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Standard Guide for Performance Evaluation of Hydraulic Fluids for Piston Pumps[1]

This standard is issued under the fixed designation D6813; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers the establishment of test protocols and methodologies for determining the suitability of fluids for use in fluid power systems that incorporate axial or radial piston pumps. The suitability of all fluid types to meet specific levels of performance in piston pumps is addressed. These fluids include, but are not limited to formulations based on mineral, synthetic or vegetable oil base stocks. The finished fluids may be in the form of straight oils, soluble oils or invert emulsions.

1.2 The test protocols and methodologies described in this guide have been selected for their ability to distinguish between highly acceptable, acceptable and unacceptable fluid performance in piston pumps. They take into account the broad range of operating conditions piston pumps are subjected to, as well as the common variations in design and materials of construction among pump manufacturers.

1.3 This guide is intended to complement proprietary test protocols and methodologies employed by some piston pump manufacturers. The test protocols and methodologies within this guide may help pump manufacturers, fluid formulators and end users accurately screen potential fluids for specific performance characteristics. The results of this screening may be sufficient in certain instances for pump manufacturers to forego requirements for additional fluid performance tests.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
D95 Test Method for Water in Petroleum Products and Bituminous Materials by Distillation
D97 Test Method for Pour Point of Petroleum Products
D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D482 Test Method for Ash from Petroleum Products
D611 Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents
D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration
D665 Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water
D874 Test Method for Sulfated Ash from Lubricating Oils and Additives
D877 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes
D892 Test Method for Foaming Characteristics of Lubricating Oils
D943 Test Method for Oxidation Characteristics of Inhibited Mineral Oils
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D1121 Test Method for Reserve Alkalinity of Engine Coolants and Antirusts
D1123 Test Methods for Water in Engine Coolant Concentrate by the Karl Fischer Reagent Method
D1169 Test Method for Specific Resistance (Resistivity) of Electrical Insulating Liquids
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1401 Test Method for Water Separability of Petroleum Oils and Synthetic Fluids
D1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)

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[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.N0.07 on Lubricating Properties.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D1533 Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration
D2070 Test Method for Thermal Stability of Hydraulic Oils
D2270 Practice for Calculating Viscosity Index from Kinematic Viscosity at 40 and 100°C
D2272 Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel
D2273 Test Method for Trace Sediment in Lubricating Oils
D2422 Classification of Industrial Fluid Lubricants by Viscosity System
D2619 Test Method for Hydrolytic Stability of Hydraulic Fluids (Beverage Bottle Method)
D2624 Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
D2717 Test Method for Thermal Conductivity of Liquids
D2766 Test Method for Specific Heat of Liquids and Solids
D2783 Test Method for Measurement of Extreme-Pressure Properties of Lubricating Fluids (Four-Ball Method)
D2879 Test Method for Vapor Pressure-Temperature Relationship and Initial Decomposition Temperature of Liquids by Isoteniscope
D2882 Test Method for Indicating Wear Characteristics of Petroleum and Non-Petroleum Hydraulic Fluids in Constant Volume Vane Pump (Withdrawn 2003)[3]
D2983 Test Method for Low-Temperature Viscosity of Lubricants Measured by Brookfield Viscometer
D3427 Test Method for Air Release Properties of Petroleum Oils
D3487 Specification for Mineral Insulating Oil Used in Electrical Apparatus
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4172 Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method)
D4293 Specification for Phosphate Ester Based Fluids for Turbine Lubrication
D4308 Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter
D4310 Test Method for Determination of Sludging and Corrosion Tendencies of Inhibited Mineral Oils
D4652 Specification for Silicone Fluid Used for Electrical Insulation
D5182 Test Method for Evaluating the Scuffing Load Capacity of Oils (FZG Visual Method)
D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D5222 Specification for High Fire-Point Mineral Electrical Insulating Oils
D5534 Test Method for Vapor-Phase Rust-Preventing Characteristics of Hydraulic Fluids
D5621 Test Method for Sonic Shear Stability of Hydraulic Fluids
D6006 Guide for Assessing Biodegradability of Hydraulic Fluids

[3] The last approved version of this historical standard is referenced on www.astm.org.

D6046 Classification of Hydraulic Fluids for Environmental Impact
D6080 Practice for Defining the Viscosity Characteristics of Hydraulic Fluids
D6158 Specification for Mineral Hydraulic Oils
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
D6376 Test Method for Determination of Trace Metals in Petroleum Coke by Wavelength Dispersive X-ray Fluorescence Spectroscopy
D6546 Test Methods for and Suggested Limits for Determining Compatibility of Elastomer Seals for Industrial Hydraulic Fluid Applications
D6547 Test Method for Corrosiveness of Lubricating Fluid to Bimetallic Couple
D6595 Test Method for Determination of Wear Metals and Contaminants in Used Lubricating Oils or Used Hydraulic Fluids by Rotating Disc Electrode Atomic Emission Spectrometry
E70 Test Method for pH of Aqueous Solutions With the Glass Electrode
E203 Test Method for Water Using Volumetric Karl Fischer Titration
E659 Test Method for Autoignition Temperature of Liquid Chemicals
F312 Test Methods for Microscopical Sizing and Counting Particles from Aerospace Fluids on Membrane Filters

2.2 *AFNOR Standards:*[4]

AFNOR NF E48-690 Hydraulic Fluid Power. Fluids. Measurement of Filterability of Mineral Oils
AFNOR NF E48-691 Hydraulic Fluid Power. Fluids. Measurement of Filterability of Minerals Oils in the Presence of Water
AFNOR NF E48-692 Hydraulic Fluid Power. Fluids. Measurement of Filterability of HFC and HFD Class Fire Resistant Fluids

2.3 *ANSI (NFPA) Standards:*[5]

