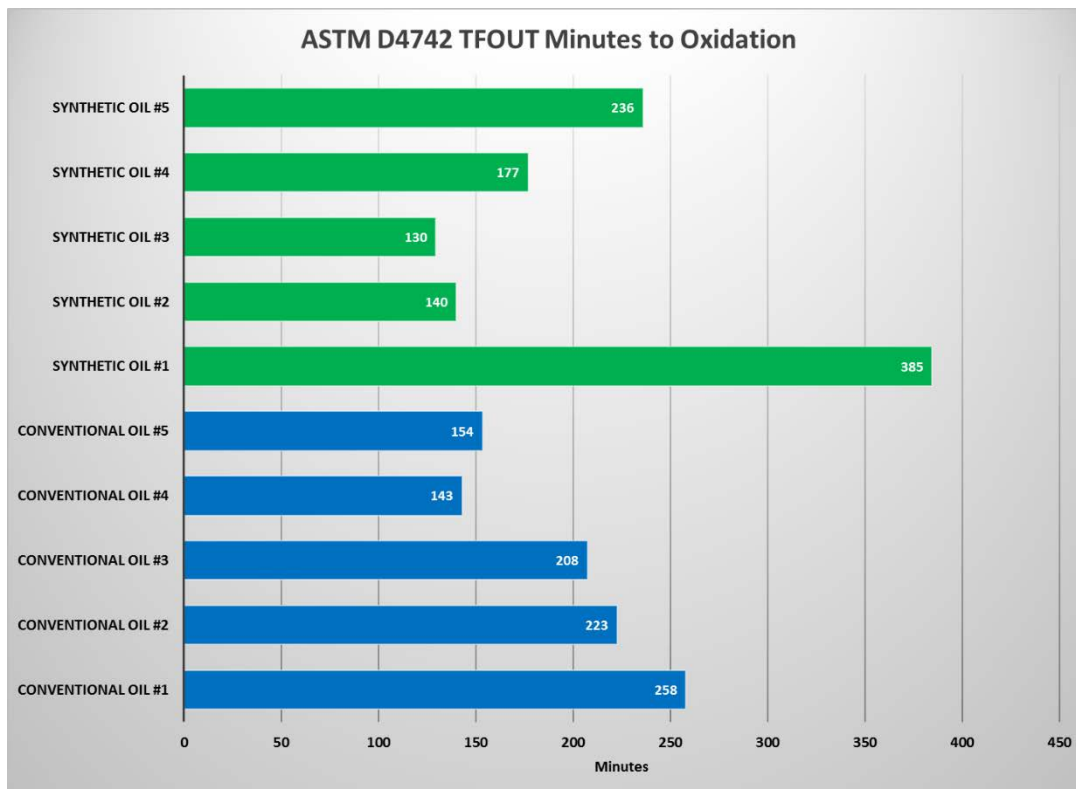


Figure 23: ASTM D4742 minutes to oxygen pressure drop (reported as the average of two replicate measurements)

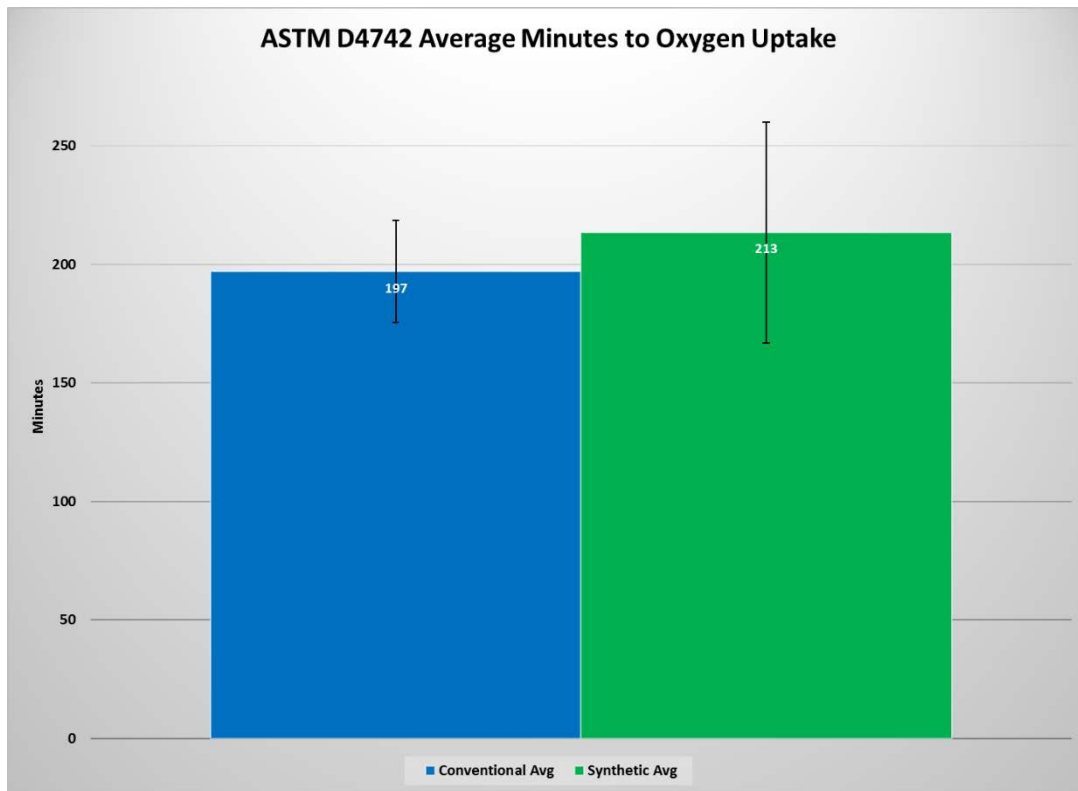


Figure 24: ASTM D4742 average time to oxygen pressure drop (reported as the average of two replicate measurements)

Synthetic oil #1 significantly outperformed all other oils tested. The performance of the remaining oils was independent of base oil composition; both conventional and synthetic oils exhibited large standard deviations. The results from the TFOUT test do not suggest that base oil composition is a significant factor in regards to oxidation resistance.

