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Physical and Chemical Properties of Engine Oils

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FUELS AND LUBRICANTS REPORT

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PHYSICAL AND CHEMICAL PROPERTIES OF ENGINE OILS

1. INTRODUCTION: This Information Report discusses a number of the physical and chemical properties of new and used engine oils. Where appropriate, standardized methods of test for these properties are listed. This report provides those concerned with the design and maintenance of internal combustion engines with information relative to the terms used to describe engine lubricants.

1.1 In addition to the basic function of lubrication (reducing friction and wear between moving parts), the oil must also (1) provide a seal between cylinder walls, pistons, and piston rings, (2) dissipate heat from critical areas, (3) neutralize acids formed during combustion, (4) disperse contaminants to prevent accumulation of deposits, (5) protect internal engine parts from rust and corrosion, and (6) control oxidation to prevent excessive viscosity changes. In performing these functions, the oil can be subjected to extreme temperature variations, ranging from below -40°C during shutdown periods in winter to 200°C or higher while the engine is operating. In certain engine configurations, such as turbocharged, hot soak temperatures after shutdown can exceed 350°C in areas where engine oil is present. A wide variety of contaminants may be introduced into the crankcase by way of blowby or fresh-air ventilation. While some contaminants are inert, others are chemically active or can catalyze chemical reactions, some of which may be undesirable.

2. GENERAL DESCRIPTION OF ENGINE OIL COMPONENTS: Fully formulated lubricants consist of (1) base stocks and (2) the additives that are necessary to produce the required performance in the finished product. Base stocks are of two general types--petroleum and synthetic. The additives used to enhance performance consist of many types of chemicals. These engine oil components will be described in the following sections.

2.1 Base Stocks:

2.1.1 Petroleum Base Stocks: Crude petroleum oil as it comes from the ground is a mixture of literally hundreds of hydrocarbon molecules of three basic types--paraffinic, naphthenic, and aromatic. Crude oils are classified according to the predominant type of hydrocarbon molecules they contain.

The first step in refining crude oil into useful products is the separation according to boiling range by atmospheric and/or vacuum distillation. The various fractions are then further processed into gaseous products, gasoline, diesel and burner fuels, lubricating oil stock, asphalt, etc. The lubricating oil stock is vacuum distilled, providing a series of base stocks of various levels of volatility and viscosity. Generally speaking, the viscosity for the distillate (neutral) fractions ranges from 11-15- cSt at 40°C, while the viscosity for the residual (bright stock) fractions ranges from 140-1200 cSt at 40°C. These fractions generally require further treatment to make them suitable for use in engine oils.

Historically, a nomenclature has evolved to identify neutral and bright stock fractions by viscosity. neutral fractions are referred to by their nominal viscosity at 100°F in Saybolt Universal Seconds (SUS). For example, a 150 neutral is a distillate fraction with a nominal viscosity at 150 SUS at 100°F (29 cSt at 40°C).

In similar fashion, bright stocks are referred to by their nominal SUS viscosity at 210°F. For example, 150 bright stock is a residual fraction with a nominal viscosity of 150 SUS at 210°F (30.6 cSt at 100°C).

The as-distilled base stock fractions may contain unstable components, such as nitrogen and sulfur-containing compounds, metal-containing compounds, and aromatic hydrocarbons of various structures. Many of these compounds can adversely affect the stability and performance properties of base stocks and the efficiency of various additives to enhance these properties for engine oil applications. These compounds are usually removed through extraction processes, using solvents such as phenol, furfural, or n-methyl pyrrolidone, or are modified by hydrotreating or hydrocracking.

Waxy materials present in the base stock fractions may crystallize and agglomerate or congeal at low temperatures and thereby impede low-temperature flow. These materials may be removed by solvent dewaxing processes employing solvents such as methyl-ethyl ketone or propane, or by catalytic dewaxing.

These extraction and modification processes can be carried out either before or after final distillation into viscosity fractions. The choice depends on the processes employed.

The physical and chemical properties of the finished base stocks will not be solely a function of crude source, but also will be dependent on the processes employed and the degree of refining severity employed. The engine oil compounder blends the various components to achieve the viscometric properties required and adds additive agents to achieve the performance levels desired for a given application.

