Biobased Hydraulic Fluids

Test Methods Relevant to Specification Protocols

Prepared for HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

LOU HONARY

PROFESSOR AND DIRECTOR
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HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Test Methods Relevant to Specification Protocols

CATEGORY 1

PHYSIO-CHEMICAL PROPERTIES
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: A. IODINE VALUE

1A-1.0 Scope: The iodine value will be used to evaluate the degree of unsaturation of the fatty acids in the biobased hydraulic fluid. It can also be used as a measure of solvency power.

1A-2.0 Test method: AOCS Cd 1d-92 (WIJS METHOD)

1A-3.0 Test Procedure: Based on the procedures described in the AOCS Da 15-48 standard test method.

1A-4.0 Acceptance limits: Refer to the specific hydraulic oil specification and if the report of values obtained is within acceptable range. These values are often used in combination with other physio-chemical properties to determine suitability of oils within a specification.

Some petroleum products like Exxon-Mobil SpectraS synthetic oil may have an aniline point of 160 °C while a Citgo Tufflo 50 solvent refined paraffinic oil having aniline point of 116; and a vegetable oil having an aniline point of 30-50 or a higher solvency power.

Department at its discretion may reject a product if its iodine value in conjunction with other specifications do not meet expected requirements.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: B. ANILINE POINT - ASTM D 611

1B-1.0 Scope:

The aniline point (or mixed aniline point) is useful as an aid in the characterization of pure hydrocarbons and in the analysis of hydrocarbon mixtures. Aromatic hydrocarbons exhibit the lowest aniline values, and paraffins, the highest values. Cycloparaffins and olefins exhibit values that lie between those for paraffins and aromatics. In homologous series the aniline points increase with increasing molecular weight. It is occasionally used in combination with other physical properties in correlative methods for hydrocarbon analysis.

1B-2.0 Test Method:

Test according to ASTM D 611

1B-3.0 Test Procedure:

The test methods described in ASTM D 611 cover the determination of the aniline point of petroleum products and hydrocarbon solvents. Test Method A is suitable for transparent samples with an initial boiling point above room temperature and where the aniline point is below the bubble point and above the solidification point of the aniline-sample mixture. Test Method B, a thin-film method, is suitable for samples too dark for testing by Test Method A. Test Methods C and D are for samples that may vaporize appreciably at the aniline point. Test Method D is particularly suitable where only small quantities of samples are available. Test Method E describes a procedure using an automatic apparatus suitable for the range covered by Test Methods A and B.

These test methods also cover the determination of the mixed aniline point of petroleum products and hydrocarbon solvents.
having aniline points below the temperature at which aniline will crystallize from the aniline-sample mixture.

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 limitations prior to use.

1B-4.0 Acceptance limits: Refer to the specific hydraulic oil specification and if required report the values obtained is within acceptable range.
### Category 1: C. POUR POINT

1C-1.0 Scope: This test method will be used to determine the minimum temperature for which biobased hydraulic fluids remain fluid.

For biobased hydraulic fluids this number could be deceptive because biobased oils have different characteristics than petroleum oils and freeze above their pour point due to long term exposure to cold temperature. Other methods like Brookfield Viscosity and long-term cold temperature storage performance tests are used in conjunction with Pour Point.

1C-2.0 Test Method: ASTM D 97 (manual method) or ASTM D 6749 (automatic method)

1C-3.0 Test Procedure: The ASTM D 97 and ASTM D 6749 standard test methods should be followed as given.

1C-4.0 Acceptance Limit: The pour point as measured by ASTM D97 must be below temperatures in the specifications. But for all the specifications, the pour point of a hydraulic fluid used for the Honary Hydraulic Oil Test Recommendations should be at least 20 degrees lower than the coldest ambient temperature of where the equipment is operated.
Automatic Pour Point Tester (left) and Manual Unit
Category 1: C.1. LOW TEMPERATURE FLUIDITY


1C.1.2.0 Test Method: ASTM D 6351-9R05

1C.1.3.0 Test Procedure: The ASTM D 6351 standard test method should be followed as given.

1C.1.4.0 Acceptance Limit: The pour point as measured by ASTM D 6351 to be reported relevant to the specifications.

Note: Low temperature fluidity is often combined with other test parameters from pour point and from Brookfield viscosity results.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: D. FLASH POINT

1D-1.0 Scope: This test method will be used to evaluate the flash point of biobased hydraulic fluids by the Pensky-Martins Closed Cup test.

The closed cup method is recommended to ensure evaporatives are contained within the cup for better representation of the flash point when they are exposed to the open flame in the test.

1D-2.0 Test Method: ASTM D 93

1D-3.0 Test Procedure: The ASTM D 93 standard test method for determination of flash point by Pensky-Martins Closed Cup test should be followed as given.

1D-4.0 Acceptance limit: The flash point measured by the Pensky-Martns Closed Cup test method must be a minimum of 200 °C (292 °F). But, some individual specifications may have higher or lower than 200 °C (292 °F) requirement.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: E. FIRE POINT

1E-1.0 Scope: This test method will be used to evaluate the fire point of biobased hydraulic fluids by the Cleveland open cup method. The option in using open cup test for the fire point is recommended because the evaporative materials will escape during the heating and resulting in a flash point that is reflective of the actual product.

1E-2.0 Test Method: ASTM D92

1E-3.0 Test Procedure: The ASTM D92 standard test method for determination of fire point by Cleveland Open Cup should be followed as given.

1E-4.0 Acceptance Limit: The fire point measured by the Cleveland open cup method in general should be a minimum of 220 °C (428 °F) for vegetable oil based hydraulic fluids. Some specifications, however, will require higher or lower flash points.

Open Cup Flash/Fire Points Tester
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: F. FLAMMABILITY – ASTM D 5306 – Also called Linear Flame Propagation

1F-1.0 Scope: This test method will be used to determine the flame propagation of fluids when exposed to hot temperatures or open flames

1F-2.0 Test Method: ASTM D 5306 Standard test method for determining flammability

1F-3.0 Test Procedure: The ASTM D 5306 Standard test method for determining flammability should be followed as given.

1F-4.0 Acceptance Limit: The flammability should be reported according to the test for comparison with the relevant specifications. Often the value is expected not to exceed 0.3 cm/sec.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: G. HIGH PRESSURE – HIGH TEMPERATURE SPRAY IGNITION– STP Document #5003

1G-1.0 Scope: This test method is adapted from Mine Safety and Health Administration (MSHA) and is Standard Test Procedure (STP) for Conducting the Temperature-Pressure Spray Ignition Test Used for the Approval of Fire-resistant Hydraulic Fluids

1G-2.0 Test Method: Adapted from Mine Safety and Health Administration’s Standard Test Procedure

1G-3.0 Test Procedure:

The following establishes MSHA’s Standard Test Procedure (STP) for Conducting the Temperature-pressure Spray Ignition Test Used for the Approval of Fire-resistant Hydraulic Fluids.

The procedure involves forcing hydraulic fluid heated to 66 °C (± 3°C) or 150 °F (± 5°F) and at 150 psi through an atomizing nozzle to produce a spray. The spray is then subjected to three different ignition sources for 1 minute each at 18”, 24” and 36” from the spray nozzle.

TEST EQUIPMENT -- The equipment used to conduct the temperature-pressure spray ignition test consists of the following components: 1. a pumping unit and heating system, 2. a spray gallery, 3. three ignition devices, and 4. a stopwatch.

1G-3.1. Pumping Unit: consists of a 5-gallon reservoir with a 1 HP electric motor gear driven pump attached. The pumping unit is equipped with the necessary hoses and valves to direct the hydraulic fluid through an adjustable pressure regulator that is set at 150 psi for spraying.

1G-3.2. 110-Volt immersion Heater: controlled by a solid state electronic SCR power controller and driver capable of maintaining the fluid at 150°F ± the spray nozzle.

1G-3.3. A 110-Volt solenoid valve, normally closed, actuated by an electric timer capable of a 0-60 sec. operation. 5.1.1.4. An atomizing round-spray nozzle having a discharge orifice of 0.012” diameter and capable of discharging 3.28 gallons of water per hour at an angle of 90° and at a pressure of 150 psi. The spray nozzle is mounted on the wall of the spray gallery.
1G-3.4. A thermocouple connection with a digital display and a 0-300 psi pressure gauge mounted on the spray gallery near the nozzle to constantly monitor the temperature and pressure of the spray (150°F and 150 psi).

