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Fluid Properties

NONCURRENT NOTICE

This specification has been declared "NONCURRENT" as of November 1999. It is recommended, therefore, that this document not be specified for new designs.

Each of these "NONCURRENT" documents is available from SAE upon request.

1. SCOPE:

This report summarizes data relative to liquid fluids and their properties which are of interest to Aerospace Fluid Power technologists.

2. FLUID CHARACTERISTICS:

This section discusses and defines those fluid properties that are commonly used in fluid power system design. It should be noted that the values listed in the tabulation are average properties and in the case of a specification fluid where there is permissable range they can vary within that range. In the case of practically all fluids, they will also tend to vary somewhat from batch to batch. The specification or the fluid manufacturer should be consulted for the limits of this variation.

2.1 Test Sources:

2.1.1 ASTM Tests: For many of the fluid properties, which are tabulated in Addendum 1, standardized tests have been developed by the American Society for Testing and Materials (ASTM). In the discussion of the properties the number assigned to the test for that property is shown, e.g., ASTM D-286 for Self-Ignition Temperature.

2.1.2 Federal Test Method Standard No. 791: In addition to the ASTM tests many of the properties are also covered by one of the tests listed in the Federal Standard. In some cases Federal Standard Tests exist for properties not covered by ASTM tests.

2.2 Definition of Properties:

These properties are grouped by their basic nature and are in the same sequence as in the tabulation.

2.2.1 Density (ASTM D-1298 or D-941): Density is the mass of a unit volume of the fluid and, unless otherwise stated, is in grams per milliliter at 77 F. It is used particularly in calculations of system weight, Reynolds number, and viscosity.

2.2.2 Coefficient of Thermal Expansion (ASTM D-1250): The Coefficient of Thermal Expansion is the change in volume of a unit volume per degree of temperature change. The ASTM Method indicated is intended for use with petroleum base fluids and does not cover synthetic fluids. A low coefficient of thermal expansion is particularly desirable for a fluid used in a system which is required to operate over a wide temperature range, as it will minimize the fluid capacity that must be provided for changes in system volume. It is generally expressed as cu. in./cu. in./°F, however many fluid manufacturers report the value in cc/cc/°F, which is the same number.

2.2.3 Viscosity (ASTM D-445): Viscosity is that bulk property of a fluid, semi-fluid, or semi-solid substance which causes it to resist flow. Fluid systems and components have conflicting requirements as to high or low viscosity. A high viscosity provides strong lubricating films and reduces internal leakage. Low viscosity results in reduced pressure loss in lines in components, less heating, and more rapid control response.

Viscosity (μ) in the normal, that is Newtonian, sense is often called dynamic or absolute viscosity. Dynamic viscosity is defined by the equation:

$$\mu = \frac{F}{A}\frac{ds}{dv}$$

"F/A" is the shear stress, "v" the velocity, "ds" the thickness of an element measured perpendicular to the direction of flow: $\frac{dv}{ds}$ is known as the rate of shear.

The c.g.s unit is the poise (dyne sec/cm^2), the M.K.S. unit is the Poiseuille (Newton sec/m^2), which is equal to the S.I. (International System unit) (1 N sec M^{-2} = 10 poise). The English unit is the Reyn (lb sec/in^2).

Viscosity is also stated in terms of Saybolt Universal Seconds (S.S.U), which is related to centipoises as follows:

$$\mu = \left(.0022\,t - \frac{1.80}{t}\right)\rho \times 100$$

where

μ = dynamic viscosity in centipoise
t = Saybolt Universal Seconds
ρ = Specific gravity

Kinematic or Static viscosity (γ) is the ratio of dynamic viscosity to density at a specified temperature and pressure.

$$\gamma = \frac{\mu}{\rho}$$

The c.g.s. unit is the Stoke (cm^2/sec).

The English unit is the Newt (in^2/sec).

The S.I. Unit is m^{2}s^{-1} = 10^6 centistokes

2.2.3.1 Conversion of Kinematic Viscosity to Saybolt Universal Seconds (ASTM D-446): For values of dynamic viscosity below 70 centistokes at fluid temperatures of 100 F and 210 F the conversion to S.S.U. units is non-linear and the following factors can be used - 100 F cs x 4.635, 210 F cs x 4.667.

2.2.4 Viscosity Index (ASTM D-2270): Viscosity Index is a measure of a fluid's change of viscosity with temperature. The higher the viscosity index the smaller the relative change in viscosity with temperature. Two different indices are used. The earlier usage, according to Dean and Davis, applies to fluids having a V.I. from 0 to 100. It compares the fluid with two reference fluids having a V.I. of 0 and of 100. V.I. (extended) applies to fluids having a V.I. of at least 100. It compares the fluid with a reference fluid with a V.I. of 100.

2.2.4.1 Viscosity Temperature Coefficient (V.T.C.): The Viscosity Temperature Coefficient is an indication of the degree of viscosity change with temperature.

$$VTC = 1 - \left(\frac{V_1}{V_2}\right)$$

where

V_1 = Viscosity in CS at 210 F
V_2 = Viscosity in CS at 100 F

A low VTC indicates less change of viscosity and a high value indicates a greater change.

2.2.5 Bulk Modulus: The Bulk Modulus is a measure of the degree of compressibility of a fluid and is the reciprocal of compressibility. It is usually expressed in pounds per square inch. The higher the bulk modulus, the stiffer is the fluid. The natural frequency of many systems is nearly proportional to the square root of the bulk modulus, and therefore, a high bulk modulus is generally desirable for servomechanisms to obtain faster response, more accurate positioning, better stability, and a higher system spring rate.