4.4.7 ASTM D7528 Bench Oxidation by Romaszewski Oil Bench Oxidation (ROBO Apparatus)

ASTM D7528 is a bench oxidation procedure that simulates oil aging that occurs in the Sequence IIIG engine test. In contrast to ASTM D4742, the ROBO oxidation test overwhelms the antioxidant additives within the base oil in order to measure rheological changes upon aging. Oil viscosity increase and deposit formation have been identified as primary oil-related factors to engine damage [8]. The kinematic viscosity at 40°C is measured after aging and compared to the kinematic viscosity at 40°C before aging. Additionally, low-temperature pumpability after aging is measured using ASTM D5293 Cold-Cranking Simulator (CCS) & ASTM D4684 Mini-Rotor Viscometer (MRV) tests. The CCS test is a high-shear test designed to simulate oil flow in engine bearings during cold-weather startup. The MRV test is a low-shear test designed to simulate pumping characteristics of an oil that has been idle in cold weather [15].

ASTM D7528 specifies that the value from the CCS test be used to determine the temperature at which the MRV test is measured. The CCS test is measured at the temperature specified for the original viscosity grade in SAE J300 [28]. If the apparent viscosity from the CCS test is higher than the maximum



apparent viscosity as specified by SAE J300, then the MRV test is measured at 5°C higher temperature than specified in SAE J300. To pass the bench oxidation test, ILSAC GF-5 specifies that the MRV apparent viscosity must be less than 60000 cP and no yield stress is detected.

A test oil was mixed with a catalytic amount of iron ferrocene, heated to 170°C, and stirred for 40 hours. During this process, nitrogen dioxide and air was introduced below the reaction surface and air flowed across the surface of the liquid at negative pressure. After 40 hours, the oxidized oil was cooled and subjected to the above viscometric tests. Evaporated oil was condensed and weighed to calculate evaporative loss. This test was carried out once on each oil as specified by ASTM D7528 [29].

While antioxidant additives are responsible for increasing oil stability, increases in kinematic and apparent viscosities can also provide insight into the effectiveness of detergents and dispersants within the test oil. When the base oil and additive packages are oxidized by either heat and oxygen or reaction with combustion products, they can polymerize. Above 150°C, aldehydes and ketones can be formed. These oxidation products can be further oxidized to produce acids and additional high-molecular weight products. The polymeric products become insoluble and fall out of the bulk fluid, leading to viscosity increases, particulate-related abrasive wear, and deposit formation. The acids can attack metal surfaces, leading to corrosion. The oxidation products are partially mitigated by detergent/dispersant packages as discussed earlier. If the base oil, oxidation conditions, and other additives are kept constant, the effectiveness of the detergent/dispersant additives can be gauged by relative viscosity increases.

It is especially important to note that viscosity increases caused by oxidation are not a substitute for shear stability. In other words, a HTHS viscosity decrease is NOT compensated by an oxidation induced viscosity increase.