1G-3.5. A hydraulic hose and 3-way valve located near the solenoid to direct the fluid from the spray position to the re-circulate position. In the re-circulate position the fluid is continuously cycled from the reservoir to the nozzle valve and back to the reservoir tank to reheat.

1G-3.6 Spray Gallery: consisting of a stainless steel sink (3” wide, 5’ long and 6”deep) mounted on adjustable legs for drainage. The stainless steel sink is marked at 18”, 24”, and 36” from the tip of the nozzle in order to assist in the placement of each ignition device (kerosene trough, propane torch, and arching device) during the test.

1G-3.7. Stainless steel hood is 3’6” wide and 6’6” long with a 6” facade that tapers to a 12” diameter exhaust duct.

1G-3.8. Exhaust Fan: is a 1 HP 2,000 rpm backward type centrifugal fan capable of 2,200 CFM air flow at 1” SP and is mounted on the roof.

1G-3.9. The Ignition Devices: Consisting of a propane torch (Benzomatic or equivalent) attached to a 14.1 oz. propane cylinder. The tip of the torch has a ½” I.D. blow-torch head that produces a 5” long outer blue flame and a 1” long inner light blue flame when the gas valve is fully opened.

1G-3.10. Arcing Device: in which a continuous arc is produced by a 12,000 volt transformer across a ½” gap in the electrodes.

1G-3.10. Metal Trough: is 20” long, 2” wide, and 2” deep and has a hinged lid. The trough is filled with cotton waste and soaked with approximately 50 ml of kerosene which when ignited will produce a flame 4-6” in height along the width of the trough during the test.

1G-3.11. Timer - A stopwatch to measure the length of burn time, if any, of the sprayed hydraulic fluid. 6.0

TEST SAMPLES: Based on the following procedure.

PROCEDURES FOR PREPARATION OF TEST SAMPLES

A. Prior to beginning the test the analyst should complete the appropriate information on the Temperature Pressure Spray Ignition Test Sheet.

B. The hydraulic fluid to be tested is poured into the reservoir, the valves positioned to re-circulate the fluid from the reservoir to the nozzle valve and back to the reservoir tank. The pump and the heater should be set at 66 °C (150 °F) and turned on. When the fluid has reached 150°F, one of the ignition devices is placed in the sink at the 18” mark. The exhaust fan should be turned on and the valves set to direct the spray to the nozzle.
C. The timer can then be activated for a 60-second spray at the 18” mark. Usually one or two 60-second sprays with no ignition devices are performed prior to the testing in order to clean the hydraulic hose lines and to allow the temperature to equalize. 7.4. After a 60-second spray with each ignition device at the 18” mark, the valves are repositioned in order to re-circulate the fluid back into the reservoir tank. Using this testing sequence the test is then repeated at the 24” and 36” marks with each of the ignition devices in the spray for 60-seconds. Clean Up

CLEAN UP -After test completion, the pump unit, spray gallery, and ignition devices must be drained and cleaned. Cleaning and draining the pump system after each test will reduce maintenance costs and down time.

ACCEPTANCE LIMITS:

Pass/fail test method is used as follows: “If the test procedures do not result in an ignition of any sample of fluid or if an ignition of a sample does not result in flame propagation for a time interval not exceeding 6 seconds at a distance of 18” or more from the nozzle tip to the center of each ignition device, the fluid will be considered fire-resistant according to the test requirements of this section.”

Record the “Pass” or “Fail” tests results on the Temperature Pressure Spray Ignition Test Sheet.

__________________

Note: Alternatively ISO based standards for determination of spray ignition characteristics of fire-resistant fluids can be used.


Part 1: Spray flame persistence – Hollow-cone nozzle method, which was prepared by ISO/TC 28 ‘Petroleum products and lubricants’ of the International Organization for Standardization, has been adopted by Technical Committee CEN/TC 19 ‘Petroleum products, lubricants and related products’, the Secretariat of which is held by NNI, as a European Standard.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, and conflicting national standards withdrawn, by June 2000 at the latest.

In accordance with the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: H. FLAME PROPAGATION (cm/sec)

1H. FLAME Propagation – ASTM D 5036

1H-1.0 Scope: This test method will be used to determine the flame propagation of fluids when exposed to hot temperature

1H-2.0 Test Method: ASTM D 5306 Standard test method for determining flame propagation

1H-3.0 Test Procedure: The ASTM D 5306 Standard test method for determining flame propagation should be followed as given.

1H-4.0 Acceptance Limit: The flammability should be reported according to the test for comparison with the relevant specifications.

Category 1: Ha. Autoignition -- ASTM E659 and STP 5002 VERSION: 2009-03-19 -- Standard Test Procedure for Conducting the Autoignition Temperature Test on Hydraulic Fluids Submitted for MSHA Approval: 30 CRF, Section 35.20 Mine Safety and Health Administration, Approval (MSHA) & Certification Center

1Ha.-1.0 Scope: This test method is MSHA’s Standard Test Procedure (STP) for Conducting the Autoignition Temperature Test on Hydraulic Fluids Submitted for MSHA Approval under 30 CFR, Part 35. Autoignition - the minimum self-ignition temperature [at atmospheric pressure] at which a hydraulic fluid will burst into flame.

1Ha.-2.0 Test Method: The purpose of the test is to determine the lowest autoignition temperature of a hydraulic fluid at atmospheric pressure when using the syringe-injection method.
1Ha.-3.0 Test Procedure:

<table>
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<th>Equipment</th>
<th>Type and Model</th>
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<tbody>
<tr>
<td>Autoignition Test Apparatus</td>
<td>Koehler Model K47000 conforming to the specifications of the ASTM E659 Standard</td>
</tr>
<tr>
<td>Fume Hood</td>
<td>QA&amp;MT Laboratory</td>
</tr>
<tr>
<td>Erlenmeyer Flask</td>
<td>500-milliliter capacity, borosilicate glass round bottom, short-necked boiling flask</td>
</tr>
<tr>
<td></td>
<td>0.25-millimeter capacity, calibrated in .01cc divisions</td>
</tr>
<tr>
<td>Syringe Needle</td>
<td>No. 18, 2-inch stainless steel</td>
</tr>
<tr>
<td>Stopwatch</td>
<td>Calibrated in 0.1 second units</td>
</tr>
<tr>
<td>Datalogger</td>
<td>Agilent Technologies - Model 34970A</td>
</tr>
<tr>
<td>Compressed Air</td>
<td>Available within QA&amp;MT fume hood</td>
</tr>
</tbody>
</table>

1Ha.-4.0 Acceptance Limit:

Locate the lowest non-ignition temperature recorded on the Test Sheet. If the lowest non-ignition temperature is higher than 600 °F, the sample has passed the autoignition temperature criteria as defined in 30 CFR, Subpart B, Section 35.20. If the lowest non-ignition temperature is lower than 600 °F, the sample has failed. Record the “Pass” or “Fail” tests results on the Test Sheet.

1Hb. FLAME Propagation


1Hb-1.0 Scope:
This International Standard specifies a method for the assessment of the persistence of a flame applied to various points within a pressurized spray of liquid fire-resistant fluid. This International Standard is one of two basic measures of fire-resistance.

1Hb-2.0 Test Method:
ASTM D 5306 Standard test method for determining flame propagation

1Hb-3.0 Test Procedure:
The ASTM D 5306 Standard test method for determining flame propagation should be followed as given.

1Hb-4.0 Acceptance Limit:
The flammability should be reported according to the test for comparison with the relevant specifications.

Category 1: Hc.1 Fire Resistance Using Cetane Test Method

Scope:
Using the test method used to determine Cetane rating of diesel fuels, this test is used to determine combustion of the hydraulic oil under high compression pressures.