Bulk modulus varies with both temperature and pressure. Values used must be representative of the operating conditions in the using system, therefore they must indicate both temperature and pressure applicability. The values listed in the tabulation do not indicate pressure and can be used only as an indication of the relative bulk modulus of the various fluids. For system design purposes the fluid manufacturer's curves should be consulted.

In addition to the variation of bulk modulus with temperature and pressure, several means of expressing the property have been developed. In the tabulation secant bulk modulus values are listed.

Secant Bulk Modulus $Vo\left(\frac{P_o - P_1}{V_o - V_1}\right)$ is defined as the total change in fluid pressure divided by the total change in fluid volume per unit of the initial volume under pressure.

Tangent Bulk Modulus P x V is defined as the change of fluid pressure with respect to volume change. Both of these values may be calculated isothermally or adiabatically. The adiabatic values more closely match the thermo-dynamics of a hydraulic system.

Dynamic Bulk Modulus ρv_s^2, determined by sound propogation, is defined as the product of the mass fluid density (ρ) and the square of the speed of sound (v_s) through the fluid.

2.2.6 Neutralization Number (ASTM D-974 or Fed. Method 5105): The neutralization number is a measure of the acidity or basicity of a fluid. It is defined as milligrams of potassium hydroxide required to neutralize the acidity in one gram of fluid or the equivalent of the basicity expressed in a similar manner. A low neutralization number is not necessarily a reliable index of the corrosivity of a fluid, but a change in acidity or basicity is often used as a measure of deterioration of a fluid in use. With colored fluids, such as MIL-H-5606, ASTM method D-664 is often used.

2.2.7 Thermal Conductivity: Thermal Conductivity is a measure of the quantity of heat that will flow in a unit time through a unit area and thickness having a difference in temperature between its face. It is particularly useful in determining the heat transfer characteristics of a system.

2.2.8 Specific Heat: Specific Heat is the amount of heat (BTU) required to raise the temperature of a unit mass (lb.) of the fluid one degree F as some specified temperature.

2.2.9 Specific Heat Ratio: Specific Heat Ratio (K) is the ratio of the specific heat of a material at constant pressure (C_p) and the specific heat at constant volume (C_v).

2.2.10 Pour Point (ASTM D-97): Pour Point is the lowest temperature at which a fluid will pour or flow under specified conditions. It is usually expressed in 5 F increments and is, in effect, the temperature approximately 5 F above the temperature at which no flow or movement is observed in 5 seconds. In general, it is considered to be the low limit of pumpability, however, the practical limit is somewhat higher.

2.2.11 Freezing Point: Freezing Point is the temperature at which a liquid solidifies at standard atmospheric pressure. At pressures other than one standard atmosphere the freezing point varies. Freezing characteristics must be determined for each pure fluid, solution, or mixture. The test for freezing point of aircraft fuels is defined and specified in ASTM D-2386. For high purity compounds ASTM D-1015 is an acceptable method.

2.2.12 Boiling Point: The Boiling Point is the temperature at which a liquid vaporizes at standard atmospheric pressure. At pressures other than one standard atmosphere the boiling point varies. The boiling point increases with increased pressure for pure fluids. The boiling points of fluid solutions and mixtures vary greatly with solution and mixture proportions, as well as with pressure. ASTM D-86 is used to determine the distillation range of jet fuels and certain other petroleum products. ASTM D-1160 describes one distillation method at reduced pressure for heavy petroleum products. Other methods may also be used to determine this data.

2.2.13 Flash Point (ASTM D-92): The Flash Point is the temperature to which a combustible fluid must be heated at one standard atmosphere to give off sufficient vapor to form momentarily a flammable mixture with air when a small flame is applied under specified conditions. The test method is referred to as "Cleveland Open Cup" and the result is expressed in increments of 5 F.

2.2.14 Fire Point (ASTM D-92): Fire Point is the temperature to which a fluid must be heated at one standard atmosphere so that the released vapor will burn continuously when ignited under specified conditions. There is also a closed cup (Pensky-Martens) test used for determining flash and fire points, particularly for heavy fuel oils and other highly viscous materials. The ASTM designation is D93. Due to the concentration of vapor evolved the value determined is somewhat lower than that with the Cleveland Open Cup.

2.2.15 Spontaneous Ignition Temperature (ASTM D-2155 or D-286): The spontaneous or autogenous ignition temperature is often used as a measure of the flammability characteristics of a fluid. It is one of the basic indices used in evaluating the fire resistance of a fluid and is the temperature at which ignition of a fluid takes place with a source of ignition being provided.

Method D-286 produces data which are extremely susceptible to test conditions and has been obsoleted and replaced by D-2155. However, this method is more difficult to handle, therefore, D-286 is still reported. A new method called the Phoenix AIT (Phoenix Chemical Laboratory, Inc.) sponsored by the Air Force Materials Laboratory, is currently under consideration by the ASTM.

The tabulated data are all understood to be based on D-286. As data based on D-2155 are added they will be indicated by an asterisk (*), and data based on Phoenix AIT by a double asterisk (**).

2.2.16 Critical Temperature and Critical Pressure: Critical Temperature is that temperature above which a fluid cannot be held in a liquid state by pressure alone. The pressure under which a fluid may exist as a gas in equilibrium with the liquid at the critical temperature is the Critical Pressure.

2.2.17 Critical Volume: Critical Volume is the volume occupied by a unit mass of a fluid at its critical temperature and pressure. It is stated in the tabulation in cubic feet per pound.