▪ Volatiles Collected

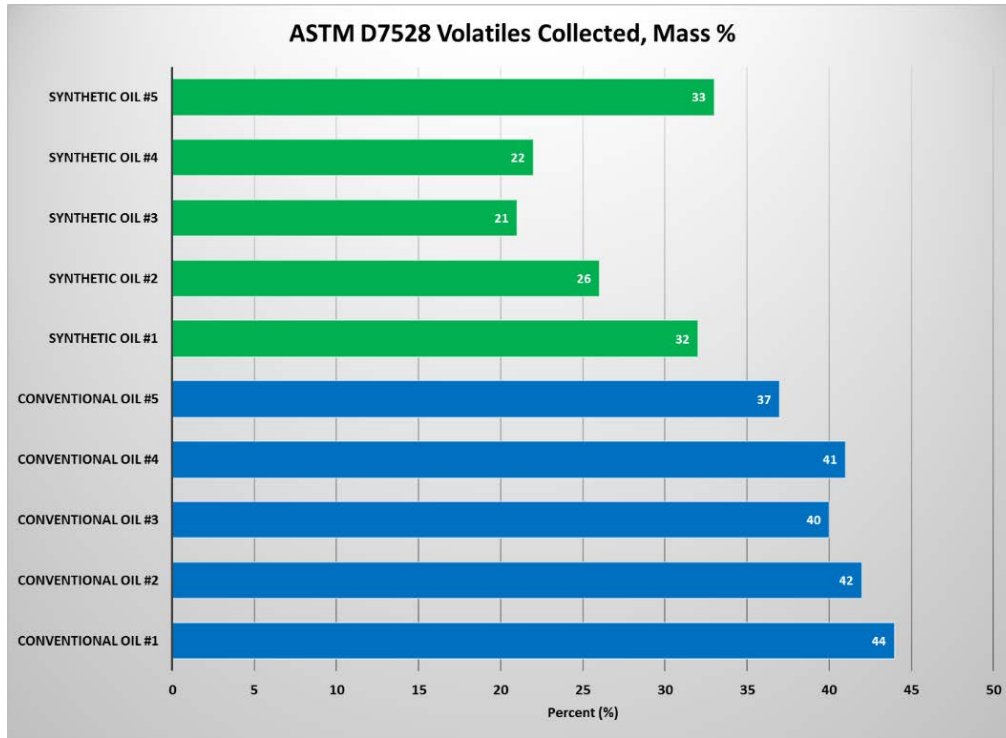


Figure 25: ASTM D7528 volatiles collected as percent of total mass

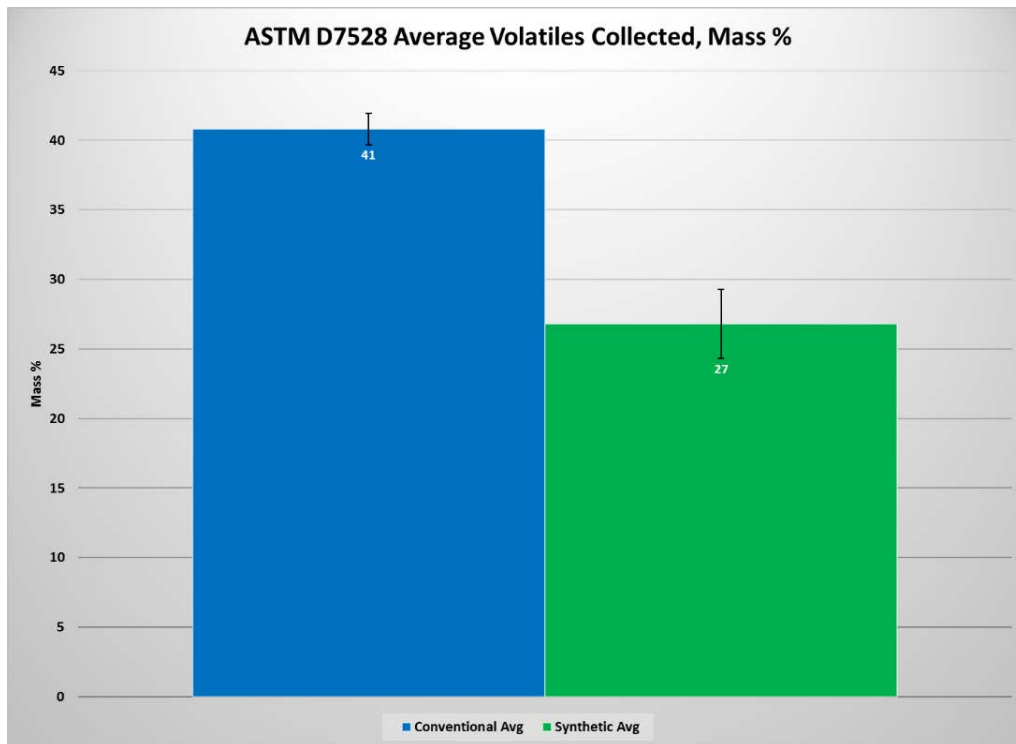


Figure 26: ASTM D7528 average volatiles collected as percent of total mass



The volatility data collected from ASTM D7528 are consistent with data from ASTM D5800. All tested synthetic oils outperformed all tested conventional oils with a small standard deviation within both groups.