Apparatus:

Engine: The engine used for this test shall be the standard CFR cetane rating (method 5) engine specified in the ASTM Manual of Engine Test Methods for Rating Fuels, modified by:

a. Attachment of a volume plug (see figure 1) to the variable compression plug, Waukesha Part No. 105100A, or equal, to extend the compression ratio range of the engine to 50:1.

b. Modification of cooling system to provide circulation of cooling water from an external source. A thermometer, Waukesha Part No. 0105180A. or equal, shall be inserted into the cooling water outlet adapter attached to the cylinder head.
c. **Combustion indicator:** A 0 to 2000 lb/in² range strain gauge transducer shall be used as the pressure sensing element. A 0.062-inch open tip thermocouple (see figure 2) shall be used as the temperature sensing element. The pressure signal and the temperature signal shall be amplified and recorded on a recording oscillograph.

d. **Engine operating conditions:**

   Speed – 900 ± 9 revolutions per minute (r/min).

   Injection advance – 13 degrees before top dead center.

   Injection opening pressure – 1500 ± 50 lb/in².

   Injection rate – 30 ± 0.5 mL per minute.

   Air intake temperature – 60 ± 1°C

   Water jacket temperature – 27 ± 1°C.

   Other engine operating conditions as specified in supplement III on operation (cetane) in ASTM Manual of Engine Test Methods for Rating Fuels.

**Test procedure:** The engine shall be motored (with fuel bypass valve open) for 45 minutes or longer at a compression ratio of 50:1 until all engine operating conditions have been established. During this warm-up period, adjustments may be made to establish operating conditions and to purge fuel injection system.

With the compression ratio set at 50:1, the fuel bypass valve shall be closed. The engine shall be run under this condition for 15 seconds continuous injection. At the end of the injection period, the fuel bypass valve shall be opened and the engine motored for 45 seconds. The oscillograph shall be observed for indications of combustion.

To determine the lowest compression ratio for combustion, successive determinations shall be made by reducing the compression ratio two increments per determination until no evidence of combustion is observed. This shall be followed with two additional injection 15 second runs, each preceded by a 45 second period of motoring with no injection. Indication of combustion in one or more of the three 1 minute runs shall be considered evidence that the fluid is combustible for that determination. The reported compression ratio value shall be the lowest compression ratio at which ignition is observed.

**Evidence of combustion:** Any increase in either pressure or temperature signal, or both, during the period of injection shall be considered evidence that the fluid is combustible at that compression ratio.
Indication of combustion which may occur immediately following the 15 second period of injection (fuel bypass valve open) shall not be considered as evidence that a fluid is combustible.

**Reference fluid**: Each unknown sample shall be bracketed with a reference fluid. The fluid used shall be an approved tertiary butyl phenyl triaryl phosphate ester fluid and shall be rated in the same way as the unknown sample. Fire resistance measurements obtained on an unknown sample shall be considered valid only when the compression ratios of the reference fluid determined during the bracketing runs exceeds the minimum compression ratio requirements of 42:1. When the fire resistance of the reference fluid does not meet the minimum requirements, engine condition shall be checked. Procedures detailed in the operating manual for cleaning and overhaul of engine shall be followed.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: I. WATER CONTENT  ASTM D 6304 Determination of Water Content in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fisher titration

1I-1.0 Scope: This purpose of this test is to determine the maximum amount of water allowed in a biobased hydraulic fluid by using the Karl Fischer Method. Karl Fischer can be more accurate than simple weight loss because in the weight loss method volatiles other than water can be lost which is translated into an artificially high water content. Knowledge of the moisture content can be important since some polymers degrade when molded wet results in reduced properties. Also, hygroscopic materials like nylon absorb moisture and knowledge of the water content can be important in understanding performance.

1I-2.0 Test Method: ASTM D 6304

1I-3.0 Test Procedure: A small, weighed sample is placed into the Karl Fischer drying oven at a predetermined temperature for a predetermined period of time. The time and temperature values are arrived at by testing a similar material and varying the temperature and bake time independently to determine optimal conditions for removal of all water in the sample. If the temperature is too low or the retention time too short all of the water may not be driven off. A temperature value too high can degrade the polymer and actually generate water in some cases.

The water in the sample is vaporized and carried by dry oxygen and free nitrogen into a reaction vessel with methanol. The methanol traps the water which is titrated to an end point with a Karl Fischer reagent to determine the amount present. The
ASTM D 6304-07 standard test method should be followed as given.

11-4.0 Acceptance Limit

The acceptance limit: For each product varies but the maximum water content in no case should exceed 0.1 percent of the total volume of the fluid. Specific tests would specify percentages of allowable water below 0.1 percent.

Instrument used for determination of water content using The Karl Fischer Method is described as ASTM D 6304

Additional information for water sensitivity:

**Water sensitivity:** To determine conformance of the hydraulic fluid shall be tested in accordance with the following procedure. The light transmittance of the water treated hydraulic fluid is usually recommended to be a minimum of 90%.

**Preparation of test samples:** Clean two 475 mL glass bottles with caps by washing with a detergent (Alconox or equivalent), rinsing with tap water, then water IAW Type III of ASTM D1193, then anhydrous isopropyl alcohol and finally filtered petroleum ether. After the petroleum ether rinse, allow the bottles to drain upside down in the dust-free clean room where they are to be used. Clean a 250 mL volumetric flask, a funnel, a punch and the top of the can by the same method used to clean the 475 mL bottles above. In the clean room, shake the can to be tested (clean and hermetically sealed) to distribute uniformly any settled material. Punch the top of the can and transfer a 250 mL sample of oil into each of the cleaned bottles using the volumetric flask and the funnel mentioned above. To one of the samples add 0.50 mL of water conforming to type II of ASTM D1193, using a clean, 1.0 mL graduated pipette. Place the cap on the bottle and shake it thoroughly for 60 seconds. Allow this mixture to stand for 24 hours at a temperature of 24 ± 3°C (75 ± 5°F).
**Light transmittance test procedure:** At the end of the 24 hour period, place the untreated hydraulic fluid sample in a single beam spectrophotometer capable of being adjusted to 100% light transmittance at approximately 540 nanometers (nm), using a cell with a path length of 1 centimeter (cm). Adjust the light transmittance at 540 nm to 100%. Remove the untreated sample and replace it with the water-treated sample, again using a cell with a 1 cm path length. Record the transmittance reading. (NOTE: The comparison described in 4.3.3.6.2 may be performed in a differential mode, as an alternative.)
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physico – Chemical Properties

Category 1: J. HOMOGENEITY

1J.1 Scope: This method will be used to evaluate the compatibility of additives with the biobased oils, adapted from Caterpillar BF-1 specification. (Test methods is similar to Trace Sediments in Lubricating Oils – ASTM D 2273)

1J.2 Test Method: According to the test method, the test fluid is held at -32 °C (-26 °F) for 24 hours, then warmed to room temperature, and centrifuged. The absence of sedimentation or separation of insoluble material indicates that the oil and the additive are homogeneous.

1J.3 Test Equipment: Centrifuge tubes- 100 mL

High speed centrifuge capable of producing 100,000 m/s² relative centrifugal force

1J.4 Test Procedure: A quantity of 100 mL sample of the test fluid is put into a 100 mL centrifuge tube. The sample is stopped and held at -32 °C (-26 °F) for a minimum of 24 hours. Allow the sample to reach room temperature and then centrifuge for 30 minutes at 100,000 m/s². The tube containing the test sample is then examined for sedimentation or separation of insoluble material.

1J.5 Acceptance limits:

The maximum amount of precipitation should not exceed 0.01 volume percent.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: K. Miscibility   ASTM D 2273

1K-1.0 Scope: This test method is used to determine the miscibility of the base oil with additives and also with other oils.


1K-3.0 Test Procedure: The ASTM D 2273 standard test method should be followed as given.

1K-4.0 Acceptance Limit: The maximum amount of precipitation should not exceed 0.01 volume percent.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Category 1: L. FLUID CLEANLINESS – ISO 4406

1L-1. Scope: This method will be used to evaluate the cleanliness of the fluids according to International Standards Organization (ISO) level of particle contamination within the oil.

1L-2. Test Method: ISO 4406

1L-3. Equipment Particle Counter

1L-4. Test Procedure: The ISO 4406 standard test method should be followed as given. Three two-digit numbers representing 2, 5, and 15 micron size particles contained in a standard quantity of fluids shall be used.