2.2.18 Surface Tension (ASTM D-971): Surface tension is the contractive surface force of a liquid by which it tends to assume a spherical form and to present the least possible surface. It is expressed in dynes/cm.

2.2.19 Refractive Index (ASTM D-1218): Refractive Index is the ratio of the velocity of light (of a specified wavelength) in air to its velocity in the liquid under examination. Its value is that it may provide a simple means of identification of similar fluids.

2.2.20 Dielectric Strength (ASTM D-117 or D-877): The dielectric strength of a fluid is the average voltage gradient at which electrical failure or breakdown occurs under prescribed conditions.

2.2.21 Dielectric Constant (ASTM D-150): The dielectric constant is the ratio of the capacitance of the fluid dielectric to that of air or vacuum, when testing both with electrodes of the same configuration.

2.2.22 Volume Resistivity (ASTM D-257): Volume Resistivity is the ratio of the potential gradient parallel to the current in the fluid to that of the current density. It is measured in ohm-centimeters. It is an important measure of the ionic contamination in dielectric fluids - water, chlorides, etc.

2.2.23 Elastomer Compatibility (SAE AIR 786): The compatibility of elastomers and fluids is very complex and no one factor is a full measure of compatibility. SAE AIR 786, Elastomer Compatibility Considerations Relative to O-Ring and Sealant Selection, should be used as a guide. Tests with ASTM Method D-471 measures the percentage change in weight, volume, tensile strength, hardness, and elongation of elastomers following immersion in a reference fluid or the fluid being investigated. Moreover, the specific application of the seal determines to a considerable extent the magnitude of the change in the properties of the elastomer which is acceptable. Many of the fluids listed in the tabulation are compatible with more than one elastomer. In general, the elastomer listed is the one believed to be that in most general use. Also, due to its availability and favorable properties, Buna-N is generally preferred when it is suitable. In some cases the thermal range in which the fluid will be used dictates the elastomer.

2.2.24 Moisture Content (ASTM D-1744): This is a measure by percent of water in a fluid. D-1744 is referred to as the Karl Fischer Titration Method. In some cases a distillation method (ASTM D-95) is used, however, this indicates basically free water only. With fluids of low hydrolytic stability the moisture content in the fluid can be quite critical. It can also affect corrosion and tends to reduce lubricating qualities.

2.3 Additional Properties and Characteristics:

2.3.1 Lubricating Qualities: Since to quite an extent the lubricating qualities of a fluid depend upon its application, any complete definition will also depend on the specific application. Similarly, there is no one accepted test to indicate the lubricating quality of a fluid. Each test that has been developed, such as the Shell Four Ball (ASTM D-2266), and the Falex EP, tends to stress one aspect of lubrication more than others. In almost every fluid application there is some area where the lubricating quality of the fluid is of consequence, therefore, it must be considered in fluid selection.

2.3.2 Oxidation-Corrosion Stability (Fed. Method 5308.4): Oxidation-Corrosion Stability indicates the extent to which a fluid in the presence of oxygen will tend to corrode various metals, or produce products of degradation which will corrode metals. All oxidation-corrosion tests involve exposing the fluid to air or oxygen, usually at elevated temperature, in the presence of system metals. Two basic aspects of the problem are necessary considerations in fluid selection. First, the effect of air or oxygen on the fluid, and second, the effect of the products of fluid oxidation on the materials of system construction.

2.3.3 Hydrolytic Stability (Fed. Method 3457): The tendency of fluids to be chemically affected by the presence of water is referred to as hydrolytic stability. The characteristic is determined by exposing the fluid to water and measuring the changes that occur in the fluid. Various methods are used as a relative indicator of the property. The instability effects are generally accelerated by elevated temperature. The products of the reaction vary widely with the chemical nature of the fluid. They may be corrosive and attack the materials of system construction, or a sludge or gel which will clog filters or orifices, or accumulate on metal surfaces impeding heat transfer.

2.3.4 Storage Stability (Fed. Method 3465): The resistance of a fluid to change during long periods of storage or disuse is its measure of storage stability. The characteristic is important if a system is to be idle for long periods of time. There are various mechanisms involved in lack of stability, from separation of the components of the fluid to a basic chemical change, or a low rate of reaction with materials of system construction.

2.3.5 Shear Stability (Fed. Method 3471.1): Shear stability is the ability of a fluid to withstand shearing without permanent loss of viscosity. Many fluids are formulated using polymeric thickeners to give better temperature-viscosity characteristics. Such fluids have complex viscosity behavior since they are non-Newtonian. Mechanical shear may be defined as a force pulling the fluid in opposite directions. System components with small clearances and high fluid velocities cause high shear rates. The fluid viscosity drops due to deformation or alignment of the long chain polymer molecules in the direction of flow. Such loss is temporary and reversible. When the polymer molecules are ruptured a permanent viscosity loss occurs.

2.3.6 Volatility (ASTM D-1160): A desirable characteristic of a hydraulic fluid is low volatility, i.e., a low vapor pressure or high boiling point. This can affect system performance in terms of fluid loss or vaporization. In the case of a single compound fluid this can be related directly to vapor pressure. In a complex fluid volatility is evidenced by a loss of the low boiling constituents and results in an increase of viscosity.

2.3.7 Foaming (ASTM D-892): Almost all liquid fluids will form a certain amount of foam when aerated. With many liquids the foam will collapse rapidly when aeration ceases. If foam is drawn into a system it can cause serious malfunctions. Some liquid fluids contain foam suppressing additives. Gas/liquid separated system design will reduce foam formation.