- Percent Kinematic Viscosity Increase

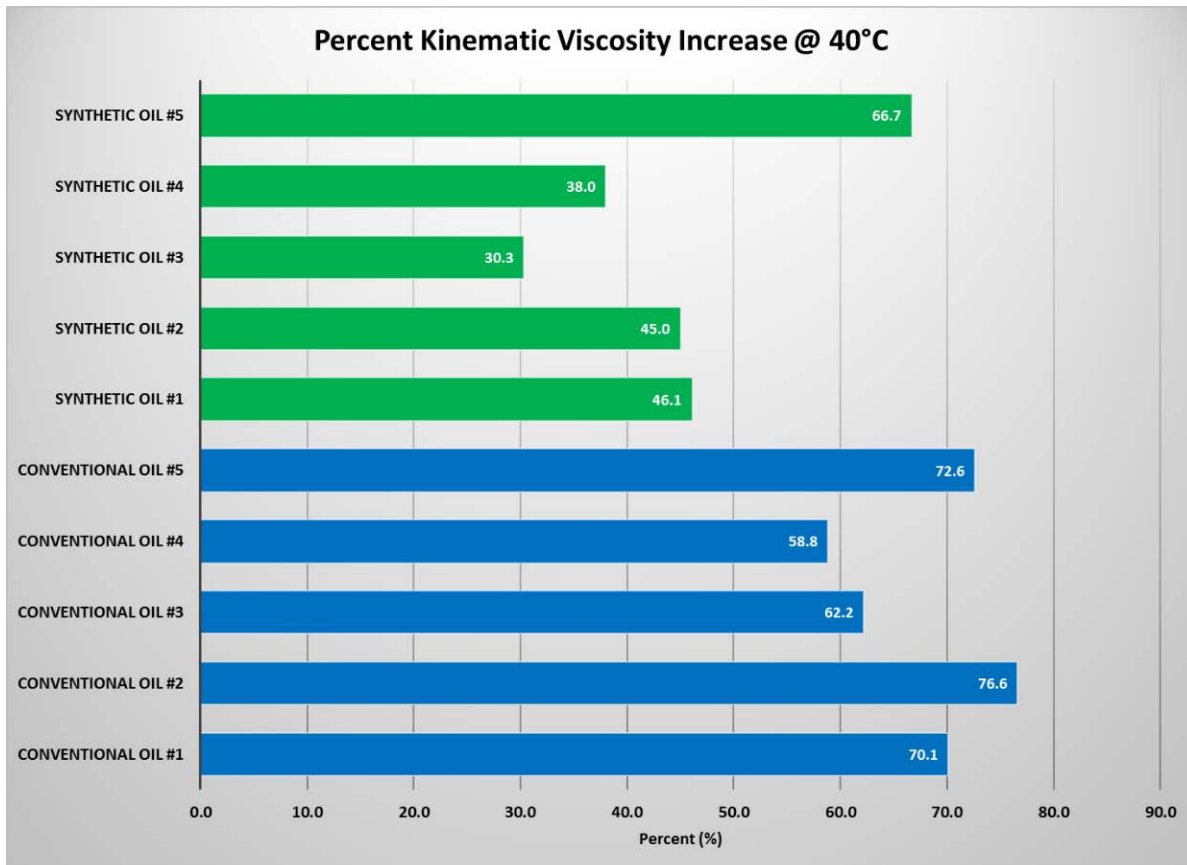


Figure 27: ASTM D7528 kinematic viscosity changes

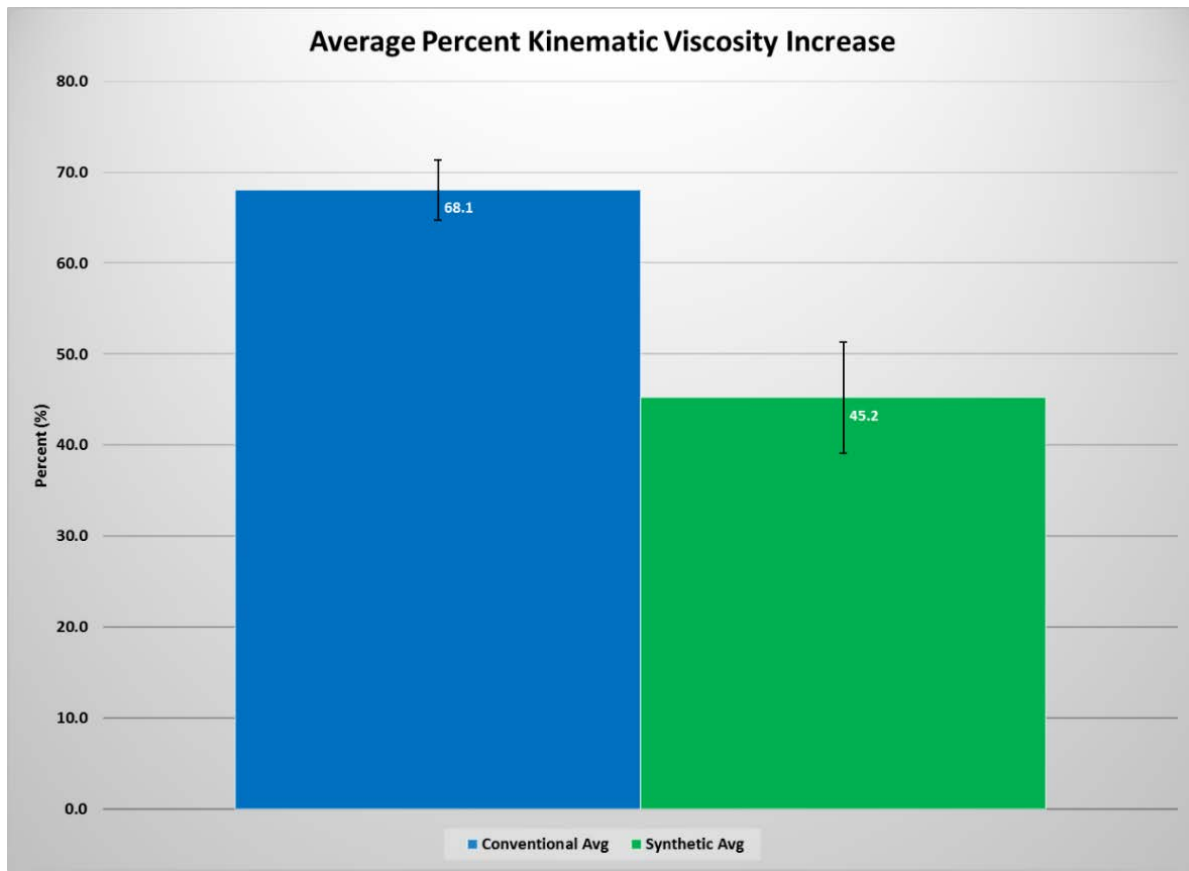


Figure 28: ASTM D7528 average kinematic viscosity changes

In terms of kinematic viscosity, the average percent increase of tested conventional oils was 51 percent greater than the average percent increase of tested synthetic oils.



