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HYDROCARBON-BASED HYDRAULIC FLUID PROPERTIES

FOREWORD

This document discusses in qualitative terms the properties of a fluid relevant to use for aerospace hydraulic systems. Further, it discusses the effect of the fluid properties on the design of aerospace hydraulic systems and components. AIR1362 and AIR1116 also are concerned with fluid properties, but contain specific data on current fluids.

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1. SCOPE:

This document discusses the relative merits of the properties of hydrocarbon-based hydraulic fluid in relation to the fluid formulation, aerospace hydraulic system design and the related materials compatibility. In some cases, numerical limits are suggested, but, in general, the effect of a property is noted qualitatively.

1. (Continued):

The properties of the fluid must be considered in the design of a hydraulic system, but it is possible to design a system to be less sensitive, or more robust, to a particular fluid property. For this reason, the property of the hydraulic fluid must be weighed for each individual hydraulic system, taking into account the system's basic design, function and environment, as well as the fluid toxicity and disposal issues. Besides the hydraulic system itself, ground handling and servicing needs of the system must also be considered.

The only absolute characteristic of a hydraulic fluid is that it be a liquid throughout the range of use. All other fluid properties must be considered in hydraulic system design. See MIL-HDBK-118.

Phosphate ester-based hydraulic fluids, not covered in this document, have some unique properties which need to be considered separately. See AS1241 for information on phosphate ester-based hydraulic fluids.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 ASTM Publications: Available from ASTM, 1916 Race Street, Philadelphia PA 19103-1187.

ASTM D 92	Cleveland Open Cup Flash and Fire Points
ASTM D 97	Pour Point of Petroleum Products
ASTM D 445	Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)
ASTM E 659	Autoignition Temperature of Liquid Chemicals
ASTM D 892	Foaming Characteristics of Lubricating Oils
ASTM D 941	Density and Specific Gravity of Liquids (by Pycnometer)
ASTM D 972	Evaporation Loss of Lubricating Greases and Oils
ASTM D 1744	Water in Liquid Petroleum Products by Karl Fischer Reagent
ASTM D 2603	Shear Stability
ASTM D 2624	Electrical Conductivity of Aviation and Distillate Fuels
ASTM D 2717	Thermal Conductivity of Liquids
ASTM D 2766	Specific Heat of Solids and Liquids
ASTM D 2780	Solubility of Fixed Gases in Liquids (Ostwald Coefficient)
ASTM D 2879	Vapor Pressure, Isoteniscope
ASTM D 4172	Wear Prevention Characteristics of Lubricating Fluids (Four-Ball Method)
ASTM D 4308	Electrical Conductivity of Liquid Hydrocarbons by Precision Meter

2.1.1 (Continued):

ASTM D 4636 Corrosiveness and Oxidation Stability of Hydraulic Oils, Aircraft Turbine Engine Lubricants and Other Highly Refined Oils
ASTM D 5306 Linear Flame Propagation Rate of Lubricating Oils and Hydraulic Fluids
ASTM F 313 Insoluble Contamination of Hydraulic Fluids by Gravimetric Analysis

2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-HDBK-118 Design Guide for Military Application of Hydraulic Fluids
MIL-HDBK-200 Quality Surveillance for Fuels and Lubricants
FED STD 313 Material Safety Data Sheets, Preparation and Submission of
FED STD 791 Lubricants, Liquid Fuels, and Related Products; Methods of Testing
Method 3458 Low Temperature Stability
Method 3603 and 3604 Rubber Swelling

2.1.3 Related Publications: The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

2.1.3.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale PA 15096-0001.

AIR810 Degradation Limits of Hydrocarbon-Based Hydraulic Fluids, MIL-H-5606, MIL-H-6083, MIL-H-83282, and MIL-H-46170 Used in Hydraulic Test Stands
AIR974 Long-Term Storage of Missile Hydraulic Systems
ARP1083 Airborne Hydraulic and Control System Survivability for Military Aircraft
AIR1116 Fluid Properties
AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
AIR1362 Physical Properties of Hydraulic Fluid
AIR1922 System Integration Factors That Affect Hydraulic Pump Life
AIR4002 8000 psi Hydraulic Systems, Experience and Test Results
AIR4713 Aerospace - Chlorinated Solvent Contamination of MIL-H-5606/MIL-H-83282 Vehicle Hydraulic Systems

3. HYDRAULIC FLUID PROPERTIES:

A commonly used method is listed below, although other acceptable methods may be used in many cases. Care must be used comparing data from the different methods for different fluids.