1L-5. Acceptance: A maximum measured value of xx/yy/zz is allowed. Where x, y, and z would represent numbers that change depending on the sensitivity of the hydraulic equipment. Hydraulic oils that are used in equipment that utilize electro-hydraulic servo and proportional valves, for example would require cleanliness levels as low as ISO 18/15/12. General hydraulic fluids on the other hand may require ISO 21/19/15 rating.

Additional information on ISO Cleanliness

ISO Cleanliness Code ISO 4406-1999

The ISO cleanliness code is used to quantify particulate contamination levels per milliliter of fluid at 3 sizes 4µ[c], 6µ[c], and 14µ[c]. The ISO code is expressed in 3 numbers (ie: 19/17/14). Each number represents a contaminant level code for the correlating particle size. The code includes all particles of the specified size and larger. It is important to note that each
time a code increases, the quantity range of particles is doubling.

**Understanding ISO Cleanliness Codes**

When setting target ISO fluid cleanliness codes for hydraulic and lubrication systems it is important to keep in mind the objectives to be achieved. Maximizing equipment reliability and safety, minimizing repair and replacement costs, extending useful fluid life, satisfying warranty requirements, and minimizing production down-time are attainable goals. Once a target ISO cleanliness code is set following a progression of steps to achieve that target, monitor it, and maintain it, justifiable rewards will be yours.

**Set the Target**

The first step in identifying a target ISO code for a system is to identify the most sensitive on an individual system, or the most sensitive component supplied by a central reservoir. If a central reservoir supplies several systems the overall cleanliness must be maintained, or the most sensitive component must be protected by filtration that cleans the fluid to the target before reaching that component.

**Selecting Target ISO Cleanliness Codes**

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<tr>
<th>ISO 4406:1999 Code Chart Particles per milliliter</th>
<th>Range Code</th>
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<th>Up to / Including</th>
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<td>160000</td>
<td></td>
</tr>
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</table>
Cleanliness Tester (Particle Counter) Designed to Measure and Print Cleanliness Numbers
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio – Chemical Properties


1M.1.0 Scope: This test method will be used to determine the dielectric property of oils using disk electrode. The dielectric breakdown voltage is a measure of the ability of an insulating liquid to withstand electrical stress. The breakdown test uses AC voltage in the power-frequency range from 45 to 65 Hz. The suitability for this test method has not been determined for a liquid’s viscosity higher than 900 cSt at 40 °C.

1M.2.0 Test Method: ASTM D 877

1M.3.0 Test Procedure: The ASTM D 877 standard test method should be followed as given.

1M.4.0 Acceptance Limit: The minimum dielectric constant of the oils as measured by the ASTM D 877 should be at minimum 40 KV.

Dielectric Tester
Test Method D 1816 should be used to determine the breakdown voltage of filtered and degassed liquids.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio – Chemical Properties

Category 1: N. Foaming Characteristics

1N.1 Scope: This test method will be used to determine the foaming characteristics of hydraulic fluids at specified temperatures. The method of empirically rating the foaming tendency and the stability of the foam are described.

For **Foaming Tendency** usually, usually 5 minutes of air blowing time is required to build foam. For **Foaming Stability**, usually 10 minutes of settling time is allowed for the foam to collapse.

1N.2 Test Method: ASTM D 892 modified as described in the test procedure outlined below

1N.3 Test Procedure: ASTM D 892 standard test method will be used to evaluate the foaming characteristics of hydraulic fluids with the following modifications. The test will be divided into two parts. The first part uses the standard ASTM D 892 and the second part uses ASTM D 892 with 0.1 volume percent of water added to simulate water accumulating in hydraulic applications.

1N.4 Equipment: Foaming Apparatus

1N.4 - PART 1: Is based on the standard ASTM D892 test method without water added.

1N.4 PART II: Determines the foaming of hydraulic fluids having 0.1 volume percent added water. This procedure measures the effect of a small amount of water on the foaming of hydraulic fluids. Water is mixed with the test fluid and the foaming characteristics are measured following the ASTM D 892 standard test method.

1N.5 Procedure: Since vegetable base oils and vegetable based formulated oils already have some [absorbed moisture] or may absorb some moisture after manufacturing, a moisture test shall be conducted before the start of the test. The total of available moisture in the product and the water added should not exceed 0.5
mL. Assuming 0% moisture present mix 500 mL of the fluid to be tested with 0.5 mL of distilled water in a blender for 5 min at low speed (1000 RPM) and then for 1 min at high speed (1300 RPM). Allow any foam to dissipate before determining the foam by all three sequences of the ASTM D892 test method.

1N.6 Acceptance limits:

<table>
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<tr>
<th></th>
<th>Without Added Water</th>
<th>With 0.10% Water</th>
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<tr>
<td><strong>Sequence II:</strong></td>
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</tr>
<tr>
<td><strong>Sequence III:</strong></td>
<td>25/0</td>
<td>25/0</td>
</tr>
</tbody>
</table>

Foaming Apparatus with two Temperature Baths. One for 25 and one for 95 degrees C and glass tube used to hold sample.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio – Chemical Properties

Category 1: O.  RUST AND CORROSION PREVENTION PROPERTIES – ASTM D 665

1O.1 Scope: This test method will be used to determine the corrosion protection offered by hydraulic fluids to a finished ferrous surface under dynamic humidity conditions. Adapted from BF-1 Caterpillar Biodegradable hydraulic oil specification

1-O.2 Test Method: Cleaned ferrous rods are exposed to dynamic humidity conditions and the rod is monitored for the appearance of corrosion spots over time, adapted from Caterpillar BF-1 specifications.

1-O.3 Test Equipment: 500 mL Erlenmeyer flask, Wide mouth 25 mL Erlenmeyer flask Modified No. 10 rubber stopper

Bath capable of maintaining a temperature of 32 ± 1 °C (90 °F); Water jacket, Drill or lathe rated at 2500 revolutions per minute

Bath, controlled at 27 ± 1°C (81 °F) with pump capable of circulating solution through water jacket

1-O.4 Test Materials: Test specimen: The test specimen is made from a 14 mm (9/16 inch) outside diameter cold drawn rod of C1018 steel and finished to a maximum of 0.279 micron (11 microinch) arithmetical average. The finished part from vendor must be free from scratches, rust and must be protected for storage by coating with MIL-C-1507B fluid. Supplier for test specimen is Centerless Grinding Co., 1411 S. Laramie Avenue, Cecero, Illinois 60650.

Toluene - ACS reagent purity
Isopropanol - ACS reagent purity

Metal polishing cloth - Grade A - 320 (25mm [1"] side), Carborundum
Grit 320 Kim-wipe tissue or equivalent absorbent wiper.
1-O. 5 Test Procedure: Use three separate rods for each hydraulic fluid. The rod specimens shall be given a preliminary cleaning by immersing in a hot 50% mixture of toluene and isopropanol to remove the rustproof coating.

Chuck the test specimen in a lathe or drill (fixed position) and run at 2500 revolutions per minute. Use a 356x25 mm (14x1 inch) strip of the abrasive cloth and pass slowly from the chuck end to the specimen tip. Pull the abrasive cloth slowly from one end to the other in opposition to the rod rotation to provide a fresh surface on the paper while progressing down the specimen. The pass should take approximately 20 seconds. Make three passes using a new strip of abrasive cloth each time. The final overall specimen finish shall range from 0.278 to 0.356 micron (9 to 14 microinches) arithmetical average, except for the chucking area. CAUTION: Do not use chucking area as the tested portion of the rod.

Rinse rods with toluene and wipe clean with toluene-soaked kim-wipe tissue. Rinse again with toluene followed by dipping six times in clean toluene at 57°C (135°F) for 15 seconds each.

Remove any adhering drop at the bottom of rod with a clean piece of kim-wipe after each dipping. Dip the rod six times into a 500mL flask containing clean isopropanol at 49°C (120°F). Allow the rod to air dry and immediately immerse the 152 mm (6 inch) test section of the specimen 6 times per minute for 1 minute in a 250 mL graduated cylinder containing 200 mL of the fluid to be tested.