ANSI/(NFPA) Standard T2.13.7R1-1996 Hydraulic Fluid Power—Petroleum Fluids—Prediction of Bulk Moduli
ANSI/Standard NFPA/JIC T2.24.1-1990 Hydraulic Fluid Power—Systems Standard for Stationary Industrial Machinery
ANSI/(NFPA) Standard T3.9.20-1992 Hydraulic Fluid Power—Pumps—Method of Testing and Presenting Basic Performance Data for Pressure Compensated Pumps
ANSI/(NFPA) Standard T3.9.33-1997 Hydraulic Fluid Power—Pumps—Method of Testing and Presenting Basic Performance Data for Load Sensing Pumps
ANSI/(NFPA) Standard T3.16.2-R1-1997 Hydraulic Fluid Power—Design for Nonintegral Industrial Reservoirs

[4] Available from AFNOR, Administration des Ventes, 11, avenue Francis de Pressensi, 93571 Saint-Denis La Plaine Cedex.
[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

2.4 *CETOP Standard:*

CETOP RP 67H Antiwear Vane Pump Test for Hydraulic Fluids[6]

2.5 *DIN Standards:*[7]

DIN 51348 Testing of Fire Resistant Governor Fluids; Determination of Hydrolytic Stability

DIN 51373 Testing of Fire Resistant Governor Fluids; Determination of Oxidative Stability Including Evaluation of Catalyst Plates

DIN 51389/2 Determination of Lubricants; Mechanical Testing of Hydraulic Fluids in the Vane-Cell-Pump; Method A for Anhydrous Hydraulic Fluids

DIN 51389/3 Determination of Lubricants; Mechanical Testing of Hydraulic Fluids in the Vane-Cell-Pump—Part 3: Method B for Aqueous Not Easily Inflammable Hydraulic Fluids

DIN 51515, Part 1 Lubricants and Governor Fluids for Steam Turbines; L-TD Lubricating Oils and Governor Oils; Minimum Requirements

DIN 51554, Part 3 Testing of Mineral Oils; Test of Susceptibility to Aging According to Baader; Testing at 95°C

2.6 *Energy Institute Standard:*[8]

IP 281 Determination of Anti-Wear Properties of Hydraulic Fluids—Vane Pump Method

2.7 *ISO Standards:*[9]

ISO 4021 Hydraulic Fluid Power—Particulate Contamination Analysis—Extraction of Fluid Samples From Lines of an Operating System

ISO 4402 Hydraulic Fluid Power—Calibration of Automatic-Count Instruments for Particles Suspended in Liquids—Method Using Classified AC Fine Test Dust Contaminant

ISO 4404 Petroleum and Related Products—Determination of the Corrosion Resistance of Water-Containing Fire-Resistant Fluids for Hydraulic Systems

ISO 4406 Hydraulic Fluid Power—Fluids—Method for Coding The Level of Contamination by Solid Particles

ISO 4407 Hydraulic Fluid Power—Fluid Contamination—Determination of Particulate Contamination by the Counting Method Using a Microscope

ISO 5884 Aerospace—Fluid Systems and Components—Methods for System Sampling and Measuring the Solid Particle Contamination of Hydraulic Fluids

ISO 6073 Petroleum Products—Prediction of the Bulk Moduli of Petroleum Fluids Used in Hydraulic Power Systems

ISO 6743/4 Part 4: Family H (Hydraulic Systems), Lubricants, Industrial Oils and Related Products (Class L) : Classification Part 4: Family H (Hydraulic Systems)

ISO 11171 Hydraulic Fluid Power—Calibration of Automatic Particle Counters for Liquids

ISO 12922 Lubricants, Industrial Oils and Related Products (Class L)—Family H (Hydraulic Systems)—Specifications for Categories HFAE, HFAS, HFB, HFC, HFDR and HFDU

ISO 13357-2 Part 2: Petroleum Products—Determination of the Filterability of Lubricating Oils—Part 2: Procedure for Dry Oils

ISO 14935 Petroleum and Related Products—Determination of Wick Flame Persistence of Fire-Resistant Fluids

ISO 15029 Petroleum and Related Products—Determination of Spray Ignition Characteristics of Fire-Resistant Fluids—Part I: Spray Flame Persistence—Hollow Cone Nozzle Method

2.8 *LUX Standard:*[10]

LUX 5.9 Determination of the Corrosion Inhibiting Properties of Fluids, Requirements for Tests Applicable to Fire-Resistant Fluids Used for Power Transmission and Control (Hydrostatic and Hydrokinetic), April, 1994

2.9 *SAE Standards:*[11]

SAE J745 Surface Vehicle Recommended Practice, Hydraulic Power Pump Test Procedure

SAE J1276 MAR86 Standardized Fluid for Hydraulic Component Tests

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *abrasive wear*—wear due to hard particles, including wear debris or fluid contaminants, or hard protuberances forced against and moving along a hard surface.

3.1.2 *axial piston pump*—in the axial piston pump, the pistons are positioned axially, parallel to the driveshaft, and their reciprocating motion is caused by an inclined swash plate as illustrated in Fig. 1.

3.1.3 *bent axis piston pump*—in the bent axis piston pump, the axis of the cylinder barrel is held at a fixed angle relative to the centerline of the driveshaft as illustrated in Fig. 2.

3.1.4 *biodegradable*—capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms that can be measured by standardized tests, in a specific period of time, reflecting available disposal conditions.

3.1.5 *biomass*—any material, excluding fossil fuels, which is or was a living organism that can be used as a fuel. Peanut hulls, agricultural waste, corn and other grains, and sugar are all examples of biomass.

3.1.6 *case drainage*—leakage from around piston clearances and control valves to the case drain port in the pump housing which returns fluid to the reservoir.

[6] Per the CETOP website, this standard is no longer available for purchase and is officially withdrawn. Most CETOP technical documents have been replaced by ISO standards over the years (a cross-reference list is available from CETOP). This standard will be retained pending completion of work in CEN/TC19/WG28.

[7] Available from Beuth Verlag GmbH (DIN-- DIN Deutsches Institut fur Normung e.V.), Burggrafenstrasse 6, 10787, Berlin, Germany.

[8] Available from Energy Institute, 61 New Cavendish St., London, WIG 7AR, U.K., http://www.energyinst.org.uk.

[9] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.

[10] Available from European Safety and Health Commission for the Mining and Other Extractive Industries, Doc. No. 4746/10/91, EN, Luxembourg.