3.1 General:

The sequence of fluid property listing has no bearing on the relative importance. Moreover, strength in one characteristic can often compensate for weakness in another.

3.2 Viscosity:

Viscosity describes the resistance of a fluid to the relative motion of its molecules when a shear force is applied. See ASTM D 445. It is one of the most important properties defining the fluid's usable temperature range. Viscosity/temperature curves should be provided in the fluid descriptive data. The viscosity temperature relationship is referred to as the viscosity index. A fluid thickened with a viscosity index improver, such as polymethylmethacrylate, generally has a good viscosity index or small changes in viscosity with temperature changes. The disadvantage of viscosity index improved fluids is they suffer permanent viscosity loss under shear strain conditions as experienced in hydraulic systems. The actual viscosity under shear conditions is somewhere between the measured viscosity and the viscosity of the base oil. This behavior, viscosity loss under shear conditions, is called shear instability.

If a fluid is not thickened with a viscosity index improver it is more likely to be shear stable and does not have a permanent viscosity loss in applications. It is therefore important to know if a fluid is shear stable or not.

Generally, kinematic viscosity data is provided for a fluid [centistoke (cSt)] which must be multiplied by the density of the fluid at that temperature to yield absolute viscosity [centipoise (cP)]. Absolute viscosity is the parameter required for pressure drop equations in a hydraulic system. It is also desirable that pressure-viscosity curves at various temperatures be furnished.

3.2.1 Maximum Viscosity: The maximum viscosity describes the minimum usable temperature of a fluid. For a system, two levels of maximum viscosity are important in establishing the usability of a fluid and the design criteria to be used. These two maximum viscosities are first, the maximum starting viscosity, and second, the maximum operating viscosity. The generally accepted maximum starting viscosity level is 2125 cP or 2500 cSt for a hydrocarbon oil. This viscosity can be tolerated only briefly and will likely cause filters to go into bypass mode. While fluids with higher viscosities can be pumped by using larger pumps and increased diameter line sizes, the significant weight penalty associated with those design changes are usually unacceptable for aerospace applications. Therefore, the true maximum viscosity level, ignoring the aforementioned weight penalties, is several times this 2125 cP value.

The pump, system friction, engine and/or aerodynamic heating rapidly increase the fluid temperature once a system has been started. This increase in temperature rapidly decreases the viscosity to the maximum operating viscosity level, the viscosity at which full system operation can be expected. This viscosity level is one of the basic system design criteria and is on the order of 425 cP or 500 cSt for a hydrocarbon oil. Acceptable low temperature performance is, however, designated in the specification of an aircraft or by analysis and may correspond to a higher or lower viscosity. The wording may be that a system operates without detrimental effect at a specific temperature and meets full performance at another specific temperature. A higher maximum operating viscosity increases the system design problems, whereas a lower operating viscosity decreases them and results in system weight saving.

3.2.2 Minimum Viscosity: As with maximum viscosity, two levels of minimum viscosity are important in establishing usability of a fluid and the design criteria to be used. The first level of 1.7 cP or 2 cSt for a hydrocarbon oil is generally accepted as a tolerable minimum for efficient pump operation. The second level viscosity, as low as 0.43 cP, or 0.5 cSt for a hydrocarbon oil (or less), is the minimum viscosity of the fluid that can be pumped. With some types of pumps, the efficiency will be reduced at these very low viscosities. Extremely low viscosity may cause reduced lubricity, with resulting reduced component life. Low viscosity increases internal and external leakage in slide, servo and similar valves and in actuator packings causing reduced system efficiency and design penalties.

3.3 Pour Point:

Normally this property is of no importance to the hydraulic system or component designer. It does, however, indicate an absolute low temperature limit fluidity of the fluid and it is advisable to operate at least 10 °C above a fluid pour point. See ASTM D 97.