2.1.2 Re-Refined Petroleum Base Stocks: Used lubricating oils have been subjected to recycling processes for over 65 years. Recently, legislation and technical improvements in recycling processes have increased the interest in re-refined base stocks. Sufficient evidence is available to indicate that, providing proper techniques and quality controls are employed, re-refined petroleum base stocks can be successfully used in engine oil applications.

2.1.3 Synthetic Base Stocks: Certain chemical compounds have been found to be suitable as base stocks for engine oil. These are referred to as synthetic lubricants and are defined as having been produced by chemical synthesis. These are manufactured by organic reactions such as alkylation, condensation, esterification, polymerization, etc. Starting materials may be one or more relatively pure organic compounds. Generally of simple composition, these compounds are obtained by chemically processing fractions from petroleum, natural gas, vegetable, or animal oil bases. When vegetable or animal oil base lubricants are derived from natural non-petroleum sources rather than from synthesis, they are not considered synthetic lubricants unless the naturally occurring product has been chemically changed.

Classes of chemical compounds that might be used as synthetic base stocks after processing are shown in Table 1 along with distinct generic identification of the resulting fluids.

A synthetic lubricant base stock may consist of any of the fluids shown in Table 1, or a mixture of compatible base fluids. This blending is usually practiced to enhance physical properties.

Some synthetic base stocks are compatible with petroleum base stocks, and the two types may be blended to obtain desired physical and chemical properties. Such combinations are referred to as "partial synthetic base stocks."

Some synthetic base stocks are not compatible with either other synthetics, or with petroleum base stocks. Therefore, lubricants containing synthetic base stocks shoud not be indiscriminately mixed.

The additive agents necessary in petroleum base stocks, synthetic base stocks, or partial synthetic stocks intended for engine oils are also synthesized materials. However, even though these materials are synthesized, they should be referred to as additives and not included in the base stock description.

2.2 Additive Agents: A lubricant additive agent is defined as a material designed to impart or enhance the performance properties of the base stock. These additive agents are used to concentration levels ranging from several parts per million to greater than 10 volume percent. Generally, they are materials that have been chemically synthesized to supply the desired performance features, and they frequently contain an oil-solubilizing hydrocarbon moiety as part of the molecule. Some additive agents are naturally occurring materials that have undergone only minor modifications to obtain the desired property.

Additives can carry out their task of enhancing or imparting new oil properties in one of three ways--protection of engine surfaces, modification of oil properties, protection of the base stock. Engine protectors include anti-wear agents, extreme pressure (EP) agents, anti-rust agents, corrosion inhibitors, detergents, dispersants, and friction modifiers. Oil modifiers include pour point depressants, seal swell agents, and viscosity index (VI) improvers. Base stock protectors include anti-foam agents, antioxidants, and metal deactivators. Some additives possess multifunctional properties.

Additive combinations contribute unique performance features which are required to satisfy the lubrication needs of today's engines, oil change intervals, and service conditions. However, some additive components may either enhance or interfere with the function of another additive component. Therefore, the finished engine oil must be formulated to achieve optimum performance through the combined properties of both the base stock and the additives.

3. PHYSICAL AND CHEMICAL PROPERTIES:

A tabulation of the physical and chemical properties of an oil can assist the user and the oil refiner in defining a consistently uniform product. These properties are used to establish acceptable levels of additive components in finished oils. However, there is no direct correlation between oil composition and oil performance in the engine. Oil compounder-blenders can relate physical and chemical properties to performance for their oils only when engine and/or field tests have been successfully completed and directly related to a specific combination of base stock and additive. Some of these performance characteristics of engine oils are discussed in SAE J183 and SAE J1423.

While the physical and chemical properties of an oil do not generally define oil performance, these individual properties are meaningful and are related to the oil's ability to fulfill its function as a lubricant. The following sections discuss these properties and their lubrication function.