[11] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

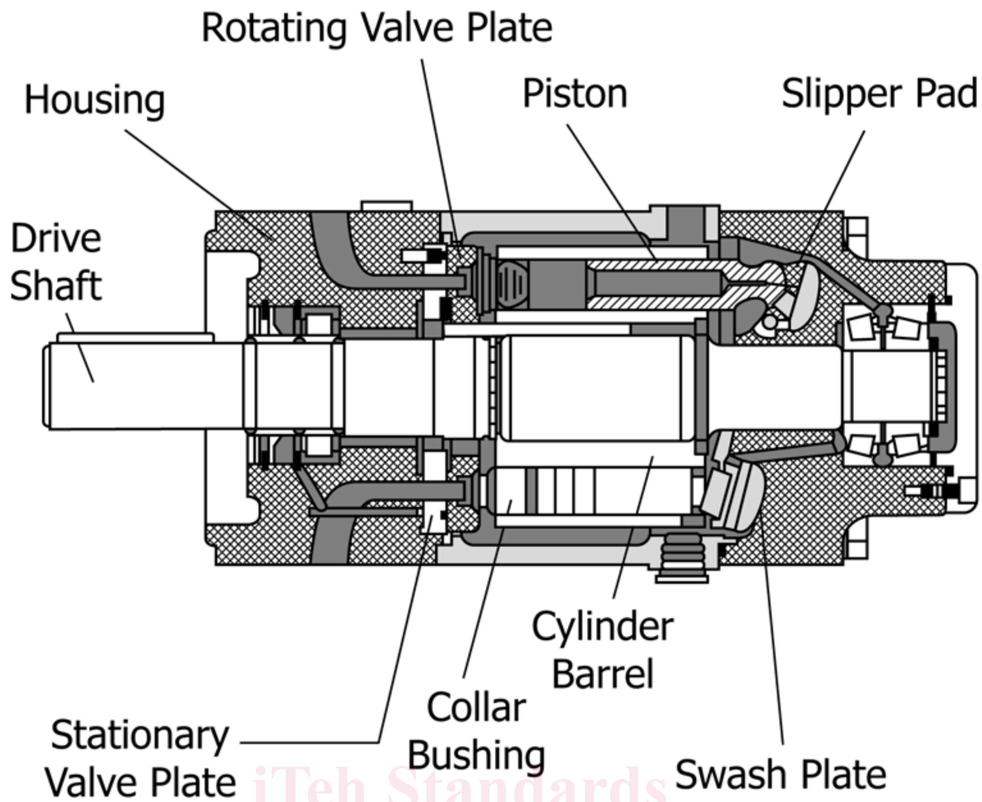

FIG. 1 Illustration of an Axial Piston Pump

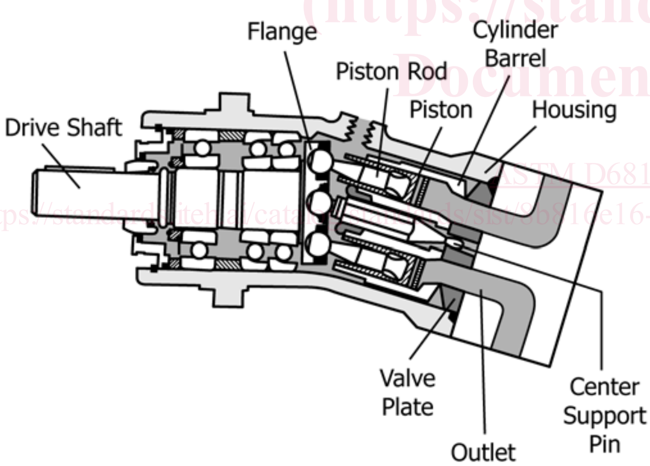

FIG. 2 Illustration of a Bent Axis Piston Pump

3.1.7 *cycled volume*—cycled volume testing subjects a hydraulic pump or component to repeated pulses of volume flow from a predetermined minimum to a maximum flow at a constant pressure.

3.1.8 *delivery*—the flow output per unit time expressed in litres per minute (L/min) or in gallons per minute (gal/min).

3.1.9 *displacement (geometrical)*—the volume of hydraulic fluid that is transported through the hydraulic pump during a single rotation of the pump shaft and is expressed in volume output per revolution (cm^3/rev or $in.^3$/rev).

3.1.10 *face plate (valve plate, port plate, lens plate)*—the face plate, which is held at a fixed position, controls the timing of the inlet and outlet of the fluid flow, depending on the position of the cylinder barrel, during rotation of the pump.

3.1.11 *filterability*—a measure of the fluid's ability to pass through filter media.

3.1.12 *fixed displacement*—the amount of flow cannot be varied per each shaft rotation although it can be varied by varying the rotational speed of the shaft.

3.1.13 *flow degradation*—flow degradation refers to the loss of flow through the hydraulic pump caused by lubrication wear, cavitation erosion, or contamination wear and is expressed as the ratio of flow rate delivered after the test to the flow rate delivered before the test.

3.1.14 *fluid residence time (turnover time)*—the average time that a given volume of fluid remains in the reservoir from the time of entry into the reservoir from the system until it enters the pump inlet is determined by the reservoir volume/flow rate.

3.1.15 *hydraulic power*—the output power of a hydraulic pump which is defined by:

$$W\ (\text{Watt}) = \frac{\text{Delivery}\ (\text{L/min}) \times \text{Pressure}\ (\text{kPag})}{60} \quad (1)$$

$$\text{hp}\ (\text{Horsepower}) = \frac{\text{Delivery}\ (\text{gal/min}) \times \text{Pressure}\ (\text{psig})}{1714} \quad (2)$$

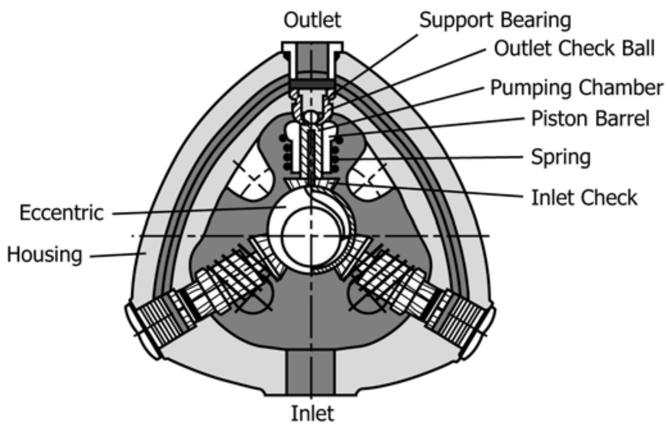

FIG. 3 Schematic Illustration of a Radial Piston Pump

3.1.16 *inlet pressure (minimum)*—the minimum inlet pressure, specified by the pump supplier, for each set of operating parameters.