3.4 Low Temperature Stability:

This is not generally a design consideration, but describes a fluid's resistance to separation, gelling, solidification, decomposition and other forms of degradation during storage at extremely low temperature. Unless the effects of low temperature reverse themselves when the temperature is increased, a fluid is either unusable or will require special storage and handling. This irreversibility also affects the usability of the fluid in an aerospace vehicle resulting in undesirable ground handling requirements. See FED-STD-791 Method 3458.

3.5 Storage Stability:

This property is of considerable importance in field logistics. A fluid which requires special storage procedures and storage degradation checks is undesirable. Storage life guidelines are provided in MIL-HDBK-200.

3.6 Lubricity:

Most, if not all, hydraulic fluids consist of a base fluid and performance improving additives, including a lubricity additive. The presence of an additive, the type of additive and the concentration all significantly affect the results of lubricity tests and system performances. Care must be taken in comparing test results to use the same test conditions and to compare formulated fluids to formulated fluids and base stocks to base stocks. The four ball wear test is valuable for preliminary screening of a fluid. It is quick, low cost, uses small fluid samples and has satisfactory repeatability and reproducibility. See ASTM D 4172. The piston pump wear test is a much more reliable indication of the hydraulic system usability of a fluid. It is generally performed at the maximum use bulk oil temperature of the fluid or of the pump. For specification purposes, it is desirable to run the test on a pump which is representative of the general type of pumps expected to be used with the fluid. Good indication of lubricity in one pump will not mean similar indication in pumps of different manufacturers. Lubricity is not only necessary for the pumps, but also for the slide, servo and similar valves and for the effect on packing life. However, in general, a fluid which has good lubricity in a piston pump will also have the necessary lubricity for such valves.

3.6 (Continued):

In the development of new fluids, poor pump lubricity does not necessarily indicate an unusable fluid, but may rather indicate need for further pump development or the use of a different type of pump. Adjustments may also be possible in the fluid formulation to improve lubricity.

3.7 Combustion Indices:

3.7.1 Flash Point, Fire Point and String Propagation Rate: These properties are primarily related to system safety and not to hydraulic system design as such. See ASTM D 92 and ASTM D 5306.

Certain fluids can be used at temperatures greatly in excess of their flash and fire points, although system and personnel safety must be kept in mind. These properties also serve as a good index of volatility and vapor pressure. For system design volatility and vapor pressure should be considered for possible build-up of combustible fumes.

3.7.2 Autoignition Temperature: This property is important to establish a top usable temperature limit of the hydraulic system environment without the use of special design precautions. If the temperature in the area surrounding hydraulic lines or components is greater than the autoignition temperature, the lines or components may need to be either rerouted or shielded for safety. See ASTM E 659.

3.8 Vapor Pressure:

Vapor pressure is a necessary design property generally provided in fluid descriptive data as a function of temperature. High vapor pressure can limit the usable maximum temperature of a fluid, by causing pump cavitation and sponginess in the entire hydraulic system if vapor pockets are formed. See ASTM D 2879.

3.9 Power Transmission:

3.9.1 Bulk Modulus: Bulk modulus is the reciprocal of compressibility and is a function of pressure and temperature. Both secant and tangent bulk moduli under isothermal and adiabatic conditions should be provided. It is of great importance in dynamic considerations of hydraulic system design. Since it is basically base stock related, great care must be used selecting desirable high bulk modulus base stocks. (Because no standard test method exists, data from different sources should not be considered comparable. However, data from the same source on different fluids should be comparable.) See AIR1362.

3.9.2 Gas Solubility: The percent of soluble gas versus pressure and temperature of a fluid should be stated in the fluid descriptive data and is a necessary factor in hydraulic system design. Release of dissolved gas in a hydraulic system can cause pump cavitation and system sponginess (low bulk modulus). See ASTM D 2780.