TABLE 1--CLASSIFICATION OF SYNTHETIC BASE FLUIDS

Class	Synthetic Fluids (Examples)
Synthetic Hydrocarbons	
Alkylated aromatics	Alkylbenzenes
Polyalphaolefins	Polyalphaolefins (hydrogenated)
Polybutenes	Polybutenes
Organic Esters	
Dibasic acid esters (Diesters)	Adipates, azelates, dodecanedioates
Polyol esters	Neopentyl or hindered esters
Polyesters	Dimer acid esters
Others	
Halogenated hydrocarbons	Chlorofluorocarbon polymers, fluoroesters, fluorethers
Phosphate esters	Phosphate esters of isopropyl phenol and cresylic acids
Polyglycols	Polyalkylene glycols
Polyphenyl ethers	Meta bis (m-Phenoxyphenyl) benzene
Silicate esters	Disiloxane derivatives
Silicones	Phenyl, methyl and alkylmethyl silicones

3.1 VISCOSITY:

3.1.1 Definition: Viscosity is one of the most important and most evident properties of an oil, and is defined as its resistance to flow, given by the following expression:

$$\text{Viscosity} = \frac{\text{Force/Area}}{\text{Velocity/Film Thickness}} \qquad \frac{\text{Shear Stress}}{\text{Shear Rate}}$$

If the viscosity is independent of the shear stress or shear rate, the oil is said to be "Newtonian" in nature. Most single grade oils are in this category.

3.1.2 VISCOSITY INDEX: Viscosity changes rapidly with temperature. For oils, the relationship between viscosity and temperature is given by the following empirical relationship:

$$\log\log(\text{viscosity} + 0.7) = A + B \log(\text{absolute temperature})$$

A and B are constants, specific for each oil

This relationship, known as the Walther equation, forms the basis for special viscosity-temperature charts published in ASTM D341, Viscosity-Temperature Charts for Liquid Petroleum Products. These charts permit the plotting of viscosity-temperature data as straight lines over the temperature range in which the oils are homogeneous liquids. The slope of these lines is a measure of the change in viscosity with temperature; is dependent on the chemical composition of the oil; and is described by an empirical relationship called viscosity index (VI). The higher the viscosity index, the smaller the change in viscosity with temperature (slope). ASTM D2270, Calculating Viscosity Index from Kinematic Viscosity at 40 and 100°C is used to determine VI values. ASTM DS39b, Viscosity Index Tables for Celsius Temperatures, is based on ASTM D2270 and allows for more convenient determination of VI.

For engine oils, a small change in viscosity with temperature (high viscosity index) is desirable to provide a wide range in operating temperature over which a given oil will provide satisfactory lubrication. At low temperatures, a relatively low-viscosity oil is desirable to permit adequate cranking speed during starting, and then adequate flow to the oil pump and the entire engine oiling system after starting.

At high temperatures in a running engine, the oil viscosity must be high enough to maintain adequate film thickness between rotating or rubbing parts to minimize wear. Using a higher-viscosity oil generally reduces oil consumption and blowby, but increases friction associated with oil film shearing.

3.1.3 Viscosity Index Improvers: To extend the upper temperature limit at which an oil will still provide satisfactory lubrication, polymeric additives, called viscosity index (VI) improvers are widely used. At low temperatures, properly selected VI improvers have little effect on viscosity and thus do not adversely affect starting and oil flow. As the oil temperature increases, the viscosity of the oil containing a VI improver decreases more slowly than the same oil without a VI improver, thus increasing the viscosity index. As a result, an adequate oil film thickness is provided at a higher temperature than if no VI improver is used.

Generally, oils containing a VI improver exhibit a decrease in viscosity as the shear rate is increased, with the base stock viscosity being the lower limit in extreme cases. Such oils are called "Non-Newtonian." This reversible decrease in viscosity due to shear is called "temporary shear loss." Some VI improvers can be permanently, partially altered by shearing, causing a non-reversible reduction in viscosity called "permanent shear loss." The magnitude of these temporary and permanent losses is dependent on the type and molecular weight of the VI improver used, as well as the actual service conditions.

In addition to the VI improver effects, oil viscosity is influenced by fuel dilution, oil oxidation, volatilization, and contamination with combustion by-products. To be considered pertinent, the viscosity of an engine oil must be determined using test procedures and operating conditions which have been shown to correlate with results observed in engines.

3.1.4 Viscosity Measurement: The current SAE J300 viscosity classification system classifies oils into categories according to their viscosities measured at a low shear rate and high temperature (100°C), and at both low and high shear rates at low temperatures (-5 to -35°C).

Low-shear-rate viscosity is measured using ASTM D445, Kinematic Viscosity of Transparent and Opaque Liquids, and is reported in centistokes. Viscosity is measured most commonly at 100°C, and also at 40°C if viscosity index is to be determined.

At low temperature, the high-shear-rate viscosity is measured by a multi-temperature version of ASTM D2602, Apparent Viscosity of Engine Oils at Low Temperature using the Cold Cranking Simulator, which is described in the Appendix to SAE J300. Such results have been correlated with low-temperature cranking and starting performance.