3.1.17 *leakage flow*—this is related to the annular clearance between the piston and the cylinder; increased clearances due to erosion and wear results in a loss of volumetric efficiency (see 3.1.26).

3.1.18 *leakage pressure (case drain pressure)*—back-pressure that the case experiences during leakage which is determined by the size of the case drain port, hose, fluid viscosity, and the rate of leakage flow to the reservoir via the case drain.

3.1.19 *operating pressure*—the pressure at the discharge port of the hydraulic pump.

3.1.20 *pulsed (cycled) pressure*—pulsed pressure testing subjects a hydraulic pump or component to repeated pressure pulses (at a constant volume), often from close to zero (minimum load) to a predetermined maximum pressure, in order to evaluate fatigue life or moving part interaction problems and leakage.

3.1.21 *pump capacity (pump displacement)*—the actual pump displacement expressed in volume per revolution (cm^3/rev).

3.1.22 *radial piston pump*—in the radial piston pump, the pistons are positioned radially, perpendicular to the driveshaft, and piston motion is caused by the use of a fixed cylinder and rotating cam plate as illustrated in Fig. 3, or a rotating block around a stationary cam can also be used.

3.1.23 *reservoir, hydraulic*—a container for the storage of a fluid used in a hydraulic system.

3.1.24 *shaft power*—the input power driving the hydraulic pump (often from an electric motor) which is defined by:

$$\text{W (Watt)} = \frac{\text{Torque (N·m)} \times \text{Speed (rpm)}}{9.549} \quad (3)$$

$$\text{hp (Horsepower)} = \frac{\text{Torque (lbf·in.)} \times \text{Speed (rpm)}}{63\,025} \quad (4)$$

3.1.25 *swash plate (creep plate, wear plate, wobble plate)*—in a swash-plate (axial) piston pump, the shaft rotates the piston block, thus rotating the pistons, which are held against the surface of a swash plate by springs and a retainer plate. For the piston pump to produce a flow, the swash plate must be held at some angle relative to the centerline of the shaft and the angle will force the pistons to move in and out of the piston or cylinder barrel of the pump as shown in Fig. 1.

3.1.26 *total efficiency*—hydraulic pumping efficiency, or total efficiency (E_T), is a combination of two efficiencies, volumetric efficiency (E_v) and mechanical efficiency (E_m) and is determined from variable displacement.

$$E_v = \frac{\text{Actual Flow Output}}{\text{Theoretical Flow Output}} \quad (5)$$

$$E_m \frac{\text{Theoretical Torque Input}}{\text{Actual Torque Output}} \quad (6)$$

$$E_T = E_v \times E_m \quad (7)$$

3.1.27 *variable displacement*—the amount of flow per each shaft revolution may be varied to limit the outlet flow to a preselected value.

4. Significance and Use

4.1 Users of hydraulic equipment which includes piston pumps would like assurance that the fluids they use will allow their systems to operate safely with reasonable equipment life. This assurance is commonly provided by the fluid supplier in the form of results of standardized tests on the fluid, or demonstrated success in field use in similar systems, or both. This guide will help fluid developers and users develop testing protocols which demonstrate the suitability of a fluid for its intended use, including any required limitations on hydraulic system operating conditions.

4.2 The significance and use of each test method cited in this guide will depend upon the system in use and the purpose of the test method. Use the most recent editions of ASTM test methods.

5. Fluid Classification

5.1 Mineral oil hydraulic fluids are classified in Specification D6158. Fire-resistant hydraulic fluids are classified in ISO 6743/4 and the specifications for these fluid classes are provided in ISO 12922.

5.2 *Mineral Oil Hydraulic Fluids:*

5.2.1 *Type HH Hydraulic Oils*—Non-inhibited refined mineral oils for hydraulic systems that do not have specific requirements of oxidation stability, rust protection, or anti-wear properties. Type HH oils are usually intended for total loss systems or very light duty equipment.

5.2.2 *Type HL Hydraulic Oils*—Refined mineral oils with improved rust protection and oxidation stability for hydraulic systems where relatively high temperatures and long periods of operation time are expected, and where there is the possibility of water or humidity that could rust metal parts of the machinery. These oils are intended for use in systems where only full film lubrication is expected between the moving parts. Usually systems working at low pressures specify HL oils. Some high-pressure piston pumps can operate satisfactorily on these oils.

5.2.3 *Type HM Hydraulic Oils*—Oils of HL type with improved anti-wear properties, for general hydraulic systems, especially for those working at high pressure and where the possibility of metal to metal contact exists. Type HM oils are usually specified for hydraulic systems with vane pumps, or when the system is intended to work at maximum pump capacity for long periods of time.

5.2.4 *Type HV Hydraulic Oils*—Oils of the HM type with improved viscosity/temperature properties, for general hydraulic systems where equipment is intended to operate over a wide range of ambient temperatures.

5.3 *Fire-Resistant Hydraulic Fluids:*

5.3.1 *Type HFA Hydraulic Fluids*—Fire-resistant hydraulic fluids that may be further classified as:

5.3.1.1 *Type HFAE Hydraulic Fluids*—Mineral oil-in-water emulsions containing less than 20 % by volume mineral oil.

5.3.1.2 *Type HFAS Hydraulic Fluids*—Mineral oil-free aqueous synthetic polymer-thickened solutions, often microemulsions, containing >80 % water. These fluids are suitable for use at low working pressures and temperatures varying from 5 to <55°C.