▪ Cold-Cranking & Cold-Pumping Viscosity Increase

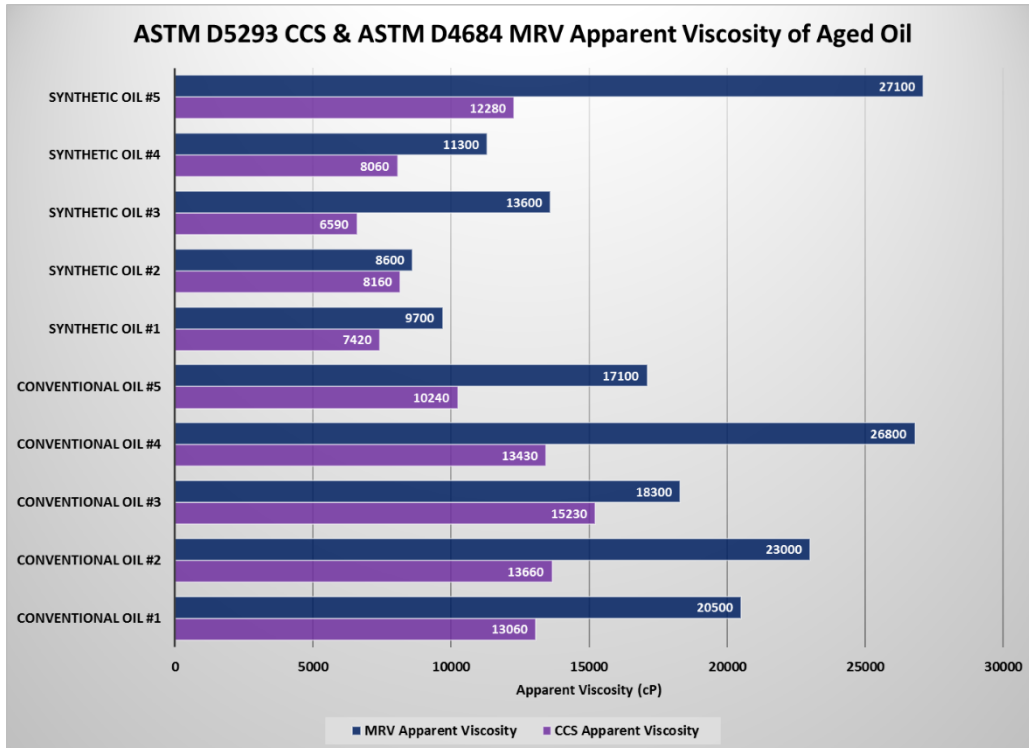


Figure 29: ASTM D5293 & ASTM D4684 aged oil viscosity

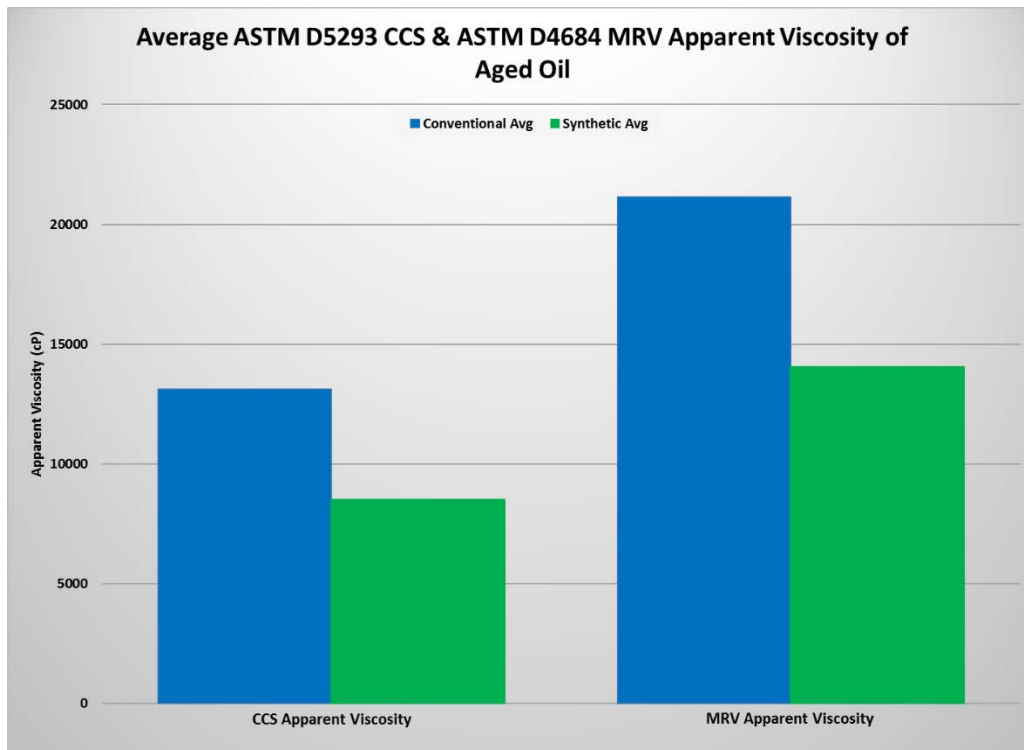


Figure 30: ASTM D5293 & ASTM D4684 average aged oil viscosity



SAE J300 specifies a maximum CCS viscosity of 6600 cP at -30°C for SAE 5W-20 engine oil. Only synthetic oil #3 met this specification after oxidation. Therefore, this oil performed the MRV test at -35°C; the remaining oils performed the MRV test at -30°C. As a rule of thumb, MRV viscosity tends to double with every 5-degree drop in temperature. Therefore, the MRV value of 13600 cP corresponding to synthetic oil #3 should be halved to enable direct comparison with the other oils tested⁴.

All tested oils met the maximum MRV apparent viscosity of 60000 cP at -30°C or -35°C as defined by ILSAC GF-5. However, tested conventional oils exhibited a greater viscosity increase than tested synthetic oils. On average, the CCS and MRV viscosities of tested conventional oils were 54 percent and 50 percent more viscous than tested synthetic oils, respectively.

Overall effects of viscosity increases are largely dependent on the specific engine and its condition. For example, an engine that already has deposits in its oil galleries could be more susceptible to damage from insufficient oil flow.

In addition to flow-limited behavior, viscosity increases induced by ASTM D7528 have other implications. The rheological changes indicate that polymerization of the base oil is occurring. Additional oxidation products can form acids and other high-molecular weight products within the oil. If detergent/dispersant packages are inadequate or are being oxidized as well, the oxidation products can form sludge and varnish deposits, cause particulate-based abrasive wear, and induce corrosion within the engine.

4.5 Summary of Findings

All tests with the exception of ASTM D4742 found significant differences in the average performance between tested conventional and synthetic oils. When the percent differences across each conducted test are combined and averaged (equal weight was given to each test), synthetic oils outperformed conventional oils in the conducted tests by 47 percent.

All tested oils were licensed by ILSAC & API at the time of testing. If an engine oil meets specific requirements of the vehicle manufacturer, either a conventional or a synthetic oil may be used. However, a synthetic oil may provide more protection in extreme operating environments or provide some additional protection in cases where manufacturer specified oil change intervals are not closely followed by the consumer. Additionally, the test results suggest that use of a synthetic oil may result in less engine wear over the life of the vehicle.

4.6 Secondary Research

Oil companies have evaluated the performance of conventional and synthetic engine oils by sampling used engine oils from real-world vehicles. AAA reviewed published research in this area to understand real-world performance. In one study, a matrix of almost 500 used oil samples were obtained from vehicles operating in and around Houston, Texas [18]. One hundred and twenty of the nearly 500 samples were formulated using full synthetic base stocks. Within the samples, numerous brands and additive chemistries were represented.

⁴ This is NOT accounted for in Figure 30.



A rapid decrease in oxidation resistance occurred in mineral-based engine oils after 3,000 to 4,000 miles of use. In some cases, very low oxidation resistance was found after 2,000 miles of use. Significantly better results were observed for synthetic based lubricants [18]. The authors did not attempt to attribute this to the better stability of the synthetic base stock or the specific additive package. It was also found that synthetic-based engine oils retain the ability to neutralize acids appreciably longer than mineral-based engine oils. It was concluded that many of the better performing engine oils subjected to real-world use were formulated using synthetic base stocks [18].

5 Inquiry #2: What is the percentage of 2016 model year vehicles that “require” synthetic engine oil?

There is a vast selection of engine oils available to the consumer. Vehicle manufacturers utilize various types of engine designs, each with specific lubrication requirements.

5.1 Objective

Determine the percentage of 2016 model year vehicles that require synthetic engine oil as specified in the owner’s manual.

5.2 Methodology

The fluid requirements for 2016 model year vehicles were analyzed using a comprehensive shop repair database.

5.3 Findings

Only two low-volume, high-performance vehicles were found to specify synthetic oil as required. However, the majority of vehicle manufacturers require compliance to an internal specification for warranty purposes. The internal specifications of one American, Asian, and European manufacturer were evaluated in order to generalize manufacturer requirements.

Most vehicle manufacturers regard their internal oil specifications as proprietary; however, it is possible to determine what oils meet the specification. This is accomplished by assessing a comprehensive list on the manufacturer’s website, or by reading the label of a specific oil to determine what specifications are met.

Of the three manufacturers surveyed, two required adherence to an internal specification. These specifications included dozens of motor oils, the majority of which were classified as a full synthetic. The remaining oils were classified as a “synthetic blend.” The third manufacturer recommended use of their licensed oil; however, oils meeting ILSAC GF-5 and API SN specifications are permissible for use if they are of the recommended viscosity for the specific vehicle.

A tiny fraction of 2016 model year vehicles specifically “require” synthetic engine oil; however, the majority of vehicle manufacturers mandate that oils used in their vehicles meet proprietary internal specifications in addition to ILSAC GF-5 and API SN specifications. When selecting an engine oil, consult the owner’s manual to determine what, if any, manufacturer specification is required.