After the last dip, place the test section of the rod in a beaker (on a nonskid surface) containing approximately 25 mm (1 inch) of the test fluid. Push the pre-drilled rubber stopper down the rod until a 76 mm (3 inch) section protrudes. Hang the rod vertically by the exposed 76 mm (3 inch) section and allow the test fluid to drain for 30 min. Next, place the rod vertically in a 500 mL Erlenmeyer flask containing 100 mL of distilled water and a 25 mL Erlenmeyer flask containing 15 mL of distilled water. Place the 25 mL flask so that the test fluid from the rod cannot enter the smaller flask.

Immerse the assembly to the bottom of the stopper in a constant temperature bath maintained at 32 ± 1 °C (90 °F). Place the water jacket over the exposed 76 mm (3 inches) of rod and circulate water controlled at 27 ± 1°C (80°F). This will maintain a 5°C (41 °F) differential over the length of the rod.
CAUTION: Care should be taken so that the test rod is not touched with bare hands. Plastic gloves should be worn at all times when handling the rod.

1.0.6 Acceptance Limits:

Minimum time is 200 hours to failure. The specimen shall be examined for appearance of corrosion spots every 24 hours. Failure is defined as six or more spots per any linear inch (as viewed without magnification). The first 9.5 mm (3.8 inch) below the contact line between the stopper and the rod shall be disregarded. Two specimen failures in less than 200 hours shall be considered a failure.
Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: Oa: COPPER STRIP CORROSION

1-Oa.1 Scope: This test method will be used to evaluate the corrosiveness of hydraulic fluids to copper.

1-Oa.2 Test Method: ASTM D 130

1-Oa.3 Test Procedure: The ASTM D130 standard test method will be used to evaluate the copper strip corrosion characteristics of hydraulic fluids under the following conditions:

- Oil Temperature: 100 °C (212 °C)
- Time of Immersion: 3 h

1-Oa.4 Acceptance Limits:

1-Oa4.1. Slight tarnish is allowed. Any observed rating above 1a according to chart is considered to be a failure.

1-Ob.1.0 Scope:

The Humidity Cabinet Test (ASTM D1748) is designed to measure the ability of preservative coatings to protect metal parts from rusting under conditions of high humidity. The test apparatus consists of a cabinet designed with a rotating circular stage for holding test panels. Humidity control is provided by diffusing air through approximately 25 gallons of heated water in the bottom of the cabinet.

1-Ob.2.0 Test Method:

ASTM D 1748 – Standard Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet

1-Ob.3.0 Test Equipment: Humidity Cabinet

1-Ob.4.0 Test Procedure:

Preservative oils are tested by coating specially-prepared steel panels with the oil by dipping. The panels are allowed to drain. They are then placed on the rotating stage and exposed to 100% relative humidity @ 120°F vapor temperature for varying periods of time. The test length is determined by individual specifications. Some specifications such as the Federal VV-L-800A call for 8 days protection, while others such as the MIL-L-21260A require 30 days protection. At the conclusion of the required test exposure, the panels are removed, washed with the solvent and rated for rust. The general criteria for pass or fail are as follows:

1-Ob.5.0 Acceptance Limits:

PASS - No more than 3 dots of rust per test surface (one side of panel), no one of which is larger than 1 mm in diameter. FAIL - One or more dots of rust larger than 1 mm in diameter, or 4 or more dots of any size.
Humidity Cabinet (ASTM D 665) – (left) and Test Specimen New and Failed
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: Oc. Turbine Oil Rust Test

1-Oc.1.0 Scope:
This test method will be used to measure the ability of industrial oils to prevent rusting under conditions of water contamination. Adapted from the Lubrizol Corporation publications on fuel and lubricant testing capabilities.

1-Oc.2.0 Test Method: ASTM D 665

1-Oc.3.0 Test Equipment: A special cylindrical steel specimen made from #1018 cold finished carbon steel and container for holding the specimen and the test fluid.

1-Oc.4.0 Test Procedure: The standard test method D 665 test method should be followed as given.

1-Oc.5.0 Acceptance: In order to pass this test, the specimen must be completely free from visible rust when examined without magnification under normal light. For this test, a modification of the ASTM D 665 using three parts is used as follows:

1-Oc.5.0-A Using distilled water, except that the pin is not solvent washed prior to rating.

1-Oc.5.0-B The test pin from (1O-5.0-A) is immersed in distilled water for an additional 24 hours at 60 °C (140 °F) with stirring. The pin is removed and rated.

1-Oc.5.0-C The test pin from (1O-5.0-B) is replaced in the distilled water and the test is continued for an additional 72 hours at 60°C (140 °F), without stirring.
In order to pass each stage, the pin must be completely free of rust.

HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: Od.

Salt Fog Test  ASTM B 117

1-Od.1.0 Scope:

The Salt Fog Test was developed as an accelerated test for the resistance of metals particularly plated metals. It is used for evaluating organic coatings pre preservative oils where coated specimens are exposed to the setting fog of an atomized, neutral (pH 6.5-7.2) sodium chloride solution.

1-Od .2.0 Test Method:  ASTM B 117

1-Od .3.0 Test Equipment:  Standard salt spray cabinets with pertinent accessories

1-Od .4.0 Test Procedure:  According to ASTM B 117, the chamber temperature is maintained between 92 °F and 97 °F, and spray nozzles are adjusted so the spray does not impinge directly on the test specimens. The atomization and quality of the five percent salt fog and the composition of the solution is specified and controlled for the test. The air is cleaned in a scrubber and heated to maintain a relative humidity within the cabinet of 95 to 98 percent. The specimens are placed in the cabinet at an angle of 15 to 30 degrees from the vertical. At the conclusion of the test, the panels are inspected and rated for resistance to rust.

1-Od 5.0 Acceptance:  Specification MIL-L-3150B describing the performance of preservative oil requires 48 hours in this test, with no more than three spots of rust. For biobased hydraulic oil a minimum of 100 hours under the test condition are required for the specimens with no more than three spots of rust to pass.
Salt Fog Tester Based on ASTM B117
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: Oe. Corrosion and Oxidation Stability – ASTM D 4636

1-Oe.1.0 Scope: This test method covers the testing of hydraulic oils, aircraft turbine engine lubricants, and other highly refined oils to determine their resistance to oxidation and corrosion degradation and their tendency to corrode various metals. Petroleum and synthetic fluids may be evaluated using moist or dry air with or without metal test specimens.

1-Oe.2.0 Test Method: ASTM D 4636 is at 168 hours and at 135 °C (275 °F) and weight change of \( \text{mg/cm}^3 \)

1-Oe.3.0 Test Equipment: As described

1-Oe.4.0 Test Procedure: This test method consists of a standard test procedure, an alternative Procedure 1, and an alternative Procedure 2. As there are variations possible with this test method, it will be up to the particular specification to establish the conditions required. In addition to temperature, the variables to specify if other than those of the standard procedure or alternative Procedure 1 or 2 are: test time, air flow and humidity, sample frequency, test fluid quantity, and metal specimen(s).

1-Oe.5.0 Acceptance: Interpretation of results should be done by comparison with data from oils of known field performance. The accelerated conditions likely will cause one or more of the following measurable effects: mass change and corroded appearance of some metals; change of viscosity; increase in acid number; measurable reaction products in the form of sludge; and mass loss of oil due to evaporation. For biobased products the results
of this test should complement the test results from other oxidation stability tests.

HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

CATEGORY 1: P. DEMULSIBILITY – ASTM D 2711

1-P.1.0 Scope: This test method will be used to determine the ability of biobased hydraulic fluids to separate water when introduced into the oil from the atmosphere of other external sources.

1-P.2.0 Test Method: ASTM D 2711

1-P.3.0 Test Procedure: The ASTM D 2711 should be used as described.

1-P.4.0 Acceptance Limit: Upon completion of the test, there should be at minimum 37 mL water separated from the mixture before 20 minutes time has elapsed.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

Category 1: -Q. Hydrolytic Stability -ASTM D 2619

1-Q.1.0 Scope:

Hydraulic fluids are frequently treated with additives to provide desirable characteristics. As exposure to atmospheric moisture can be expected over a period of use, it is important to determine the hydrolytic stability of these fluids.

1-Q.2.0 Test Method:

ASTM D 2619 -- depends upon the catalytic effect of copper at elevated temperatures in the presence of water to accelerate the rate of hydrolysis.