5.3.2 *Type HFB Hydraulic Fluids*—Water-in-mineral oil emulsions containing <60 % mineral oil, which are used as fire-resistant hydraulic fluids at operating temperatures of 5 to <55°C.

5.3.3 *Type HFC Hydraulic Fluids*—Thickened water-glycol fluids containing >35 % water which are suitable for use at operating temperatures of -20 to <60°C.

5.3.4 *Type HFD Hydraulic Fluids*—Anhydrous synthetic fire-resistant fluids used at operating temperatures of <120°C. Type HFD fluids are further subdivided into Types HFD-R and HFD-U. Type HFD-R fluids are based on phosphate esters and Type HFD-U fluids are based on polyol esters.

5.4 *Biodegradable Hydraulic Fluids:*

5.4.1 *Type HETG Hydraulic Fluids*—Typically, biodegradable, water–insoluble hydraulic fluids derived from vegetable oils. These fluids may be used at operating temperatures of -20 to <80°C.

5.4.2 *Type HEES Hydraulic Fluids*—Typically biodegradable fluids derived from synthetic esters, such as polyol ester and diesters, which may be used at operating temperatures of −35 to <90°C.

5.4.3 *Type HEPG Hydraulic Fluids*—Polyalkylene glycol derived fluids that may be water-soluble or insoluble with varying degrees of biodegradability and fire resistance. These fluids are suitable for use at operating temperatures of -30 to <90°C.

5.4.4 *Type HEPR Hydraulic Fluids*—Biodegradable fluids whose basestocks are derived from polyalphaolefin and related hydrocarbons.

5.4.5 *Other Biodegradable Fluids*—Paragraphs 5.4.1 – 5.4.4 describe HETG, HEES, HEPG, and HEPR fluids as biodegradable fluids. However, there are other types of biodegradable fluids not included in a listing. Fluid biodegradability is established by specific testing protocol. For example, some fire-resistant fluids of the HFC and HFD type are readily biodegradable as established by Guide D6006, but this is not reflected in the current ISO specifications. In this guide, reference to biodegradable fluids indicates that they pass appropriate biodegradability standards, not necessarily their placement on a listing of biodegradable fluid classes.

6. Fluid Properties and Performance Testing Procedures

6.1 The hydraulic fluid is a component of the total hydraulic system and to be used properly, various properties of the fluid must be considered relative to system design. These properties are determined by various tests procedures which include: physical properties, chemical properties, oxidative stability, corrosion, fire-resistance, biological and ecological compatibility, other bench tests, and pump tests. A summary of important fluid properties and associated test procedures is provided in Table 1.

NOTE 1—Every test is not appropriate for every fluid class shown in Table 1. The test procedures that are appropriate for a given fluid class are identified by an "X."

NOTE 2—Every fluid test shown in the table need not be performed before for every pump test; however, it is recommended that after selecting those tests that are deemed most critical for the hydraulic fluid to be tested, that the test selection and properties of interest be reviewed with the component manufacturer to ensure that the fluid properties will meet the design and operational requirements for both the pump/motor/components and the application of interest before the hydraulic piston pump test is conducted.

6.2 *Typical Physical Properties :*

6.2.1 *ISO Viscosity Grade (Classification D2422)*—The International Standards Organization has established a viscosity classification system for industrial fluid lubricants. Such lubricants are classified by grades designated as ISO-VG based on their viscosities in centistokes at 40°C. The choice of viscosity grade for use in a particular hydraulic system should meet the manufacturer's recommendations.

6.2.2 *Viscosity (Test Methods D445 and D2983, and Practice D6080)*—Viscosity is the measurement of a fluid's resistance to flow; it is considered to be the most important characteristic of a hydraulic fluid. The optimum value is always a compromise; it has to be high enough, at the working temperature, to ensure that the fluid will not leak through the seals or junctions and to maintain proper lubrication. Also, the viscosity has to be low enough to ensure fluid flow at start-up and to maintain system efficiency and lubrication and avoid cavitation.

6.2.2.1 High VI hydraulic fluids often contain high molecular weight thickeners, called viscosity index (VI) improvers, which may impart non-Newtonian characteristics to the fluid. These polymers may shear degrade with use, and reduce the in-service viscosity of the fluids. Practice D6080 provides uniform guidelines for characterizing oils in terms of both their high and low temperature viscosities before and after exposure to high shear stress. Since the performance of fluids at temperatures higher than 40°C is determined in the worst case, that is, most severe situation, by the sheared oil viscosity, the viscosity and viscosity index used to characterize fluids in this practice are those of the sheared fluid.

6.2.2.2 Practice D6080 classifies oils at low temperature by their new oil properties. Low temperature viscosities do not decrease greatly, if at all, with polymer shear degradation. Furthermore, this approach ensures that the fluid will be properly classified under worst-case conditions, that is, when the fluid is new. Practice D6080 may be used with new or used,

TABLE 1 Hydraulic Fluid Physical Property Characterization Tests

Characteristics	Hydraulic Fluid Classification												Test According to:
	HH	HL	HM	HV	HETG	HEES	HEPG	HEPR	HFA	HFB	HFD	HFC	
Kinematic viscosity at 40°C	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D445
Low Temperature Viscosity	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2983, ASTM D6080
ISO Viscosity Grade	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2422
Viscosity Index	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2270
Pour point	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D97
Density at 15°C	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D1298, ASTM D4052
Air release at 50°C	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D3427
Foam volumes (5 min. blowing, 10 min settling)	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D892
Sequence I													
Initial Volume													
Final Volume, Time													
Sequence II													
Initial Volume													
Final Volume, Time													
Sequence III													
Initial Volume													
Final Volume, Time													
Emulsion stability at 54°C	X	X	X	X	X	X	X	X			X		ASTM D1401
Viscosity Stability (Ultrasonic Test)	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D5621
Dielectric Breakdown Voltage (45-65 Hz)	X	X	X	X									ASTM D877
Electrical Conductivity at 20°C	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D4308
Thermal conductivity	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2717
Specific heat capacity at 20°C	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2766
Vapor pressure	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2879
Bulk Modulus	X	X	X	X	X	X	X	X	X	X	X	X	ISO 6073
Fluid Cleanliness													
Instrumental Test Method	X	X	X	X	X	X	X	X	X	X	X	X	ISO 11171
Microscopic Test Method	X	X	X	X	X	X	X	X	X	X	X	X	ASTM F312, ISO 4407
Cleanliness Code	X	X	X	X	X	X	X	X	X	X	X	X	ISO 4406
In-Line Sampling Method	X	X	X	X	X	X	X	X	X	X	X	X	ISO 4021
Drum Sampling	X	X	X	X	X	X	X	X	X	X	X	X	ISO 5884
Sediment Content	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2273
Seal Compatibility	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D6546