The low-temperature, low-shear-rate viscosity is measured using a Mini-Rotary Viscometer (MRV) by ASTM D3829, Predicting the Borderline Pumping Temperature of Engine Oil. This method has been shown to correlate with the flow of oil to the oil pump and throughout the engine oiling system during cold-start operation in most, but not all applications. Recent field experience indicates the MRV method may not insure satisfactory low-temperature fluidity for all oils in all types of engines. As a result, a modification of the stable pour point test (Federal Test Method Standard No. 791B, Method 203) has been added temporarily as Appendix B to SAE J300 while modifications to the MRV method are being evaluated. The modified Federal Test Method subjects the oil to several days of low-temperature cycling and subsequent pour point measurements. It has been shown that this test does predict the ability of an oil to flow to the oil pump inlet after the engine is started.

Several experimental methods are being evaluated for measuring oil viscosity at very high shear rates, and most commonly at higher temperatures (100--150°C). These methods are intended primarily to simulate operating conditions occurring in engine bearings.

3.2 Other Tests Pertinent to New and Used Oils:

3.2.1 Cloud Point and Pour Point: The cloud point of a moisture-free oil is defined as the temperature at which a cloud or haze appears in the lower portion of the test oil when tested (i.e., cooled) by ASTM D2500, Cloud Point of Petroleum Oils. The haze indicates the presence of some insoluble fractions, such as wax, at the temperature noted. In most applications, this haze will have little practical significance.

The pour point of an oil is defined as the lowest temperature at which the oil can be poured when tested by ASTM Method D97, Pour Point of Petroleum Oils. The pour point can be directly related to whether or not the oil can be poured from a container at low temperatures. The pour point has little relationship to the rate at which oil will flow to the suction side of the oil pump. More precise and correlatable viscometric methods, such as MRV, have been developed which better predict the ability of an oil to flow to the oil pump and throughout the system at low temperature. In actual practice, the oil in the crankcase will be a mixture of oil and small amounts of fuel fractions, the composition depending on several factors. (See paragraph on Fuel Dilution.)

Some oils display an increase in pour point when exposed to repeated cycling at temperatures below and above the pour point. Federal Test Method, Standard No. 791B, Method 203, Stable Pour Point of Engine Oils, describes a procedure for evaluating the tendency of the pour point to so increase.

The cloud and pour points of engine oils do not directly relate to the cranking or starting of engines but may be indicative of the engine's ability to pump the lubricant to vital parts after starting has occurred.

3.2.2 Flash Point and Fire Point: The flash point of a petroleum product is the lowest temperature to which the product must be heated under specific conditions to give off sufficient vapor to form a mixture with air that can be ignitied momentarily by a specified flame.

Fire point is the lowest temperature to which a product must be heated under prescribed conditions to burn continuously when the mixture of vapor and air is ignited by a specified flame.

Flash and fire points are significant from the viewpoint of safety and should be related to the temperatures to which petroleum products will be subjected in storage, transportation, and use. Normally, engine oils will present no hazards in this respect. For new engine oil, relatively low flash and fire points are indications of volatile oil components and thus may be related to oil consumption at high temperature. The minimum flash point that can be tolerated must be determined in each application. Flash point is also used to indicate contamination of used oil by a volatile product such as gasoline or diesel fuel. Methods of obtaining this type of information are ASTM D56, Flash Point by Tag Closed Tester, ASTM D92, Flash and Fire Points by Cleveland Open Cup; ASTM D93, Flash Point by Pensky-Martens closed Tester; ASTM D1310, Flash Point by Tag Open Cup Tester; and ASTM D3828, Flash Point by Setaflash Tester. ASTM D92 is the preferred method for unused engine oils.

3.2.3 Distillation Data: The volatility characteristics of engine oils can be defined by distillation procedures. Because engine oils comprise relatively high boiling point fractions which would thermally crack in an atmospheric distillation, a reduced-pressure (vacuum) distillation method, i.e. ASTM D1160, Distillation of Petroleum Products at Reduced Pressure must be used. ASTM D2887, Boiling Range Distribution of Petroleum Fractions by Gas Chromatography which gives boiling-range distribution data by gas chromatography, is gaining acceptance and is increasingly used instead of ASTM D1160. Correlations between performance characteristics, such as oil consumption, and the volatility characteristics of the oil in use must be developed with actual engine tests.