6 Inquiry #3: What is the cost increase associated with switching to a synthetic engine oil?

6.1 Objective

Evaluate the cost impact of switching to a synthetic engine oil at an AAA Approved Auto Repair provider and as a do-it-yourselfer.

6.2 Methodology

3,423 AAA Approved Auto Repair (AAR) providers across the United States were asked to complete a questionnaire regarding the typical cost of a conventional oil change versus that of a full synthetic oil change. Variations such as coupons, promotional discounts, etc. were not considered. The price quotes were based on normal oil changes of four to five quarts with a standard oil filter. Of the 3,423 AAR providers who received the survey, 759 completed the survey. This represents a 22 percent response rate.

For the average do-it-yourselfer, the cost of oil procurement for this project was used to quantify an average price difference for five quarts of conventional engine oil versus five quarts of synthetic engine oil. The oils were purchased in one-quart containers; a cost savings for both groups might be achieved if five-quart containers are purchased. To verify the price difference found by AAA, SAE 5W-20 conventional and synthetic oils were also priced on the websites of major auto parts retailers.

6.3 Findings

According to those AAA Approved Auto Repair (AAR) providers that offer oil changes at their repair facility (97% of surveyed facilities):

- **The typical cost of a conventional oil change is \$38.** Two percent of conventional oil changes cost \$20 or less, 71% costs between \$21 and \$40, 23% costs between \$41 and \$60, and 3% costs more than \$61.
- **The typical cost of a synthetic oil change is \$70.** Two percent of synthetic oil changes cost \$40 or less, 79% costs between \$41 and \$80, 17% costs between \$81 and \$120, and 2% costs more than \$121.

The average price of the five tested conventional oils was \$26.86 for five (5) quarts while the average price of the five tested synthetic oils was \$43.55 for five (5) quarts. This is consistent with the average price difference found on the websites of the major auto parts retailers. On the retailer's websites, the average price of five one-quart containers was approximately \$28 for conventional oils and approximately \$45 for synthetic oils.

Based on the above findings, the average cumulative cost increase of using synthetic engine oil for 75,000 miles is \$320 at an AAA Approved Auto Repair Facility and \$170 as a do-it-yourselfer. These estimations are based on a typical manufacturer specified oil change interval of 7,500 miles. An automobile is often a person's second most expensive purchase after a home. Since long-term use of synthetic oil may result in less engine wear over the life of the vehicle, the cumulative cost increase of using a synthetic oil may represent a good return on investment.



7 Inquiry #4: What are current consumer trends in selection of synthetic engine oil?

Identify consumer trends related to the selection of synthetic motor oil to establish relevance and value to other findings in this report.

7.1 Objective

Obtain statistically valid information on the current oil buying habits of United States motorists.

7.2 Methodology

AAA contracted with a national research company to perform a telephone survey of 1,007 adults (18 years of age and older) living in the continental United States. Of the 1,007 interviews, 507 were from a randomly selected landline sample and 500 from a randomly selected cell phone sample. Survey responses were weighted by six variables (age, gender, geographic region, race/ethnicity, and educational level) to ensure reliable and accurate representation of the total continental U.S. population, 18 years of age and older. The margin of error for the results is +/- 3.09 percent at the 95 percent confidence level.

The following questions were asked to survey participants:

- 1) The last time you brought your vehicle in for an oil change, were you offered a choice between conventional and synthetic oil?
- 2) What motor oil did you choose? (If participants specified “conventional motor oil,” question three (3) was asked.)
- 3) Why did you choose conventional motor oil?

7.3 Test Results

- Almost one half (45%) of **drivers say they typically use synthetic motor oil for their vehicle’s oil changes**, while 30% of drivers typically use conventional motor oil and three percent typically use some other type of oil. Two out of ten (22%) drivers are unsure what type of motor oil is used for oil changes on their vehicle.
 - Women are more likely to be unsure what type of motor oil is used for their vehicle (34%) than men (8%).
 - Looking at this another way, among those drivers who know what type of motor oil is used for their vehicle’s oil changes, 58% used synthetic oil, 38% conventional oil, and 4% some other type of oil.
- Four out of ten (43%) **drivers who typically use conventional motor oil for their vehicle’s oil changes** say it is because *synthetic motor oil is too expensive*. Other reasons include *not usually being offered a choice of motor oil when getting an oil change* (27%), *not thinking that synthetic motor oil is any better than conventional oil* (23%), and a belief that *shops offering synthetic oil are just trying to sell something you don’t need* (22%). One quarter (27%) of drivers cite miscellaneous other reasons for using conventional oil, while 6% say they don’t know/have no particular reason for using conventional oil.



- Men who typically use conventional motor oil are more likely to say it is because *synthetic motor oil is too expensive* (51%) than women (31%), while women are more likely to say it is because *they are not usually offered a choice of motor oil when they get an oil change* (44%) than men (16%).
- More than one-half (56%) of **drivers believe synthetic motor oil is better for their engine**, 17% do not believe synthetic motor oil is better for their engine, and 27% are not sure.
 - Men are more likely to regard synthetic motor oil as better for their engine (66%) than women (46%), while women are more likely to say they are unsure if synthetic motor oil is better for their engine (39%) than men (15%).

8 Key Findings

1. On average, synthetic oils outperformed conventional oils in the conducted tests by 47 percent. The selected tests evaluated shear stability, deposit formation, volatility, cold-temperature pumpability, oxidation resistance, and oxidation-induced rheological changes.
2. Very few vehicles specifically “require” synthetic oil; however, most vehicle manufacturers require compliance to an internal oil specification for warranty purposes.
3. The average price difference between a conventional and a synthetic oil change is \$32 at a AAA Approved Auto Repair provider.
4. 44 percent of drivers are either not sure if synthetic motor oil is better for their engine, or do not believe synthetic motor oil is better for their engine.