Hydraulic Fluid Chemical Property Characterization Tests (Including Seal Compatibility)

Characteristics	Hydraulic Fluid Classification												Test According to:
	HH	HL	HM	HV	HETG	HEES	HEPG	HEPR	HFA	HFB	HFD	HFC	
Ash (sulfated ash) proportion by mass	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D874, ASTM D482
Water content—Hydraulic Oils	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D95, ASTM D1533, ASTM D6304, ASTM E203
pH value at 20°C									X	X		X	ASTM E70
Neutralization number	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D664, ASTM D974
Alkaline Reserve to pH 5.5 (0.1N HCl)									X	X		X	ASTM D1121
Hydrolytic Stability (mg KOH, mg Cu/cm^2)	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2619
Aniline Point	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D611

Hydraulic Fluid Thermal and Oxidative Stability, Corrosion and Bench Test Characterization Tests

Characteristics	Hydraulic Fluid Classification												Test According to:
	HH	HL	HM	HV	HETG	HEES	HEPG	HEPR	HFA	HFB	HFD	HFC	
Oxidation Stability—TOST	X	X	X	X	X	X	X	X			X		ASTM D943
Oxidation Stability—Cincinnati Milacron	X	X	X	X	X	X	X	X			X		ASTM D2070
Oxidation Stability—RBOT	X	X	X	X	X						X		ASTM D2272
Oxidation Stability—Baader Test	X	X	X	X	X	X	X	X			X		DIN 51554, Part 3
Oxidation Stability	X	X	X	X	X	X	X	X	X	X	X	X	DIN 51373
Sludging Tendency	X	X	X	X	X	X	X	X			X		ASTM D4310
Thermal Stability (Copper and Steel Rods, sludge)	X	X	X	X	X	X		X			X		ASTM D2070
Turbine Oil Rust Test	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D665
Copper Corrosion	X	X	X	X	X	X	X	X			X		ASTM D130
Galvanic Corrosion	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D6547
Vapor Phase Corrosion	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D5534

Newtonian or non- Newtonian, hydraulic fluids. This practice is used for the determination of viscosities at low temperatures applicable to all hydraulic fluids based either on petroleum, synthetic, or naturally occurring base stocks. It is not intended for water-containing hydraulic fluids.

6.2.3 *Viscosity Index (VI) (Practice D2270)*—The VI number signifies the decrease of a fluid's viscosity as the temperature increases. The greater the VI, the less viscosity changes with temperature. In general, the VI is not very critical when the system works at a stable operating temperature. When the

TABLE 1 *Continued*

Hydraulic Fluid Thermal and Oxidative Stability, Corrosion and Bench Test Characterization Tests													
Characteristics	Hydraulic Fluid Classification												Test According to:
	HH	HL	HM	HV	HETG	HEES	HEPG	HEPR	HFA	HFB	HFD	HFC	
Corrosion	X	X	X	X	X	X	X	X	X	X	X	X	LUX 5.9, ISO 4404
Aluminum													
Brass													
Cadmium													
Copper													
Magnesium													
Steel													
Zinc													
Steel and Zinc													
Copper and Zinc													
Aluminum and Zinc													
Steel and Aluminum													
Four-Ball Anti-wear	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D4172
Four-Ball Extreme Pressure	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2783
FZG-gear rig test method	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D5182
Vane pump anti-wear test	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D2882
AFNOR Filterability (dry)	X	X	X	X	X	X	X	X			X		AFNOR NF E48-690
AFNOR Filterability (wet)	X	X	X	X	X	X	X	X					AFNOR NF E48-691
AFNOR Filterability (HDC and HFD)											X	X	AFNOR NF E48-692
ISO Filterability (Dry)	X	X	X	X	X	X	X	X			X		ISO 13357-2

Hydraulic Fluid Fire-Resistance Characterization Tests													
Characteristics	Hydraulic Fluid Classification												Test According to:
	HH	HL	HM	HV	HETG	HEES	HEPG	HEPR	HFA	HFB	HFD	HFC	
Fire Point	X	X	X	X	X	X	X	X			X		ASTM D92
Flash Point (Open Cup)	X	X	X	X	X	X	X	X			X		ASTM D92
Determination of auto ignition temperature	X	X	X	X	X	X	X	X			X		ASTM E659
Factory Mutual Tests:									X	X	X	X	Factory Mutual Standard 6930
Hot Channel Ignition Test													
Spray Ignition Test													
Linear Flame Propagation Test											X		ASTM D5306
Hot Manifold Test									X	X	X	X	
Wick Flame Persistence									X	X	X	X	ISO 14935
Spray Flame Test									X	X	X	X	ISO 15029
Biodegradability	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D6006
Classification for Environmental Impact	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D6046

Hydraulic Fluid Fire-Resistance Characterization Tests													
Characteristics	Hydraulic Fluid Classification												Test According to:
	HH	HL	HM	HV	HETG	HEES	HEPG	HEPR	HFA	HFB	HFD	HFC	
Biodegradability	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D6006
Classification for Environmental Impact	X	X	X	X	X	X	X	X	X	X	X	X	ASTM D6046

variation of temperature among different points in the system is high (over 30°C), or the operational temperatures vary considerably, then a high VI (over 90) is usually recommended.

6.2.4 *Density—Relative Density (Test Methods D1298 and D4052)*—This property is of value to hydraulic system designers and operators for calculating system weight, internal pressure, wall thickness, and pump requirements. Density (or relative density) is measured at, or converted to, a standard reference temperature, normally either 15°C or 60°F, and these need to be quoted alongside the result. Test Method D1298 uses a hydrometer plus thermometer for measurement while Test Method D4052 uses a digital density meter.