1-Q.3.0 Test Procedure:

According to the ASTM D 2619, 75 grams of the test oil along with 25 grams of water and a copper strip catalyst are sealed in a 6-ounce pressure-type beverage bottle. The bottle is rotated at 5 rpm, end over end, for 48 hours in an oven at 93.3 °C (200 °F). The water and oil layers are separated, and insoluble’s from both layers are separated and weighed. Weight change of the copper catalyst is measured. Viscosity and acid number changes of the oil and acidity of the water layers are determined.

1-Q.4.0 Acceptance Limit:

The degree of hydrolysis is determined by an increase in the acid number of the water which should not exceed 28 mg KOH, and copper weight loss, which should not exceed 0.20 mg/cm².
**Hydrolytic stability:** The change in weight of a copper strip, when subjected to the products of the hydrolytic action of the test fluid as specified for 48 hours, shall be not greater than 0.3 milligram per square centimeter (mg/cm²). There shall be no pitting, etching, or visible corrosion on the surface of the copper. While a brown discoloration of the surface of the copper is permitted, a gray or black discoloration shall be cause for rejection. The acid number increase of the fluid shall be not greater than 0.2 mg of potassium hydroxide per gram of fluid. The acid content of the entire water layer shall not exceed the equivalent of 5 mg of potassium hydroxide. The amount of material insoluble in the fluid after the test (exclusive of water) shall be not greater than 0.5 percent by weight.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

CATEGORY 1: R. TURBINE OIL DEMULSIBILITY - ASTM D 1401

1-R.1.0 Scope: This test method will be used to determine the ability of hydraulic fluids to separate water when introduced into the oil from the atmosphere of other external sources.

1-R.2.0 Test Method: ASTM D 1401

1-R.3.0 Test Procedure: The ASTM D 1401 should be used as described.

1-R.4.0 Acceptance Limit: Upon completion of the test, there should be at minimum 37 mL water separated from the mixture before 20 minutes time has elapsed.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

CATEGORY 1:S. TOTAL ACID NUMBER – ASTM D 664

1-S.1.0 Scope: This test method will be used to determine the increase in the acidity of the fluids particularly due to interaction of the additives or the base oil with water and other contaminants introduced during use.

1-S.2.0 Test Method: ASTM D 664

1-S.3.0 Test Procedure: The ASTM D 664 should be used as described.

1-S.4.0 Acceptance Limit: The total acid number shall not exceed 2.0 milligrams of potassium hydroxide per gram of hydraulic oil (mg KOH/g).

CATEGORY 1: S.1. Changes in TOTAL ACID NUMBER

Based on Modified ASTM D 7043 Hydraulic Pump Test

1-S.1.1.0 Scope: This test method will be used to determine the changes in the Total Acid Number of the test oil in the Modified ASTM D 7043, which is 1000-hour hydraulic pump test required as part of oxidation stability and wear protection performance.

1-S.1.2.0 Test Method: Modified ASTM D 7043

1-S.1.3.0 Test Procedure: The Modified ASTM D 7043 should be used as described and the total acid numbers recorded every 10 hours for the first 100
hours and then every 100 hours for the next 900 hours.

1-S.1.4.0 Acceptance Limit:

The ∆ in Total Acid number in Pump Test - Modified ASTM D 7043 at zero hour and at 1000th hour should not be more than 0.5 mg KOH/g.

___________________________

Also AOCS Method Te 3a–64 Acid Value may be used for determining the acid value of base oils.

___________________________

CATEGORY 1: S2. Neutralization Number -

Neutralization Number - As hydraulic oils degrade, they form acidic byproducts. The amount of these byproducts may be determined by their neutralization number. The neutralization number is determined by finding the net acidity of the same with a known amount of standard base such as potassium hydroxide (KOH). This is known as the "acid number" and is reported as milligrams of KOH per gram of sample (mg/g).
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

CATEGORY 1: T. EVAPORATION LOSSES OF LUBRICATING OILS BY NOAK METHOD

1T-1.0 Scope: The percent weight loss of a test sample is recorded while the sample is being heated.

1T-2.0 Test Method: ASTM D 972

1T-3.0 Test Procedure: The ASTM D 972 is to be followed as described.

1T-4.0 Acceptance Limit: Report per specifications, but with 6 hours at 71 °C (160 °F), the maximum evaporation loss should not exceed 20%. Each specification, however, may have its own required value.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties


1U.1.0 Scope:

The evaporation loss of a lubricant is important in the hot zones of equipment where evaporation of part of the lubricant may increase lubricant consumption. The percent weight loss of a test sample is recorded while the sample is being heated.

1U.2.0 Test Method: ASTM D 6375

1U.3.0 Test Procedure: The ASTM D 6375 is to be followed as described.

1U.4.0 Acceptance Limit: Report per specifications
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

CATEGORY 1: V. COMPOSITIONAL ANALYSIS BY THERMOGRAVIMETRIC ANALYSIS (TGA)

1.V-1.0 Scope: In a Thermogravimetric Analysis, the percent weight loss of a test sample is recorded while the sample is being heated at a uniform rate in an appropriate environment.


Specimen size: 10 to 15 milligrams

Equipment Used: TGA7 Thermogravimetric Analyzer

1.V-3.0 Test Procedure: The ASTM E1131, ISO 11358 – should be followed. In a Thermogravimetric Analysis, the percent weight loss of a test sample is recorded while the sample is being heated at a uniform rate in an appropriate environment. The loss in weight over specific temperature ranges provides an indication of the composition of the sample, including volatiles and inert filler, as well as indications of thermal stability. Set the inert (usually N2) and oxidative gas flow rates to provide the appropriate environments for the test. Place the test material in the specimen holder and raise the furnace temperature. Set the initial weight reading to 100%, then initiate the heating program. The gas environment is preselected for either a thermal decomposition (inert - nitrogen gas), an oxidative decomposition (air or oxygen), or a thermal-oxidative combination.
1.V.4.0 Acceptance Limits: A plot of percent weight loss versus temperature is reported.

1W-1.0 Scope: This test method covers determination using a glass hydrometer, of the density, relative density (specific gravity), or API gravity of crude petroleum, petroleum products, or mixtures of petroleum and nonpetroleum products normally handled as liquids, and having a Reid vapor pressure of 101.325 kPa (14.696 psi) or less.

1W-2.0 Test Method: ASTM D 1298

1W-3.0 Test Procedure: (ASTM D 1298) is to be followed as described.

1W-4.0 Acceptance Limit: Report API Gravity at 15.6 °C (60 °F) per specifications

CATEGORY 1.Wa Specific Gravity at 15.6 °C (60 °F) -- ASTM D 1298

1Wa-1.0 Scope: This test method covers determination using a glass hydrometer, of the density, relative density (specific gravity), or API gravity of crude petroleum, petroleum products, or mixtures of petroleum and nonpetroleum products normally handled as liquids, and having a Reid vapor pressure of 101.325 kPa (14.696 psi) or less.

1Wa-2.0 Test Method: ASTM D 1298

1Wa-3.0 Test Procedure: The ASTM D 1298 is to be followed as described.

1Wa-4.0 Acceptance Limit: Report specific gravity at 15.6 °C (60 °F) per specifications
**CATEGORY 1: Wb. Pounds Per Gallon at 15.6 °C (60 °F)**

1Wb-1.0 Scope: This test method is determine the specific weight of the product at a defined temperature

1Wb-2.0 Test Method: As described below

1Wb-3.0 Test Procedure: Place one gallon of the sample oil in a glass jar in a water bath set to 15.6 °C (60 °F) and allow the temperature to stabilize. Then weight the sample and subtract the weight of the glass jar to determine the pounds per gallon weight.

1Wb-4.0 Acceptance Limit: Report per specifications to two decimal places

**CATEGORY 1Wc: Density -- ASTM D 1298**

1Wc-1.0 Scope: This test method covers determination using a glass hydrometer, of the density, relative density (specific gravity), or API gravity of crude petroleum, petroleum products, or mixtures of petroleum and nonpetroleum products normally handled as liquids, and having a Reid vapor pressure of 101.325 kPa (14.696 psi) or less.

1Wc-2.0 Test Method: ASTM D 1298

1Wc-3.0 Test Procedure: The ASTM D 1298 is to be followed as described.