2.3.8 Metallic Corrosion (Fed. Method 5308.4): Many fluids tend to inhibit the corrosion of metals of system construction. Others will selectively attack certain metals and alloys. The fluid vendor's test data should be consulted to provide advance knowledge of material compatibility.

2.3.9 Toxicity: Toxicity is indicated by the tendency of a fluid or its vapors to cause external irritation or have undesirable effects when inhaled or ingested. Determining the complete scope of the toxicity of a fluid requires extensive, costly, and time-consuming tests with several species of animals. Chemical relation to materials of known toxicological behavior provides a helpful indication. The following are some of the conditions involved in study:

(1) Epidermal application
  (a) Effect of a single large dose
  (b) Effect of repeated dosage
(2) Oral ingestion
(3) Eye irritation
(4) Subcutaneous injection
(5) Exposure to mist
(6) Exposure to vapor
(7) Periodic tests of blood and urine
(8) Pathological effects

Until adequate toxicity data are available precautions must be observed in handling any unfamiliar fluid.

2.3.10 Particulate Contamination (SAE ARP 598 and ARP 785): Particulate contamination refers to solid matter contained in any fluid which is foreign to that fluid. In general contamination levels should be specified as minimum requirements for new fluid and maximum levels considered satisfactory for operation of hydraulic systems in service. The maximum level is the basis for designing components or requiring special protection for components that must operate in a system, and for specifying the filtration required to maintain the system within contamination limits.

2.3.11 Fire Resistance: The measurement of fire resistance in hydraulic fluids is extremely complex. There is no single test that can be used to evaluate all types of fluids under all expected use conditions. The degree of fire resistance in any given test is influenced by the characteristics of the fluid, the type of flame or source of ignition, the total amount of energy available in relation to the amount of fluid, the physical state of the fluid, and many other factors. Flash point, fire point, and autogenous ignition temperature are useful indices of the flammability of a fluid. Many tests have been devised such as the hot manifold test and the spray ignition test, to indicate the fire resistance of a fluid under certain conditions. The papers presented at a symposium on Hydraulic Fluids (ref. paragraph 4.4) provide a valuable discussion of the subject.

3. FLUID SPECIFICATION:

The categorization shown for the fluids covered by Military Specifications and also for those not covered by a government specification is for convenience in listing only. It should be noted this is not an absolute classification as many of the fluids listed are used for applications in categories in addition to that in which they are listed.

3.1 Hydraulic Fluids:

MIL-H-5559	Hydraulic Fluid, Arresting Gear
MIL-H-5606	Hydraulic Fluid, Petroleum Base, Aircraft, Missile and Ordnance
MIL-H-6083	Hydraulic Fluid, Petroleum Base, for Preservation and Testing
MIL-H-8446	Hydraulic Fluid, Non-Petroleum Base, Aircraft
MIL-H-13860	Hydraulic Fluid, Petroleum Base, Artillery Recoil, Special
MIL-H-13862	Hydraulic Fluid, Petroleum Base, Artillery Recoil, Light
MIL-H-13919	Hydraulic Fluid, Petroleum Base, Fire Control
MIL-F-17111	Fluid, Power Transmission
MIL-H-19457	Hydraulic Fluid, Fire Resistant
MIL-H-22072	Hydraulic Fluid, Catapult
MIL-H-27601	Hydraulic Fluid, Petroleum Base, High Temperature Flight Vehicle
MIL-H-46001	Hydraulic Fluid, Petroleum Base, for Machine Tools
MIL-H-46004	Hydraulic Fluid, Petroleum Base, Missile
MIL-H-81019	Hydraulic Fluid, Petroleum Base, Ultra-Low Temperature
MIL-S-81087	Silicone Fluid, Chlorinated Methylphenyl-polysiloxane

3.2 Damper Fluids:

VV-D-001078	Damping Fluid, Silicone Base (Dimethyl Poly-siloxane)

3.3 Heat Transfer Fluids:

MIL-S-27875	Silicone Fluid, Electronic Coolant

3.4 Refrigerants:

MIL-C-81302	Cleaning Compound, Solvent, Trichlorotrifluoroethane

3.5 Hydrocarbon Fuels:

MIL-J-5624	Turbine Fuel, Aviation, Grades JP-4 and JP-5
MIL-F-7024	Fluids, Calibrating, for Aircraft Fuel System Components
MIL-F-25558	Fuel, Ramjet Engine, Grade RJ-1
MIL-P-25576	Propellant Kerosene
MIL-F-25656	Jet Fuel, Grade JP-6

3.6 Rocket Fuels and Oxidizers:

MIL-P-7254	Propellant, Nitric Acid
MIL-P-16005	Propellant, Hydrogen Peroxide
MIL-P-25604	Propellant, Uns-Dimethylhydrazine
MIL-P-26536	Propellant, Hydrazine
MIL-P-26539	Propellant, Nitrogen Tetroxide
MIL-P-27402	Propellant, Hydrazine Uns-dimethyl-hydrazine (50 N_2 H_4 - 50 UDMH)
MIL-P-27404	Propellant, Monomethylhydrazine

3.7 Lubricating Oils:

VV-L-800	Lubricating Oil, General Purpose, Preservative, (Water-Displacing, Low Temperature)
MIL-L-6085	Lubricating Oil, Instrument, Aircraft, Low Volatility
MIL-L-7808	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-C-8188	Corrosion Preventive Oil, Gas Turbine Engine, Aircraft, Synthetic Base
MIL-L-9236	Lubricating Oil, Aircraft Turbine Engine, 400SF
MIL-L-10295	Lubricating Oil, Internal Combustion Engine, Sub-Zero
MIL-L-17331	Lubricating Oil, Steam Turbine (Noncorrosive)
MIL-L-17672	Lubricating Oil, Hydraulic and Light Turbine, Noncorrosive
MIL-L-22396	Lubricating Oil, Reciprocating Compressor
MIL-L-25336	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, High Film Strength
MIL-L-26087	Lubricating Oil, Reciprocating Compressor, Ground Support
MIL-L-2104	Lubricating Oil, Internal-Combustion Engine, Heavy Duty.