6.2.5 *Pour Point (Test Method D97, Low Temperature Viscosity (Test Method D2983)*—The pour point is an indication of the lowest temperature at which an oil will flow by gravity. The fluid viscosity must allow the system to start up and operate at low temperatures. As a practical rule, the fluid should have a pour point 10°C below the minimum expected ambient temperature. Test Method D2983 can be used to determine the temperature at which a fluid's viscosity is less than 750 cP, which is suggested as the highest viscosity which the equipment can tolerate without risk of damage during operation.

6.2.6 *Shear Stability (Test Method D5621)*—Hydraulic fluids may be subjected to shear rates $\geq 10^6$ sec^{-1}, which may lead to a permanent viscosity loss due to polymer additive degradation. Test Method D5621 covers the evaluation of the shear stability of a hydraulic fluid in terms of the final viscosity that results from irradiating a sample of the hydraulic fluid in a sonic oscillator. Evidence has been presented that a good correlation exists between the shear degradation that results from sonic oscillation and that obtained in a vane pump test procedure.

6.2.7 *Foaming Characteristics (Test Method D892)*—In oil systems having high circulation rates, it is important that air introduced through the seals or at the reservoir tank be readily released from the body of the fluid and not collect as foam on the surface of the fluid, since this can produce cavitation or impede proper circulation. Test Method D892 measures the tendency of the oil to form foam, and the stability of the foam. There are three sequences: Sequence I at 24°C; Sequence II at 93.5°C; and Sequence III at 24°C, using the same sample tested in Sequence II.

6.2.8 *Air Release (Test Method D3427)*—Agitation of lubricating oil with air in the equipment may produce a dispersion of finely divided air bubbles in the oil. If the residence time in the reservoir is too short to allow air bubbles to rise to the surface, a mixture of air and oil will circulate through the lubrication system. This may result in the inability to maintain oil pressure, incomplete oil films in contact zones, and poor hydraulic system performance or failure. This test measures the time for the entrained air content to fall to the relatively low value of 0.2 % volume under standardized test conditions, and hence permits the comparison of the oils' capacity to separate entrained air over a period of time.

6.2.9 *Water Separability (Demulsibility) Characteristics (Test Method D1401)*—Water in large hydraulic systems may be removed from water insoluble fluids by mechanical procedures that take advantage of the demulsibility properties of the oil. A contaminant in the emulsion can affect the viscosity of the circulating fluid, creating lubrication problems and may lead to deposits. Test Method D1401 determines the gross water separation characteristics of oils.

NOTE 3—Many, if not most, used oils from Test Method D1401 contain residual levels of water equal to or exceeding amounts sufficient to shorten oil life. Therefore, rapid water separation in Test Method D1401 does not imply that testing oils with low levels of water contamination should not be done.

6.2.10 *Thermal Conductivity (Test Method D2717) and Specific Heat (Test Method D2766)*—The thermal conductivity and specific heats of hydraulic fluids are important fluid design parameters. These properties may be determined from Test Methods D2717 and D2766 respectively.

6.2.11 *Electrical Conductivity (Test Methods D2624)*—The ability of a fluid to dissipate charge during pumping and filtering operations is controlled by its electrical conductivity, which depends on the content of ionic species. Electrical conductivity is an important parameter in determining the potential for a hydraulic fluid to cause electrochemical erosion (chemical pitting). Hydraulic fluid conductivity may be determined by Test Methods D2624.

6.2.12 *Dielectric Breakdown Voltage (Test Method D877)*—Some users require that a minimum breakdown voltage be reported for applications like cherry pickers working near electric lines. This test method is used to judge if the disk electrode breakdown voltage requirements are met for insulating liquids, as delivered from the manufacturer, that have never been filtered or dried. (See Specification D3487, Specification D4652, and Guide D5222 for the minimum specified electrical breakdown.) The breakdown test uses ac voltage in the power-frequency range from 45 to 65 Hz. The sensitivity of this test method to the general population of contaminants present in a liquid sample decreases as applied test voltages used in this test method become greater than approximately 25 kV rms. If the concentration of water in the sample at room temperature is less than 60 % of saturation, the sensitivity of this test method to the presence of water is decreased.

6.2.13 This test method describes two procedures, A and B, for determining the electrical breakdown voltage of insulating liquid specimens.

6.2.13.1 Procedure A is used to determine the breakdown voltage of liquids in which any insoluble breakdown products easily settle during the interval between the required repeated breakdown tests. These liquids include petroleum oils and hydrocarbons.

6.2.13.2 Procedure B is used to determine the breakdown voltage of liquids in which any insoluble breakdown products do not completely settle from the space between the disks during the 1-min interval required in Procedure A (6.2.13.1). Procedure B should also be applied for the determination of the breakdown voltage of liquid samples containing insoluble materials that settle from the specimen during testing. These examples represent samples that may have large differences between replicate tests. The use of Procedure B will result in a more accurate value of breakdown voltage when testing such liquids. Use Procedure B to establish the breakdown voltage of an insulating liquid where an ASTM specification does not exist or when developing a value for an ASTM guide or standard. Procedure A may be used once its single operator precision has been demonstrated.

6.2.14 *Resistivity (Test Method D1169)*—Resistivity (ρ) is the property of a material which determines its resistance to flow of an electric current, expressed by:

$$\rho = R \cdot A / l \tag{8}$$

where:

R = resistance of the specimen, Ω,
A = cross-sectional area, cm^2, and
l = length of the specimen, cm.

Resistivity is the inverse of conductivity. Resistivity is an important parameter in determining the potential for electrochemical erosion (pitting corrosion) in a hydraulic system (**1**).[12] High resistivity reflects low content of free ions and ion-forming particles, and normally indicates a low concentration of conductive contaminants. Test Method D1169 involves the use of a dc galvanometer to measure electrical current flow in a test cell containing the hydraulic fluid.

