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Fluid Properties

RATIONALE

AIR1116 has been cancelled because it contains obsolete informatino and it has been superseded by AIR1362.

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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 permissible 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:

$$\mu = \frac{Fds}{A dv}$$

"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/cm²), the M.K.S. unit is the Poiseuille (Newton sec/m²), 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/in²).

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 (cm²/sec).

The English unit is the Newt (in²/sec).

The S.I. Unit is m²s⁻¹ = 10⁶ 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 $V_0 \left(\frac{P_0 - P_1}{V_0 - V_1} \right)$ 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 $P \times V$ 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 propagation, 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.