4. REFERENCE MATERIALS:

4.1 Introduction to Hydraulic Fluids, by Roger E. Hatton, Reinhold Publishing Corp., 1962

4.2 Hydraulic Fundamental and Industrial Hydraulic Oils, Technical Bulletin B-4, Sun Oil Co., 1954

4.3 Hydraulic Fluid Properties and System Performance, W. W. Le Roy and R. L. Lesl, National Conference on Industrial Hydraulics, October 1959

4.4 Symposium on Hydraulic Fluids, ASTM Special Technical Publication No. 267, ASTM, Philadelphia, 1960.

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ADDENDUM 1

HYDRAULIC FLUIDS

PROPERTIES	MEASUREMENT UNIT	MIL-H-5559	MIL-H-5606	MIL-H-6083	MIL-H-8446	
Chemical Type or Formula		Glycol-Water	Petroleum	Petroleum	Silicate Ester	
Appearance			Red	Red	Amber	
Density	G/ml @ 77°F	1.11-1.12	0.86	0.86	0.94	
Coef. of Thermal Expansion	cc/cc/°F x 10^{-4}		4.1	4.1	6.2	
Viscosity	Centistokes @ °F	9 @ 100	3000 @ -65 10.0 @ 130 5.1 @ 210	3500 @ -65 80.0 @ -40 10.0 @ 130	6500 @ -65 24.3 @ 100 8.1 @ 210	
Viscosity Index			250+	250+		
Viscosity Temperature Coef.					.67	
Secant Bulk Modulus	M PSI @ °F		259 @ 77		220 @ 100 55 @ 500	
Neutralization Number	mgKOH/g		0.07	0.2	0.1	
Thermal Conductivity - Vap.	BTU/(hr)(ft)(°F)					
- Liq.			0.077 @100	0.077 @100	0.066 @300	
Specific Heat - Vapor	BTU/(lb)(°F)					
- Liquid			0.493 @150	0.495 @100	0.56 @ 300	
Specific Heat Ratio	Cp/Cv(@77°F & 1 atm)					
Pour Point	°F		<-85	<-75	-100	
Freezing Point	°F					
Boiling Point	°F @ 760 mm HG	329	420	420	595	
Flash Point	°F		200	200	395	
Fire Point	°F		255	255	450	
Spontaneous Ignition Temp.	°F		475	475	755	
Critical Temperature	°F					
Critical Pressure	PSIA					
Critical Volume	Cu.Ft./Lb.					
Surface Tension	Dynes/Cm @ 77°F					
Refractive Index						
Dielectric Strength	KV/Mil		35+	0	35	
Dielectric Constant					2.92	
Volume Resistivity	Ohm/Cm @ 25°C					
Elastomer Compatibility			Buna-N	Buna-N	Neoprene Fluorocarb	
Moisture Content	Percent					

HYDRAULIC FLUIDS

Properties	MIL-H-13862	MIL-H-13866	MIL-H-13919	MIL-R-17111	MIL-H-19457	MIL-H-22072	MIL-H-27601	MIL-H-46004
Chem. Type or Formula	Petroleum	Petroleum	Petroleum	Petroleum	Tri-aryl Phosphate Ester	Glycol-Water	Super-Refined Min. Oil	Petroleum
Appearance	Amber	Green	Amber		Green	Amber	Clear	Clear
Density		0.88	0.89	0.86	0.846	1.04-1.06	0.85	0.846
C. of Th. Exp.		4.2	4.2		6.3		3.8	
Viscosity	110 @ -40 4.0 @ 100	3600 @ -30 55 @ 100 15 @ 210	7200 @ -40 38 @ 100 10.5 @ 210	1500 @ -65 27 @ 100 10 @ 210	499.6 @ 50 48 @ 100 5.4 @ 210	8000 @ 0 200 @ 100 80 @ 150	3700 @ -40 14.6 @ 100 3.21 @ 210	270.3 @-65 70.34 @-40 2.93 @ 100
V. I.		250+	250+		-18	140	90	
V. T. C.		.73	.72	.62	.89		.78	.60
Bulk Modulus					531 @ 100 467 @ 150 422 @ 200		207 @ 100 132 @ 300	
Neut. No.	0.03	0.00	0.00	0.3	0.1		0.01	0.03
Th. Cond.-Vap.								
-Liq.					.0735@100	0.25	.069@400	
Spec. Ht.-Vap.								
-Liq.					0.37	0.8	.542@200	
Spec. Ht. Rat.								
Pour Pt.	-50	-75	-80	-40	0	-20	-70	<-85
Freeze Pt.								
Boil. Pt.					770			
Flash Pt.	185	240	255	220	455	none	370	205
Fire Pt.			270	235	665	none	425	220
Spon. Ig. Temp.					1150		740	
Crit. Temp.								
Crit. Press.								
Crit. Vol.								
Surf. Tens.					40.2			
Refr. Index					1.551			
Diel. Str.	25	35+					37.5	
Diel. Const.					6.64			
Vol. Res.								
Elastomer				Buna-N	EPR Fluorocarb	Buna-N	Fluorocarb	Buna-N
Moisture Cont.								