3.10 Density:

Density of hydraulic fluid is important for weight calculation in the design of a system and, therefore, is desired to be low. Density is also a key parameter for inlet line sizing, for fluid acceleration, for pump response requirements, for laminar/turbulent flow characteristics, etc. If a fluid specification is being prepared to cover fluids of a known class of base material, the permissible range of density versus temperature can be specified. Density is generally base stock related. In any case, the density-temperature relationship of a fluid should be stated in the fluid descriptive data. See ASTM D 941.

3.11 Rubber Swell:

This test is run on specially compounded rubber standards, representative of the type of elastomers to be used. However, since the standards are specific published formulas, they may not be precisely the formulations used in commercial seals. By the use of these standards, it is possible to compare the relative effects of various hydraulic fluids on the different types of standard elastomers. The behavior, e.g. rubber swell, shrinkage or degradation, of a specific rubber compound in a given fluid is of considerable value in the design and installation of seals of that elastomer-fluid combination. Moreover, the free elastomer swell or shrinkage in a given fluid cannot be taken as the same as with the installed seal confined rubber swell or shrinkage in a system, but merely as a guide for design precautions. While specially compounded rubber can be used for fluid development, final fluid testing should involve commercially available elastomers of probable use. The fluid descriptive data should state free swell and engineering property change data for the commercial elastomer and fluid at conditions meaningful to designers. See FED-STD-791 Method 3603 and 3604.

3.12 Shear Stability:

The ability of a fluid formulation to withstand the shearing action of pumping and valve operation, without permanent viscosity loss, is considerably important to the life of a fluid. Shear breakdown lowers the fluid viscosity of fluids containing polymeric additives used to boost the viscosity index. Some level of viscosity decrease as a result of shearing will occur in service with any polymeric viscosity index improved fluid. The viscosity may plateau at an acceptable level and the fluid perform as desired for many hours. See ASTM D 2603. The maximum allowable shear induced viscosity loss in viscosity index improved fluids is very system dependent and long term component and system testing is required to determine that the fluid is suitable for the application. Therefore, the minimum viscosity guidelines described in 3.2.2 cannot be used in cases of viscosity index improved fluids. Nonviscosity index improved fluids do not usually experience permanent viscosity loss as a result of mechanical shearing.

3.13 Thermal Characteristics

3.13.1 Thermal Stability: The reported maximum thermal stability of a fluid may be either a bulk oil temperature or a hot spot temperature. The exact conditions of a hydraulic fluid thermal or thermal-oxidative test must be provided to ensure a fair comparison of fluids. Conditions to specify include time, temperature, metallurgy present, absence/presence of oxygen, gas flow rate, etc. Posttest analyses conducted in thermal or thermal-oxidative tests provide insight into fluid degradation and potential fluid/system problems. These analyses may include viscosity change, acid number change, metal aggressiveness and notation of the formation of particles. Means of eliminating undesirable breakdown products must be provided when a fluid is used at the thermal breakdown temperature.

3.13.2 Thermal Degradation Products: The nature of any fluid breakdown products should be stated in the fluid descriptive data. They must not cause excessive gumming of valves and other components, or tend to corrode, abrade, or otherwise destroy the materials of components. Gaseous decomposition products increase the fluid vapor pressure and flammability risks. Where gaseous products are released, means must be provided for their elimination from the system.

3.13.3 Thermal Expansion: The coefficient of thermal expansion of a fluid should be stated in the fluid descriptive data. In case this coefficient varies measurably as a function of temperature, it should be so stated. It is of considerable importance in system design, especially for the reservoir and particularly when the operational temperature range of the hydraulic system is large. (A pycnometer method is used for this determination.)

3.13.4 Specific Heat: The specific heat of a fluid should be stated in the fluid descriptive data as a function of temperature. It is of importance in the thermal management of the entire system. See ASTM D 2766.

3.13.5 Thermal Conductivity: The thermal conductivity of a fluid should be stated in the fluid descriptive data as a function of temperature. It is of importance in the thermal management of the entire system. See ASTM D 2717.

3.14 Electrical Conductivity:

The electrical conductivity of a fluid should be stated in the fluid descriptive data as a function of temperature. While not of general importance in system or component design, it is important for specific applications including wet solenoids, wet cooling coils for electric motor driven pumps and hydraulically powered emergency generators. See ASTM D 2624 and ASTM D 4308.