6.2.15 *Vapor Pressure (Test Method D2879)*—One of the most critically important properties which must be accommodated in hydraulic system design is the vapor pressure of a hydraulic fluid at its operating temperature. If the vapor pressure is sufficiently high, the potential for cavitation may increase dramatically. Vapor pressure may be measured using an isoteniscope by Test Method D2879. This test method measures the vapor pressure of the fluid as received, including most volatile components, but it excludes dissolved fixed gases such as air.

6.2.16 *Bulk Modulus (Test Method ISO 6073)*—Bulk modulus is a measure of the resistance to compressibility. The bulk modulus of a hydraulic fluid is important because power is transmitted and controlled under pressure in a hydraulic circuit. Test Method ISO 6073 (NFPA/T2.13.7R1-1996) provides a

[12] The boldface numbers in parentheses refer to a list of references at the end of this standard.

procedure for predicting the bulk moduli of hydraulic fluids. In this test method, it is assumed that there are no gas bubbles in the fluid. The useful temperature range is from 0 to 270°C with a pressure range from atmospheric to 700 000 kPa (7000 bar).

6.2.17 *Elastomer Compatibility (Test Methods D6546)*—Test Methods D6546 provide procedures for measuring physical properties of elastomer seals in the form of O-rings after exposure to industrial hydraulic fluids and thermal aging. The measured properties are then compared to the physical properties of elastomer seals that have not been exposed to the industrial hydraulic fluids and thermal aging. The changes in these properties form a basis for assessing compatibility when these changes are compared against the suggested limits.

6.2.17.1 These test methods provide procedures for exposing O-ring test specimens to industrial hydraulic fluids under definite conditions of temperature and time. The resulting deterioration of the O-ring material is determined by comparing the changes in work function, hardness, physical properties, compression set, and seal volume after immersion in the test fluid to the pre-immersion values.

6.2.18 *Sediment Content (Test Method D2273)*—This test method covers the determination of trace amounts (less than 0.05 volume %) of sediment in lubricating oils. Since oil-soluble material precipitated by the specified solvent is not intended as part of the measured sediment, this test method is not applicable in cases where precipitated oil-soluble components will appreciably contribute to the sediment readings.

6.2.19 *Fluid Cleanliness (Test Method ISO 4406, 4021, and 11171)* —Fluid cleanliness is an important parameter since dirt contaminants and wear debris may lead to erosive or abrasive wear in the system and interfere with the operation of various components such as servovalves. Therefore, reliable system performance requires contamination monitoring and control procedures.

6.2.19.1 Qualitative and quantitative determination of the particulate contaminants in a hydraulic fluid requires precision in obtaining the sample and determination of the nature and extent of the contaminant in addition to particle size and concentration. Hydraulic fluid samples must be representative of the particle contaminant in the fluid flowing at the point of sampling. The most representative sample is obtained from the system while the fluid is flowing in a turbulent manner. Line sampling procedures that provide the necessary representative system cleanliness results are described in detail in ISO 4021. A fluid samples taken in this manner is designated as a dynamic sample. There are several procedures and devises for sampling drums, barrels, etc. such as ISO 5884. Liquid automatic particle counters are an accepted means of determining the concentration and size distribution of the contaminant particles. Individual instrument accuracy is established through calibration. ISO 11171 provides procedures for:

(1) Primary particle-sizing, sensor resolution, and counting performance;

(2) Secondary particle-sizing calibration using suspensions prepared with NIST reference materials;

(3) Establishing acceptable operation and performance limits;

(4) Verifying particle sensor performance using a truncated test dust procedure; and

(5) Determining coincidence and flow rate limits in the particle counter.

NOTE 4—ISO 11171 replaces the ISO 4402 method of calibrating automatic particle counters which is now obsolete.

6.2.19.2 Quantitative counting of particles may also be performed by microscopic counting. The microscopic technique is described in Test Methods F312 and ISO 4407. Thus far, there is no standard procedure that has been reported for the use of automatic particle counters, although there are calibration procedures using a synthetic test dust (see ISO 11171). The test dusts are designated as are ISO Ultrafine, ISO Fine, ISO Medium, and ISO Coarse.

6.2.19.3 The coding procedure for contaminant number and size distribution to be used in defining the quantity of solid particles in the fluid in a given hydraulic system is described in ISO 4406. This test method provides a three-part code for contamination levels measured with automatic particle counters calibrated in accordance with ISO 11171. The reported particle sizes are 4 µm, ≥6 µm, and ≥14 µm. It also introduces equivalent particle sizes for such counters, based on calibration with NIST reference material SRM 2806.

6.3 *Typical Chemical Properties :*

6.3.1 *Neutralization Number (Test Methods D664 and D974)*—Oxidation of hydraulic fluids may be monitored by tracking increases in the acid number. Because the fresh fluid may be either alkaline or acidic, depending on the additives present, the value of the acid number of the fresh fluid is not indicative of quality. However, increasing acid numbers generally indicate increasing amounts of oxidation.

NOTE 5—With ester-based fluids, the acid number of the fresh fluid is indicative of quality, since esters hydrolyze quicker in the presence of acid.

6.3.1.1 The acid number is determined by titrating a sample of known size with a known amount of standard base (Test Methods D664 or D974). The test is performed by dissolving the oil in a mixture of toluene and isopropanol, to which has been added a small amount of water, then titrating it with a standard solution of potassium hydroxide (KOH). The end-point may be determined potentiometrically or colorimetrically with a pH-sensitive indicator. The acid number (AN) is reported in units of milligrams of KOH per gram of sample (mg KOH/g). It should be noted that the acid number obtained by Test Method D974 may or may not be numerically the same as those obtained by Test Method D664, but it is generally of the same order of magnitude.

6.3.2 *Hydrolytic Stability (Test Method D2619)*—The resistance of hydraulic fluids to hydrolysis is important. Reaction of a finished product with water can lead to the formation of corrosive substances, acids, insoluble by-products, and stable emulsions which can, in turn, cause corrosion, sticky valves, plugged filters, and change in oil viscosity. However, some hydraulic fluids are not hydrolytically stable (see Specification D4293). Hydrolytic stability may be evaluated by the Beverage Bottle Test (Test Method D2619) where the hydraulic fluid and water are heated at 200°F for 48 h in the presence of a copper