Sheet 1

HYDRAULIC FLUIDS

Properties	MIL-H-46001				MIL-H-81019	MIL-S-81087		
	Type I	Type II	Type III	Type IV				
Chem. Type or Formula	Petroleum	Petroleum	Petroleum	Petroleum	Petroleum	Silicone		
Appearance	Amber	Amber	Amber	Amber	Red			
Density	0.87	0.88	0.88	0.89	0.85	1.05		
C. of Th. Exp.						9.75		
Viscosity	33 @ 100	47 @ 100	66 @ 100	113 @ 100	6000 @-90 5 @ 130 2.5 @ 210	2500 @-65 70 @ 77 19 @ 210		
V. I.	80+	80+	80+	80+				
V. T. C.								
Bulk Modulus								
Neut. No.	0.1	0.1	0.1	0.1	0.2	0.05		
Th. Cond.-Vap.								
-Liq.						0.087		
Spec. Ht.-Vap.								
-Liq.						0.34		
Spec. Ht. Rat.								
Pour Pt.	+10	+10	+10	+20	-90	-100		
Freeze Pt.								
Boil. Pt.						730		
Flash Pt.	325	325	350	375	220	560		
Fire Pt.						640		
Spon. Ig. Temp						900		
Crit. Temp.								
Crit. Press.								
Crit. Vol.								
Surf. Tens.						21.0		
Refr. Index						1.4280		
Diel. Str.								
Diel. Const.								
Vol. Res.								
Elastomer						Fluorocarb EPR		
Moisture Cont.								

HYDRAULIC FLUIDS

Properties	Skydrol 500A	Skydrol 500B	Skydrol 7000	Skydrol HT	Oronite Hyjet	Oronite Hyjet-W	MLO-8200	AeroSafe 2300
Chem. Type or Formula	Phosphate Ester	Phosphate Ester	Phosphate Ester	Organic Phosphorus Compound	Phosphate Ester	Phosphate Ester	Silicate Ester	Phosphate Ester
Appearance	Purple	Purple	Green	Yellow	Purple	Purple	Clear	Purple
Density	1.063	1.063	1.083	1.020	1.056	1.056	0.932	1.012
C. of Th. Exp.	4.52	4.52	4.18	4.4	4.6			4.0
Viscosity	11.8 @ 100 3.95 @ 210	11.8 @100 3.95 @210	15.5 @100 4 @ 210	15.4 @100 3.35 @ 210	2770 @-65 11.8 @100 3.88 @210	12.0 @100 3.93 @210	2296 @-65 32.5 @100 11.27 @210	10.24@100 3.41 @ 210
. I.								
V. I.	238		160		230			264
V. T. C.	.67	.67	.74	.74	.70	.64	.65	.67
Bulk Modulus	340 @ 77 248 @ 150	340 @ 77	328 @ 77	320 @ 77	220 @ 100		220 @ 100 55 @ 500	234 @ 77 220 @ 100
Neut. No.	0.01	0.01	0.01	0.05	0.03	0.03	0.1	0.1
Th. Cond.-Vap.								
-Liq.	0.0777	0.0777	0.0723	0.0725			0.080	0.0898
Spec. Ht.-Vap.								
-Liq.	0.39		0.42	0.42			0.39	0.44
Spec. Ht. Rat.								
Pour Pt.	-85	<-80	-70	-80	<-90	<-90	<-100	-95
Freeze Pt.								
Boil. Pt.	709		709					
Flash Pt.	360	360		410	370		395	330
Fire Pt.	420	420		455	425		450	370
Spon. Ig. Temp.	>1200	1075	1060	730	1150		760	1020
Crit. Temp.								
Crit. Press.								
Crit. Vol.								
Surf. Tens.	30.8	32.4	28.9	30.6	26	24		27.6
Refr. Index	1.4737	1. [illegible]	1.5067	[illegible]	1.4746			1.4494
Diel. Str.	12		36	3	25		35	24
Diel. Const.	8.81		8.67				2.72	7.61
Vol. Res.	43		500	9				32.8
Elastomer	EPR	EPR	EPR	EPR	EPR	EPR	Fluorocarb	EPR
Moisture Cont.	0.29		0.29		0.29	0.40-0.60		0.29