9 Summary Recommendations

1. Motorists should consult the owner’s manual to determine what oil specifications are required for their vehicle and should always select an engine oil that meets those specifications.
2. If motorists frequently subject their vehicle to stop-and-go driving, towing, aggressive driving or operation in extreme climates, a synthetic engine oil should be considered as it may provide additional protection for the engine. Regardless of the oil used, the vehicle manufacturer recommendation for oil change intervals should be followed.
3. If long-term engine reliability is a concern, a synthetic engine oil could result in less wear over the life of the vehicle.
4. Some consumers may believe that there is no difference between conventional and synthetic engine oils, which is a mistaken assumption. If a conventional oil meets applicable manufacturer specifications, it can be used. However, quantitative differences in performance metrics exist between conventional and synthetic engine oil.

10 Contact Information

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12 Appendices

Kinematic Viscosity Stability		
	Average Unsheared Kinematic Viscosity (cSt) @ 100°C	Average Sheared Kinematic Viscosity (cSt) @ 100°C
Conventional Oil #1	8.653	7.715
Conventional Oil #2	9.083	7.631
Conventional Oil #3	8.632	7.445
Conventional Oil #4	8.681	7.802
Conventional Oil #5	8.277	7.584
Synthetic Oil #1	8.543	7.567
Synthetic Oil #2	8.247	8.025
Synthetic Oil #3	8.698	8.385
Synthetic Oil #4	8.233	7.893
Synthetic Oil #5	8.801	8.017
Conventional Avg	8.665	7.635
Conventional Upper Std Deviation	0.128	0.060
Conventional Lower Std Deviation	0.128	0.060
Synthetic Avg	8.504	7.977
Synthetic Upper Std Deviation	0.116	0.131
Synthetic Lower Std Deviation	0.116	0.131

Figure 31: ASTM D6278 Kinematic viscosity shear stability (reported as the average of two replicate measurements)



HTHS Stability		
	Average New Apparent Viscosity (cP)	Average Sheared Apparent Viscosity (cP)
Conventional Oil #1	2.73	2.57
Conventional Oil #2	2.81	2.55
Conventional Oil #3	2.67	2.47
Conventional Oil #4	2.71	2.57
Conventional Oil #5	2.64	2.58
Synthetic Oil #1	2.72	2.55
Synthetic Oil #2	2.67	2.62
Synthetic Oil #3	2.76	2.73
Synthetic Oil #4	2.70	2.65
Synthetic Oil #5	2.79	2.66
Conventional Avg	2.71	2.55
Conventional Upper Std Deviation	0.03	0.02
Conventional Lower Std Deviation	0.03	0.02
Synthetic Avg	2.73	2.64
Synthetic Upper Std Deviation	0.02	0.03
Synthetic Lower Std Deviation	0.02	0.03

Figure 32: ASTM D4683 HTHS stability before & after shear (reported as the average of two replicate measurements)

Average Viscosity Loss		
	Average Kinematic Viscosity Loss (%)	Average Apparent Viscosity Loss (%)
Conventional Oil #1	10.8	5.9
Conventional Oil #2	16.0	9.4
Conventional Oil #3	13.8	7.5
Conventional Oil #4	10.2	5.0
Conventional Oil #5	8.4	2.1
Synthetic Oil #1	11.4	6.3
Synthetic Oil #2	2.7	1.7
Synthetic Oil #3	3.6	1.3
Synthetic Oil #4	4.2	1.7
Synthetic Oil #5	8.9	4.7
Conventional Avg	11.8	6.0
Conventional Upper Std Deviation	1.4	1.2
Conventional Lower Std Deviation	1.4	1.2
Synthetic Avg	6.1	3.1
Synthetic Upper Std Deviation	1.7	1.0
Synthetic Lower Std Deviation	1.7	1.0

Figure 33: ASTM D6278 & ASTM D4683 percent kinematic & apparent viscosity losses (reported as the average of two replicate measurements)



MHT Deposits	Total Deposits (mg)
Conventional Oil #1	7.4
Conventional Oil #2	38.1
Conventional Oil #3	47.3
Conventional Oil #4	8.2
Conventional Oil #5	7.7
Synthetic Oil #1	9.9
Synthetic Oil #2	16.0
Synthetic Oil #3	12.4
Synthetic Oil #4	10.3
Synthetic Oil #5	28.5
Conventional Avg	21.7
Synthetic Avg	15.4
Conventional Standard Deviation	17.4
Upper	8.7
Lower	8.7
Synthetic Standard Deviation	6.9
Upper	3.4
Lower	3.4

Figure 34: Total ASTM D7097 MHT deposit formation (reported as the average of two replicate measurements)

33C Deposits	Total Deposits (mg)
Conventional Oil #1	24.0
Conventional Oil #2	44.6
Conventional Oil #3	47.4
Conventional Oil #4	21.4
Conventional Oil #5	14.2
Synthetic Oil #1	30.0
Synthetic Oil #2	17.6
Synthetic Oil #3	18.5
Synthetic Oil #4	18.7
Synthetic Oil #5	25.9
Conventional Avg	30.3
Synthetic Avg	22.1
Conventional Standard Deviation	13.2
Upper	6.6
Lower	6.6
Synthetic Standard Deviation	4.9
Upper	2.5
Lower	2.5

Figure 35: Total ASTM D6335 33C deposit formation (reported as the average of two replicate measurements)



Noack Volatility	
Conventional Oil #1	12.3
Conventional Oil #2	13.0
Conventional Oil #3	13.1
Conventional Oil #4	13.4
Conventional Oil #5	12.8
Synthetic Oil #1	9.0
Synthetic Oil #2	8.3
Synthetic Oil #3	7.8
Synthetic Oil #4	8.9
Synthetic Oil #5	10.3
Conventional Avg	12.9
Synthetic Avg	8.9
Conventional Standard Deviation	0.38
Upper	0.19
Lower	0.19
Synthetic Standard Deviation	0.84
Upper	0.42
Lower	0.42

Figure 36: ASTM D5800 Selby-Noack volatility (reported as the average of two replicate measurements)