1Wc-4.0 Acceptance Limit: Report per specifications
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

CATEGORY 1: X. Determination of Color – AOCS Color Cc 13b-45

1X-1.0 Scope: The biobased hydraulic fluids are identified by special green color which is to be verified against specification using the AOCS Color test

1X-2.0 Test Method: AOCS Color Cc 13b-45

1X-3.0 Test Equipment: Any high precision spectrophotometer incorporating the core color scales for edible oils and their derivatives. Some equipment include both Lovibond Colour and AOCS-Tintometer Color, scales that are accepted internationally for oil analysis, as well as Gardner Color for industrial oils and. Results can also be displayed in terms of CIE values and spectral data.

1X-4.0 Test Procedure: The AOCS Color Cc 13b-45is to be followed as described.

1X-5.0 Acceptance Limit: Report per specifications
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties


1Y-1.0 Scope: This test method covers the determination of specific heat capacity by differential scanning calorimetry. This method is similar to ISO 11357-4, but contains additional methodology not found in that method. Additionally, ISO 11357-4 contains practices not found in this standard. This method is similar to Japanese Industrial Standard K 7123, but contains additional methodology not found in that method.

1Y-2.0 Test Method: ASTM E 1269

1Y-3.0 Test Procedure: The ASTM E 1269 is to be followed as described.

1Y-4.0 Acceptance Limit: Report per specifications
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties


1Z-1.0 Scope:

This test method covers the determination of the thermal conductivity of nonmetallic liquids. It is applicable to liquids that are: (1) chemically compatible with borosilicate glass and platinum; (2) moderately transparent or absorbent to infrared radiation; and (3) have a vapor pressure less than 200 torr at the temperature of test. The thermal conductivity of a substance is a measure of the ability of that substance to transfer energy as heat in the absence of mass transport phenomena. Materials that have vapor pressures of up to 345 kPa (50 psia), absolute can be tested provided that adequate measures are taken to repress volatilization of the sample by pressurizing the thermal conductivity cell. The usual safety precautions for pressure vessels shall be followed under these circumstances.

1Z-2.0 Test Method:  
ASTM D 2717

1Z-3.0 Test Procedure:  
The ASTM D 2717 is to be followed as described.

1Z-4.0 Acceptance Limit:  
Report per specifications

1.Za.1. Scope

This test method provides a cooling time versus temperature pathway which is directly proportional to physical properties such as the hardness obtainable upon quenching of a metal. The results obtained by this test may be used as a guide in heat treating oil selection or comparison of quench severities of different heat treating oils, new or used.

1.Za.2. Equipment

A Quenchalizer sometimes called Quenchometer uses a two-liter sample of oil and an instrumented probe which is heated to 850 °C and submerged into the sample oil. The temperature of the oil and the probe are sensed and recorded to establish the cooling curve of the oil and the temperature change in the probe.
The Table below shows an example of the cooling characteristics of soybean along with the Cooling curve for the same oil in the following figure.

<table>
<thead>
<tr>
<th>Key Cooling Characteristics</th>
<th>Partially Hydrogenated Winterized Soybean Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media</td>
<td>Soy Oil Cooling Curve</td>
</tr>
<tr>
<td>Condition</td>
<td>UNI-NABL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Actual</th>
<th>Max.</th>
<th>Min.</th>
<th>˚C/Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Cooling Rate</td>
<td>77.40</td>
<td>53.00</td>
<td>47.00</td>
<td></td>
</tr>
<tr>
<td>Temp. at Max. Cooling rate</td>
<td>703.90</td>
<td>530.00</td>
<td>490.00</td>
<td>˚C</td>
</tr>
<tr>
<td>Cooling Rate at 300 ˚C</td>
<td>6.00</td>
<td>8.00</td>
<td>6.00</td>
<td>Sec</td>
</tr>
<tr>
<td>Time for Immersion at 600 ˚C</td>
<td>6.00</td>
<td>14.00</td>
<td>12.00</td>
<td>Sec</td>
</tr>
<tr>
<td>Time for Immersion at 400 ˚C</td>
<td>13.25</td>
<td>21.00</td>
<td>19.00</td>
<td>Sec</td>
</tr>
<tr>
<td>Time for Immersion at 200 ˚C</td>
<td>49.00</td>
<td>55.00</td>
<td>50.00</td>
<td>Sec</td>
</tr>
</tbody>
</table>
An Example of Cooling Curve for the Soybean Oil Above
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

CATEGORY 1: AA. Vapor Pressure – ASTM D 323 Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)

1.AA.1.0 Scope:

This test method covers procedures for the determination of vapor pressure of gasoline, volatile crude oil, and other volatile petroleum products. Because the external atmospheric pressure is counteracted by the atmospheric pressure initially present in the vapor chamber, the Reid vapor pressure is an absolute pressure at 37.8 ºC (100 ºF) in kilopascals (pounds-force per square inch). The Reid vapor pressure differs from the true vapor pressure of the sample due to some small sample vaporization and the presence of water vapor and air in the confined space.

1.AA.2.0 Test Method: ASTM D 323

1.AA.3.0 Test Procedure: The ASTM D 323 is to be followed as described.

1.AA.4.0 Acceptance Limit: Report per specifications – Most vegetable neat oils have a vapor pressure of 0 at 20 ºC (68 ºF).
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Physio-Chemical Properties

CATEGORY 1: AB: Saponification Number – ASTM D 94 Standard Test Method

1.AB-1.0 Scope:
This test method cover the determination of the amount of constituents in petroleum products such as lubricants, additives, and transmission fluids that will saponify under the conditions of the test. Because compounds of sulfur, phosphorus, halogens, and certain other elements that are sometimes added to petroleum products also consume alkali and acids, the results obtained indicate the effect of these extraneous materials in addition to the saponifiable material present. Results on products containing such materials, on used internal-combustion-engine crankcase oils, and on used turbine oils must be interpreted with caution.

1AB-2.0 Test Method: ASTM D 94

1AB-3.0 Test Procedure: The ASTM D 94 is to be followed as described.

1AB-4.0 Acceptance Limit: Report per specifications

____________________________
CATEGORY 1: AC.  Saponification Number – AOCS Cd 3-25 Saponification number

1.AC-1.0 Scope:  
This test method cover the determination of the amount of constituents in VEGETABLE OIL products such as lubricants, additives, and transmission fluids that will saponify under the conditions of the test. Because compounds of sulfur, phosphorus, the halogens, and certain other elements that are sometimes added to petroleum products also consume alkali and acids, the results obtained indicate the effect of these extraneous materials in addition to the saponifiable material present.

1.AC-2.0 Test Method: AOCS Cd 3-25

1.AC-3.0 Test Procedure:  
The AOCS Cd 3-25 is to be followed as described.

1.AC-4.0 Acceptance Limit:  
Report per specifications
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

CATEGORY 2

OXIDATION RESISTANCE PROPERTIES
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

OXIDATION STABILITY

Category 2: A. Oxidation Stability Index (OSI)

2A-1.0 Scope: This test method will be used to evaluate the oxidation stability of biobased hydraulic fluids.

2A-2.0 Test Method: AOCS Cd 12b-92 / EN 14112

2A-3.0 Test Procedure: Follow the procedure outlined in AOCS Cd 12b-92

2A-4.0 Acceptance Limit:
Report values obtained. Minimum requirement of base oil used in the formulation of all hydraulic fluids should be 100 hours with no more than 5000 ppm anti-oxidants added; and at minimum 150 hours for fully formulated hydraulic oils. Refer to each specification for specific requirement.

Oxidative Stability Instrument for Vegetable Oils
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

OXIDATION STABILITY

Category 2: B. Oxidation Stability Index (OSI) Rancimat Method

2B.-1.0 Scope: This test method will be used to evaluate the oxidation stability of biobased hydraulic fluids.

2B.-2.0 Test Method: EN 14112

2B.-3.0 Test Procedure: Follow the procedure outlined in EN 14112

2B.-4.0 Acceptance Limit:

Report values obtained. Minimum requirement of base oil used in the formulation of all hydraulic fluids should be 100 hours with no more than 5000 ppm anti-oxidants added; and at minimum 150 hours for fully formulated hydraulic oils. This assumes equal values for OSI and Rancimat values.