Sheet 2

HYDRAULIC FLUIDS

Properties	AeroSafe 2300 W	MLO-7277	MLO-60-294	Oronite 70	Oronite M2V	Monsanto OS-45 Type IV	Monsanto MCS293	Monsanto MCS3101
Chem. Type or Formula	Phosphate Ester	Super Refined Min. Oil	Deep Dewaxed Min. Oil	Silicate Ester	Silicate Ester	Silicate Ester	Polyphenyl Ether	Polyaryl
Appearance	Purple	Clear	Clear	Clear	Clear	Amber	Yellow	Yell.Brn.
Density	1.012	0.89	0.88	0.936	0.946	0.88	1.195	1.3
C. of Th. Exp.		4.33		4.8	5.0	4.8	4.3	4.1
Viscosity	10.06@100 3.33 @210	72.8 @100 7.68 @210 1.55 @400	360 @ 0 18.2 @100 1.28 @400	2593 @-65 24.4 @100 7.56 @210	2650 @-65 17.6 @100 5.45 @210	2400 @-65 12.0 @ 100 3.95 @210	13400 @ 0 25.2 @100 0.81 @500	3500 @-40 4.19 @100 1.34 @210
V. I.		69				225		
V. T. C.	.67	.89	.77	.69	.69	.70	.84	.68
Bulk Modulus		270 @ 100 155 @ 300		220 @ 100 59 @ 500	220 @ 100 57 @ 500	240 @ 65 175 @200 79.5 @400	500 @ 0 285 @ 210 190 @ 500	365 @ 100 287 @ 200 180 @ 400
Neut. No.	0.1	<0.01	0	0.1	0.04	0.03	0.01	0.01
Th. Cond.-Vap.								
-Liq.		0.0725		0.083	0.084		0.071	
Spec. Ht.-Vap.								
-Liq.		0.45		0.39	0.44	0.48	0.34	
Spec. Ht. Rat.								
Pour Pt.	<-80	-35	-70	<-100	<-110	<-85	-20	-60
Freeze Pt.								
Boil. Pt.								
Flash Pt.	330	420	390	430	420	370	445	335
Fire Pt.	370		425		500	430	540	535
Spon. Ig.Temp.		735	700	735	760	705	940	1185
Crit. Temp.								
Crit. Press.								
Crit. Vol.								
Surf. Tens.					26.9	26		
Refr. Index								
Diel. Str.		35		35	35			5.04
Diel. Const.		2.29		2.95				.29
Vol. Res.								
Elastomer	EPR	Fluorocarb	Fluorocarb		Fluorocarb	Flucrocarb	Flworocarb	Fluorocarb
Moisture Cont.	0.40-0.60							

HYDRAULIC FLUIDS

Properties	G.E. SF-1147	G.E. SF-1148	Dow ET-378	Monsanto OS-124	NaK77	Esso 5251	Dow-Corning XF-1-0294	Dow-Corning XF-1-0301
Chem. Type or Formula	Silicone	Silicone	Polyphenyl Ether (4P-3E)	Polyphenyl Ether (5P-4E)	Liquid Metal Eutectic	Triester	Silicone	Silicone
Appearance	Dk. Amber	Dk. Amber	Lt. Amber					
Density	0.89	0.92	1.18	1.198	0.871	0.95	1.217	1.15
C. of Th. Exp.	4.2	4.7	3.19				5.64	
Viscosity	6125 @-50 31 @ 100 25 @ 210	100000@-50 45 @ 100 8 @ 210	2500 @ 30 70 @ 100 1.4 @ 400	363 @ 100 2.1 @ 400 0.85@ 600	0.72 @100 0.194@1200	6800 @ -40 27.5 @ 100 5.42 @ 210	12400 @-40 60 @ 100 12 @ 210	9000 @ -40 29 @ 100 6.2 @210
V. I.								
V. T. C.	.19	.82	.91	.96		.80	.80	.79
Bulk Modulus	212 @ 75 135 @ 300	217 @ 75 140 @ 300	233 @ 200 136 @ 500 93 @ 700		463 @ 212 318 @1000		190 @ 77 86 @ 400 64 @ 500	216 @ 77 118 @ 300
Neut. No.	<0.05	<0.05	0.04				Nil	0.01
Th. Cond.-Vap.								
-Liq.	0.113	0.113	0.082	0.0768	0.238			
Spec. Ht.-Vap.								
-Liq.	0.36	0.37	0.43	0.37		0.442		
Spec. Ht. Rat.								
Pour Pt.	-65	-65	19	40		<-75	-70	-85
Freeze Pt.					9.95			
Boil. Pt.			900		1446.3			
Flash Pt.	500	530	465	550		520	430	440
Fire Pt.	600	625	555	660			500	490
Spon. Ig.Temp.	>800	>800	1100	1135		824	850	880
Crit. Temp.			1270	1781				625
Crit. Press.			242	209				
Crit. Vol.			982	1222				
Surf. Tens.	26.0	28.3		49.9			23.2	
Refr. Index			1.6620	1.6306		1.4591	1.3791	
Diel. Str.								
Diel. Const.	2.386	2.428		4.47		3.93		
Vol. Res.								
Elastomer	Fluorocarb	Fluorocarb				Fluorocarb		
Moisture Cont.								

Sheet 3

HYDRAULIC FLUIDS

Properties	Brayco 713	Brayco 718	Brayco 745	Brayco 762	Brayco 775	Brayco 810	Brayco 811	Brayco 812
Chem. Type or Formula	Petroleum	Petroleum	Petroleum	Petroleum	Hyrdocarb.	Perfluoro-alkylpoly-ether	Perfluoro-alkylpoly-ether	Perfluoro-alkylpoly-ether
Appearance	Amber	Green	Amber	Amber	Amber	Colorless	Colorless	Colorless
Density	0.85	0.89	0.89	0.855	0.86	1.91	1.89	1.91
C. of Th. Exp.	4.4	4.2	4.2	4.4	4.3	5.5	5.5	5.4
Viscosity	281 @ -65 3.58 @100 1.45 @210	43 @ 100 7.27 @210	889 @-40 21.2 @100 3.76 @210	385 @ -65 3.62 @100 1.38 @210	8800 @-40 25.5 @100 4.68 @210	16800 @ 0 153 @ 100 16.1 @ 210	9400 @-40 18.7 @100 3.29 @210	8800 @ 0 96.3 @100 10.9 @210
V. I.		133	52		110	119	110	106
V. T. C.	.60	.83	.82	.62	.82	.89	.82	.89
Bulk Modulus	204 @ 73		235 @ 100	204 @ 73	130 @ 425			
Neut. No.	0.08	0.05	0.05	0.05	0	0	0	0
Th. Cond.-Vap.								
-Liq.	0.078		0.075	0.078	0.078			0.041
Spec. Ht.-Vap.								
-Liq.	0.46		0.52	0.46	0.49	0.24	0.24	0.24
Spec. Ht. Rat.								
Pour Pt.	<-90	-50	-50	<-90	-80	-15	-55	-20
Freeze Pt.								
Boil. Pt.								
Flash Pt.	210	350	355	210	420	Does not Burn	Does not Burn	Does not Burn
Fire Pt.	220	380	390	220	445			
Spon. Ig.Temp.	523			540	745			
Crit. Temp.								
Crit. Press.								
Crit. Vol.								
Surf. Tens.						20	19	20
Refr. Index						1.300	1.296	1.300
Diel. Str.	0	0	0	0	35	35	35	35
Diel. Const.					2.02	2.15	2.15	2.15
Vol. Res.	1.5×10^{9}					10^{15}	10^{15}	10^{15}
Elastomer								
Moisture Cont.								