3.2.4 Alkalinity and Acidity: The alkalinity or acidity characteristics of petroleum products are measured by one of several standardized methods. Methods currently used include ASTM D664. Neutralization Value by Potentiometric Titration: ASTM D974, Neutralization Value by Color-Indicator Titration; ASTM D2896, Total Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration. By ASTM D664, engine oils may have both total acid and total base numbers, depending on the nature of the additives used. Certain salts commonly used as engine oil additives, such as zinc organodithiophosphate, will undergo exchange reactions with the standard titrant KOH and thereby produce false acid values. Changes in alkalinity or acidity with use give some indication of the nature of the changes taking place in the engine oil. For example, a reduction in total base number can be ascribed to depletion of additive components. An increase in total acid number may be ascribed to oxidation and/or contamination by products of combustion. Total base number of a new oil is an indication of an oil's abilty to resist the deleterious effects of using high-sulfur diesel fuels. different titration methods may yield different total base numbers on the same oil. Therefore, caution is necessary in applying total base number--oil performance relationships. For diesel engines, relationships have been published between total base number of the new oil, change in total base number during service, fuel sulfur content, and desired engine oil drain interval. The change in total base number in service can be used under certain conditions to evaluate engine oil change interval practices. Both the ASTM D2896 and ASTM D664 methods are commonly used in these instances.

3.2.5 Carbon Residue: The base-stock components of engine oils are mixtures of many compounds that differ widely in their physical and chemical properties. Some vaporize at atmospheric pressure without leaving an appreciable residue. When destructively distilled, the non-volatile compounds may leave a carbonaceous material known as carbon residue. Two methods used for evaluating base stocks in this respect are ASTM D189, Conradson Carbon Residue; and ASTM D524, Ramsbottom Carbon Residue of Petroleum Products. Engine oils containing ash-forming constituents, such as the additives commonly used in formulating oils, may have misleading high carbon residues by either method. Carbon residue has little value as a guide for predicting deposit-forming tendencies in engines.

3.2.6 Ash Content: The amount of ash formed from burning engine oils may be obtained by ASTM Method D482, Ash from Petroleum Products. However, ASTM Method D874, Sulfated Ash from Lubricating Oils and Additives, is now the method most commonly used because it is a more accurate measure of ash-forming constitutents. When tested by ASTM D482, some metals are partially volatilized and lost, giving erroneously low values. The ash produced from burning new engine oils is principally related to the quantity of ash-producing additive contained therein. In addition to the additive contribution, the ash produced by used oils will also be a function of the amount of contaminants, such as lead compounds present in the engine oil if the engine is operated on a leaded gasoline. High values can also result from other contaminants, such as dirt, iron oxide, wear metals, and corrosion products. The ash from an oil may contribute to deposits on combustion chamber surfaces, spark plugs, and exhaust valves which can influence the combustion characteristics and exhaust valve sealing of an engine. However, the mechanism for the buildup of deposits in these areas is very complex and depends on many variables in addition to the ash content of the oil.

3.2.7 Compatibility: Engine oils are expected to be homogeneous and completely miscible with all types of engine oils with which they might be mixed in service. When oils are mixed in any proportion, there should be no evidence of separation either of the components or of the oils when the mixed oils are heated to a temperature as high as 225°C and cooled to a temperature as low as the pour point of the mixture. The homogeneity and miscibility test currently used to evaluate automotive engine oils is Federal Test Method Standard No. 791B, Method 3470, Homogeneity and Miscibility of Engine Oils.

3.2.8 Foaming: Anti-foam quality is a performance characteristic that can be and has been evaluated by a specially developed engine test. Oils with poor anti-foaming characteristics have been shown to result in noisy hydraulic lifter operation and premature bearing wear. A bench test for determining this quality is ASTM D892, Foaming Characteristics of Lubricating Oils.

3.2.9 Gravity, Color, Odor: Gravity (density) may be used to characterize the basic hydrocarbon type of the base stocks. Gravity and color are factors generally associated with the quality control of manufactured products rather than with performance characteristics. ASTM D287, API Gravity of Crude Petroleum Products (Hydrometer Method); ASTM D1298, Density, Relative Density of API Gravity of Crude Petroleum and Lipkin Bicapillary Pycnometer, may be used to determine the gravity and density characteristics of oil. The color of engine oils may be specified by using ASTM D156, Savbolt Color of Petroleum Products; or more commonly ASTM D1500, ASTM Color of Petroleum Products (ASTM Color Scale).