Viscosity (cP)	5000	10000	20000	30000	40000
Conventional Oil #1	-26.7	-31.4	-35.8	-38.2	-39.7
Conventional Oil #2	-25.4	-30.2	-33.5	-35.2	-36.1
Conventional Oil #3	-25.7	-30.6	-33.8	-35.4	-36.4
Conventional Oil #4	-25.4	-31.2	-36.0	-38.5	-40.2
Conventional Oil #5	-26.9	-32.4	-37.2	-39.7	-41.4
Synthetic Oil #1	-26.4	-32.3	-37.8	-40.7	N/A
Synthetic Oil #2	-29.7	-35.7	-41.1	-43.9	N/A
Synthetic Oil #3	-29.1	-34.8	-40.0	N/A	N/A
Synthetic Oil #4	-28.4	-33.1	-36.4	-38.0	-39.1
Synthetic Oil #5	-24.5	-30.2	-34.7	-37.2	-38.7
Conventional Avg	-26.0	-31.1	-35.3	-37.4	-38.7
Synthetic Avg	-27.6	-33.2	-38.0	N/A	N/A
Conventional Standard Deviation	0.64	0.76	1.41	1.81	2.14
Upper	0.32	0.38	0.71	0.90	1.07
Lower	0.32	0.38	0.71	0.90	1.07
Synthetic Standard Deviation	1.90	1.93	2.32	N/A	N/A
Upper	0.95	0.97	1.16	N/A	N/A
Lower	0.95	0.97	1.16	N/A	N/A

Figure 37: ASTM D5133 Scanning Brookfield Test (reported as the average of two replicate measurements)



ASTM D5133 Gelation Index	Index	Temperature
Conventional Oil #1	<6	N/A
Conventional Oil #2	8.55	-38.1
Conventional Oil #3	7.8	-38.1
Conventional Oil #4	<6	N/A
Conventional Oil #5	<6	N/A
Synthetic Oil #1	<6	N/A
Synthetic Oil #2	<6	N/A
Synthetic Oil #3	<6	N/A
Synthetic Oil #4	6.25	-38.0
Synthetic Oil #5	<6	N/A
Conventional Avg	N/A	N/A
Synthetic Avg	N/A	N/A

Figure 38: ASTM D5133 Gelation Index

	Minutes to Oxidation
Conventional Oil #1	258
Conventional Oil #2	223
Conventional Oil #3	208
Conventional Oil #4	143
Conventional Oil #5	154
Synthetic Oil #1	385
Synthetic Oil #2	140
Synthetic Oil #3	130
Synthetic Oil #4	177
Synthetic Oil #5	236
Conventional Avg	197
Synthetic Avg	213
Conventional Standard Deviation	43
Upper	22
Lower	22
Synthetic Standard Deviation	93
Upper	47
Lower	47

Figure 39: ASTM D4742 minutes to oxygen pressure drop (reported as the average of two replicate measurements)



	Volatiles by mass %
Conventional Oil #1	44
Conventional Oil #2	42
Conventional Oil #3	40
Conventional Oil #4	41
Conventional Oil #5	37
Synthetic Oil #1	32
Synthetic Oil #2	26
Synthetic Oil #3	21
Synthetic Oil #4	22
Synthetic Oil #5	33
Conventional Avg	41
Synthetic Avg	27
Conventional Standard Deviation	2.32
Upper	1.16
Lower	1.16
Synthetic Standard Deviation	4.96
Upper	2.48
Lower	2.48

Figure 40: ASTM D7528 volatiles collected as percent of total mass

	New Kinematic Viscosity (cSt) @ 40°C	Aged Kinematic Viscosity (cSt) @ 40°C
Conventional Oil #1	50.30	85.57
Conventional Oil #2	53.35	94.22
Conventional Oil #3	50.62	82.13
Conventional Oil #4	51.15	81.25
Conventional Oil #5	47.29	81.61
Synthetic Oil #1	48.50	70.88
Synthetic Oil #2	44.69	64.81
Synthetic Oil #3	48.08	62.67
Synthetic Oil #4	46.75	64.50
Synthetic Oil #5	50.15	83.58
Conventional Avg	50.54	84.96
Synthetic Avg	47.63	69.29
Conventional Standard Deviation	1.94	4.88
Upper	0.97	2.44
Lower	0.97	2.44
Synthetic Standard Deviation	1.83	7.66
Upper	0.91	3.83
Lower	0.91	3.83

Figure 41: ASTM D7528 kinematic viscosity changes



	ASTM D5293 CCS Apparent Viscosity (cP)	ASTM D4684 MRV Apparent Viscosity (cP)
Conventional Oil #1	13060	20500
Conventional Oil #2	13660	23000
Conventional Oil #3	15230	18300
Conventional Oil #4	13430	26800
Conventional Oil #5	10240	17100
Synthetic Oil #1	7420	9700
Synthetic Oil #2	8160	8600
Synthetic Oil #3	6590	13600
Synthetic Oil #4	8060	11300
Synthetic Oil #5	12280	27100
Conventional Avg	13124	21140
Synthetic Avg	8502	14060
Conventional Standard Deviation	1621	3473
Upper	810	1736
Lower	810	1736
Synthetic Standard Deviation	1970	6733
Upper	985	3367
Lower	985	3367

Figure 42: ASTM D5293 CCS & ASTM D4684 MRV aged oil viscosity



Figure 43: TEOST MHT & 33C depositor rods



Figure 44: Conventional oil #1 TEOST MHT rod deposits



Figure 45: Conventional oil #1 TEOST 33C rod deposits



Figure 46: Conventional oil #2 TEOST MHT rod deposits



Figure 47: Conventional oil #2 TEOST 33C rod deposits



Figure 48: Conventional oil #3 TEOST MHT rod deposits



Figure 49: Conventional oil #3 TEOST 33C rod deposits



Figure 50: Conventional oil #4 TEOST MHT rod deposits



Figure 51: Conventional oil #4 TEOST 33C rod deposits



Figure 52: Conventional oil #5 TEOST MHT rod deposits



Figure 53: Conventional oil #5 TEOST 33C rod deposits



Figure 54: Synthetic oil #1 TEOST MHT rod deposits



Figure 55: Synthetic oil #1 TEOST 33C rod deposits



Figure 56: Synthetic oil #2 TEOST MHT rod deposits



Figure 57: Synthetic oil #2 TEOST 33C rod deposits



Figure 58: Synthetic oil #3 TEOST MHT rod deposits



Figure 59: Synthetic oil #3 TEOST 33C rod deposits



Figure 60: Synthetic oil #4 TEOST MHT rod deposits



Figure 61: Synthetic oil #4 TEOST 33C rod deposits



Figure 62: Synthetic oil #5 TEOST MHT rod deposits



Figure 63: Synthetic oil #5 TEOST 33C rod deposits