HYDRAULIC FLUIDS

Properties	Brayco 813	DuPont Krytox 143 AZ	DuPont Krytox 143 AA	DuPont Krytox 143 AB	DuPont Krytox 143 AC	DuPont Krytox 143 AD	Halocarbon 208-25H	
Chem. Type or Formula	Perfluoro-alkylpoly-ether	Perfluoro-alkylpoly-ether	Perfluoro-alkylpoly-ether	Perfluoro-alkylpoly-ether	Perfluoro-alkylpoly-ether	Perfluoro alkylpoly-ether	Chloro-fluoro-carbon	
Appearance	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless		
Density	1.92	1.86	1.88	1.89	1.90	1.91	1.8	
C. of Th. Exp.	5.6	6.1	5.8	5.6	5.7	5.3		
Viscosity	75000 @ 0 42.4 @100 35.5 @210	8000 @-40 18 @ 100 0.8 @ 400	9500 @-25 3.6 @ 100 1.1 @ 400	6900 @ 0 85 @ 100 1.8 @ 400	270 @ 100 26 @ 210 3.9 @ 400	495 @ 100 43 @ 210 6.0 @ 400	800 @ -65 26.4 @100 10.8 @210	
V.I.	133	23	90	113	134	145		
V. T. C.	.92	.81	.85	.88	.90	.91	.59	
Bulk Modulus				148 @ 100	155 @ 100			
Neut. No.	0						0	
Th. Cond.-Vap.								
-Liq.			0.049		0.054			
Spec. Ht.-Vap.								
-Liq.	0.24		0.243		0.226			
Spec. Ht. Rat.								
Pour Pt.	0	-70	-50	-45	-30	-20	-90	
Freeze Pt.								
Boil. Pt.								
Flash Pt.	Does not Burn	Does not Burn	Does not Burn	Does not Burn	Does not Burn	Does not Burn	none	
Fire Pt.							none	
Spon. Ig.Temp.							>1000	
Crit. Temp.								
Crit. Press.								
Crit. Vol.								
Surf. Tens.	21	17.0	17.8	19.4	20.5	20.3		
Refr. Index	1.304	<1.300	<1.300	<1.300	1.301	1.301		
Diel. Str.	35	38.8	41.0	51.5	41.1			
Diel. Const.	2.15	2.10	2.12	2.44	2.15			
Vol. Res.	10^{15}							
Elastomer		Fluorocarb	Fluorocarb	Fluorocarb	Fluorocarb	Fluorocarb		
Moisture Cont.								

Sheet 4

HYDRAULIC FLUIDS

Properties	DuPont Freon E-1	DuPont Freon E-2	DuPont Freon E-3	DuPont Freon E-4	DuPont Freon E-5	DuPont Freon E-6	DuPont Freon E-7T	DuPont Freon E-8
Chem. Type or Formula								
Appearance								
Density	1.538	1.658	1.723	1.763	1.792	1.82	1.84	
C. of Th. Exp.	13.0	8.9	7.7	7.0	6.5			
Viscosity	0.3 @ 77	0.6 @ 77	1.3 @ 77	2.3 @ 77	3.9 @ 77	5000 @-65 4.2 @ 100 1.3 @ 210	1470 @-40 8.3 @ 100 1.95 @210	12.0 @100 2.47 @210
V. I.								
V. T. C.						.69	.74	.79
Bulk Modulus								
Neut. No.								
Th. Cond.-Vap								
-Liq.	0.070	0.061	0.056	0.052	0.049			
Spec. Ht.-Vap.								
-Liq.	0.247	0.242	0.240	0.2393	0.239			
Spec. Ht. Rat.								
Pour Pt.	-246	-190	-160	-138	-119	-95	-95	-75
Freeze Pt.								
Boil. Pt.	105.4	220.0	306.1	380.0	435.6			
Flash Pt.						none	none	none
Fire Pt.						none	none	none
Spon. Ig. Temp.							1110	>1190
Crit. Temp.	315.59	424.90	505.71	563.34				
Crit. Press	283.6	197.9	157.7	122.1				
Crit. Vol.								
Surf. Tens.	10.4	12.9	14.2	15.2				
Refr. Index	1.2434	1.2570	1.2654	1.2704				
Diel. Str.	27.2	34.6	39.5	44.5				
Diel. Const.	3.02	2.75	2.58	2.50				
Vol. Res.	$4x10^{14}$	$>4x10^{14}$	$>4x10^{14}$	$>4x10^{14}$				
Elastomer	Buna-N	Buna-N	Buna-N	Buna-N			Buna-N	
Moisture Cont.								

Sheet 5