It is expected that engine oils will not produce offensive odors due to the nature of the base stocks or the additive agents with which the oil is compounded; nor should offensive odors be generated during use of prolonged storage of an engine oil. There are no standardized odor tests suitable for engine oils.

3.2.10 Elemental Analysis: Elemental analysis of engine oils is often used as means of quality control. Instrumental analytical techniques, such as emission spectroscopy, atomic absorption spectroscopy, X-ray emission spectroscopy, etc., are useful in this respect. Similar analysis of used oils will provide information relative to the changes in the elemental content of the engine oil. These data can also give a measure of contamination by materials such as ingested dirt, coolant, or products of combustion, especially with engines using leaded gasoline. They also can provide information relative to the extent of wear in the engine. Concentrations of the following elements are commonly determined.

1. Additive elements such as barium, sodium, calcium, zinc, copper, molybdenum, phosphorus, sulfur, magnesium, silicon, nitrogen, and boron.
2. Contaminants such as lead, silicon, etc.
3. Wear metals such as iron, copper, lead, tin, aluminum, etc.

3.2.11 Infrared Analysis: Infrared spectrophotometry techniques are valuable in determining the hydrocarbon structures found in base stocks and additives. Changes in these structures can be determined by comparing results of analyses of new and used oils. In used oils, it is also possible to measure degradation due to oxidation and/or nitration, and to identify the presence of hydrocarbon contaminants, water, antifreeze, and similar materials.

3.3 Tests Pertinent to Used Oils:

3.3.1 Used Oil Properties: The analysis of a used engine oil may be of value in establishing the condition of the oil with respect to its useful life, and may be helpful in estimating the condition of the engine. To be of most value, used oil analyses must be taken periodically during the drain interval and a trend line compared with similar analyses of the new oil. The conditions of usage also must be considered in evaluating used oil analyses.

3.3.2 Insoluble Content: Insoluble materials found in both new and used engine oils may be determined using ASTM D91, Precipitation Number of Lubricating Oils, or the more frequently used ASTM D893, Insolubles in Used Lubricating Oils. Use of these methods permits an evaluation of the contaminant content and buildup of insoluble materials through oxidation, etc. However, the results must be judged with care, because minor changes in the analytical procedure can produce different results. For example, the age and purity of the coagulant solutions specified in ASTM D893 can effect the results obtained.

With modern highly dispersant oils, the determination of insolubles becomes increasingly difficult. Use of coagulant in ASTM D893 may be required to make accurate determinations. ASTM D4055, Pentane Insolubles by Membrane Filtration, measures all insolubles greater in size than 0.8 μm. However, current precision is poor, and ASTM Subcommittee D02.08 is planning additional cooperative studies to improve precision.

3.3.3 Coolant (Moisture) Content: Small quantities of water will frequently be found in used engine oil as contamination from products of combustion, leakage from the cooling system, or condensation from atmospheric moisture. ASTM D95, Water in Petroleum Products and Bituminous Materials by Distillation, defines a process for determining the water content of used oil. For a qualitative determination, a commonly used simple test is to heat a drop of oil on aluminum foil. A snapping or crackling sound indicates free or suspended water in the oil. Cooling system leakage can be suspected when water is found in the oil on cool-down after operation for several hours under high-temperature conditions, such as interstate highway driving. The presence of glycol can be a more definite indication of leakage. Glycol is detected best by distillation of the aqueous material, followed by chemical analyses or infrared spectrophotometry on the distillate. A less-complicated procedure, which is adaptable to field kit use and gives positive, trace, or negative results is ASTM D2982, Detecting Glycol-Base Antifreeze in Used Lubricating Oils. Some additives commonly used in formulating crankcase oils contain glycol at a level that will give a positive result. If the new oil gives a positive result, the test in its simple form will be inadequate for detecting coolant glycol in used oils and the oil supplier should be consulted for advice.

3.3.4 Fuel Dilution: Engines in good mechanical condition and operated at normal temperatures will usually show a small amount of fuel dilution in the used engine oil. Low operating temperatures, rich mixtures of fuel and air, and low ambient temperatures will promote fuel dilution, particularly if the engine is in poor mechanical condition or crankcase ventilation is inadequate. High dilution reduces oil viscosity and pour point. The presence of such dilution can cause accelerated wear and promote the formation of sludge, varnish, and rust. The presence of a high dilution level may indicate a need for engine maintenance. Dilution may be determined by ASTM D322, Dilution of Gasoline-Engine Crankcase Oils or by ASTM D3607, Removing Volatile Components From Used Engine Oils by Stripping. This latter method also produces a dilution-free sample for subsequent analyses. These methods are useful only with gasoline engines since the distillation range for diesel fuels in many cases overlaps that for the engine oils used in diesel engines. Procedures applicable to both diesel and gasoline engine oils are ASTM D3524, Diesel Fuel Diluent in Used Diesel Engine Oil by Gas Chromatography, and ASTM D3525, Gasoline Diluent in Used Gasoline Engine Oils by Gas Chromatography. Flash point may also be used to approximate fuel dilution (see paragraph 3.2.2).

4. PERFORMANCE CHARACTERISTICS:

In the operation of an internal combustion engine, engine oils are expected to lubricate, cool, seal, maintain cleanliness, and protect against wear and corrosion. An oil's ability to perform these functions depends on the combined effectiveness of its base stock and additives. Although the physical and chemical tests described in the preceding sections can be used for quality control to insure manufacturing uniformity, they are not effective for accurately evaluting performance characteristics. Only actual performance evaluations in special laboratory engines and in field tests will define the capabilities of an engine oil.

Laboratory diesel and gasoline engine tests that have become industry recognized for evaluating engine oils are described in SAE J304. SAE J183 and SAE J1423 classify oils according to performance criteria based on results from engine and field tests. combustion chamber deposit control and oil consumption characteristics of engine oils are not completely defined by the test procedures outlined in SAE J304. Where these properties are of interest, specific tests must be developed using the equipment and conditions most relevant to a given situation.

Although the laboratory engine tests are necessary and valuable aids to engine-oil development and evaluation, they have limitations. In many instances, the final proof-of-performance is established by field tests of the oil in actual vehicle service. While no industry standardized field test methods are currently available, the SAE Lubricants Review Institute has furnished some guidelines in their procedures manual. The most meaningful results on a given oil are obtained by evaluation in the type of service typical of the use for which it is designed.

5. CONCLUSIONS: The lubrication requirements for modern engines are extremely complex. Current engine oils are the result of extensive research and development aimed at meeting these requirements. It is not the objective of this information report to treat the subject in detail. Rather, the purpose of this document is to define very briefly the terms frequently encountered in discussions of engine oils and engine-oil performance for those technical people not directly associated with lubricants and lubricant development. For more detailed information on these matters, the reader is referred to the technical services offered by lubricant suppliers, lubricant additive suppliers, the lubricants group of engine manufacturers, and pertinent literature available through the Society of Automotive Engineers, American Society of Lubrication Engineers, American Society of Mechanical Engineers, American Petroleum Institute, American Society for Testing and Materials, etc. Information directly related to this report may be found in the following publications:

1. "Significance of ASTM Tests for Petroleum Products." ASTM Special Technical Publication 7-C, 1977.

2. "The Physical Properties of Lubricants." American Society of Lubrication Engineers, 1951.

3. C. W. Georgi, "Motor Oils and Engine Lubrication." New York: Reinhold Publishing Corp., 1950.

4. William A. Gruse, "Motor Oils, Performance and Evaluation." New York: Reinhold Publishing Corp., 1967.

5. A. Schilling, "Automotive Engine Lubrication." Broseley, England: Scientific Publications (G.B.) Ltd., 1972.

6. R. C. Gunderson and A. W. Hart, "Synthetic Lubricants." New York: Reinhold Publishing Corp., 1962.

7. ASTM STP 315H, "ASTM Multicylinder Test Sequences for Evaluating Automotive Engine Oils."

8. ASTM STP 509A, "ASTM Single Cylinder Engine Tests for Evaluating the Performance of Crankcase Lubricants."

9. M. Campen, D. Kendrick, and A. Markin, "Growing Use of Synlubes." Hydrocarbon Processing, February 1982.

10. G. J. Schilling and G. S. Bright, "Fuel and Lubricant Additives--II. Lubricant Additives." Lubrication Vol. 63, No. 2, 1977.