Components of Rancimat with Oil Sample and Conductivity Probe in De-ionized Water
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

OXIDATION STABILITY

Category 2: C. Oxidation Stability Based On Hydraulic Pump Test –Modified ASTM D 7043 (The test is modified by requiring 10 gallons instead of 5 gallons sample oil).

2C.-1.0 Scope: This test method Change in Viscosity Based on now withdrawn ASTM D 2271 and ASTM D 2882 revised for this specification using Eaton 20V Pump Cartridges -Modified ASTM D 7043.

2C.-2.0 Test Method: Modified ASTM D 7043

2C.-3.0 Test Procedure: Follow the procedure outlined in Modified ASTM D 7043 Record the oil viscosity every 10 hours during the first 100 hours and then every 100 hours thereafter until 1000 hours of test are completed. Also total acid number, of each oil sample is measured as required as part of the specifications. The cartridge weight should be recorded before and after the test required as part of the friction and wear tests.

2C.-4.0 Acceptance Limit: Total viscosity change in this test shall not exceed 10% for the unformulated base oil (with or without anti-oxidant) and shall not exceed 8% for the fully formulated product.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

OXIDATION STABILITY


2D.-1.0 Scope:

This test method covers the evaluation of oxidation stability of inhibited steam-turbine oils in the presence of oxygen, water, and copper and iron metals at an elevated temperature. The test method is also used for testing other oils such as hydraulic oils and circulating oils having a specific gravity less than that of water and containing rust and oxidation inhibitors. This test method is widely used for specification purposes and is considered of value in estimating the oxidation stability of lubricants, especially those that are prone to water contamination. It should be recognized, however, that correlation between results of this method and the oxidation stability of a lubricant in field service may vary markedly with field service conditions and with various lubricants. The precision statement for this method was determined on steam turbine oils. For biobased hydraulic oils, the results of this test should be used in combination of other oxidation tests not on the basis of this test alone.

2D.-2.0 Test Method: ASTM D 943

2D.-3.0 Test Procedure: Follow the procedure outlined in ASTM D 943

2D.-4.0 Acceptance Limit: Report per specifications
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

OXIDATION STABILITY

Category 2: E. ASTM D 4310 Oxidation, Sludging Tendencies of Mineral Oils (1000 hours)

2E-1.0 Scope:
This test method is used to evaluate the tendency of inhibited mineral oil based steam turbine lubricants and mineral oil based anti-wear hydraulic oils to corrode copper catalyst metal and to form sludge during oxidation in the presence of oxygen, water, and copper and iron metals at an elevated temperature. The test method is also used for testing circulating oils having a specific gravity less than that of water and containing rust and oxidation inhibitors.

This test method is a modification of Test Method D 943 where the oxidation stability of the same kinds of oils is determined by following the acid number of oil. The number of test hours required for the oil to reach an acid number that is double the starting acid number in mg KOH/g is the oxidation lifetime.

2E-2.0 Test Method:
ASTM D 4310 Oxidation, Sledging Tendencies of Mineral Oils

2E-3.0 Test Procedure:
Follow the procedure outlined in ASTM D 4310. Procedure A of this test method requires the determination and report of the weight of the sludge and the total amount of copper in the oil, water, and sludge phases. Procedure B requires the sludge determination only. The acid number determination is optional for both procedures.

2E-4.0 Acceptance Limit: Report per specifications for 1000 hours of test run
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

OXIDATION STABILITY

Category 2: F. ASTM D 2893 Oxidation Characteristics of Extreme Pressure Oils

2F.-1.0 Scope:

These test methods (A and B) cover the determination of the oxidation characteristics of extreme-pressure fluid lubricants, gear oils, or mineral oils. The changes in the lubricant resulting from these test methods are not always necessarily associated with oxidation of the lubricant. Some changes may be due to thermal degradation.

2F.-2.0 Test Method: ASTM D 2893 Oxidation Characteristics of Extreme Pressure Oils

2F.-3.0 Test Procedure:

Follow the procedure outlined in ASTM D 2893.

2F.-4.0 Acceptance Limit: Report per specifications for 100 hours of test run

Rotary Bomb Oxidation Test (RBOT) Fresh and Spent Copper Catalysts
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

OXIDATION STABILITY

Category 2:  G.  Corrosiveness (bimetallic couple) - ASTM D 4636

Corrosiveness (bimetallic couple): The hydraulic fluid shall be tested in accordance with the ASTM D 6547. Following the test, there shall be no evidence of corrosion, etching, pitting, or staining in excess of three spots of corrosion on any one disk.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

CATEGORY 3

VISCOMETRIC PROPERTIES
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Viscometric Properties

Category 3: A. KINEMATIC VISCOSITY – ASTM D 445

3A-1.0 Scope: This test method will be used to evaluate the ability of biobased hydraulic fluids to provide acceptable viscometric properties in cold, hot, and ambient conditions when used in hydraulic systems.

3A-2.0 Test Methods: ASTM D445

3A-3.0 Test Procedure: The ASTM D445 standard test method should be followed as given.

3A-4.0 Acceptance Limits: Report as per required specification

Table 4: Example of Specification Requirements for Changes in Viscosity at varied Temperatures for an ISO 46 Viscosity Grade Hydraulic Oil

<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>KINEMATIC VISCOSITY (CentiStokes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>700 MAX</td>
</tr>
<tr>
<td>40°C</td>
<td>36 MIN</td>
</tr>
<tr>
<td>40°C</td>
<td>44 MAX</td>
</tr>
<tr>
<td>100°C</td>
<td>8.55 MIN</td>
</tr>
</tbody>
</table>
Test Methods Relevant to Biobased Hydraulic Oil by Professor Lou Honary – Page 79
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Viscometric Properties

Category 3: B. VISCOSITY INDEX -- ASTM D 2270 - Standard Practice for Calculating Viscosity Index From Kinematic Viscosity at 40 °C and 100 °C

3B-1.0 Scope:
This test method will be used to calculate the viscosity index for biobased hydraulic fluids from the measured kinematic viscosities at 40 and 100°C.

3B-2.0 Test Methods: ASTM D 2270

3B-3.0 Test Procedure: The ASTM D 2270 standard test method should be followed as given – As reference: 1 cSt = 1 mm²/s = 10⁻⁶ m²/s.

3B-4.0 Acceptance Limits:
Vegetable based oils have considerably higher Viscosity Index than same viscosity petroleum oils. The Biobased hydraulic fluid must have a minimum viscosity index as specified in each hydraulic oil specification.

As an example, a viscosity of 40 cSt at 40 °C and 8.55 at 100 °C will result in a calculated Viscosity Index of 200. There are on-line calculators that can be used to plug in viscosities at 40 °C and 100 °C and calculate the Viscosity Index. An example can be found at:
http://www.mehf.com/2.c.4.e.1.htm
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Viscometric Properties

Category 3: C. DYNAMIC VISCOSITY -- ASTM D 7042

3C-1.0 Scope:
This test method specifies a procedure for the concurrent measurement of both the dynamic viscosity, $\eta$, and the density, $\rho$, of liquid petroleum products and crude oils, both transparent and opaque. The kinematic viscosity, $n_\gamma$, can be obtained by dividing the dynamic viscosity, $\eta$, by the density, $\rho$, obtained at the same test temperature.

3C-2.0 Test Methods:
ASTM D 7042 Standard Test Method for Dynamic Viscosity and of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity). The result obtained from this test method is dependent upon the behavior of the sample and is intended for application to liquids for which primarily the shear stress and shear rate are proportional (Newtonian flow behavior).

3C-3.0 Test Procedure:
The ASTM D 7042 standard test method should be followed as given.

3C-4.0 Acceptance Limits: Report the value of dynamic viscosity
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Viscometric Properties

Category 3: D. BROOKFIELD VISCOSITY -- ASTM D 2983, ISO 9262, IP 267

3D-1.0 Scope:

This test method describes how to measure apparent viscosity directly without the errors associated with either interpolation or extrapolation of experimental data. The test method uses the SI unit, milliPascal-second (mPas), as the unit of viscosity instead of centiPose cP. (1 cP = 1 mPas). Viscosity values obtained by either interpolation or extrapolation are subject to errors caused by gelation or non-Newtonian response to rotor speed, or both. Only in the case of known Newtonian oils is interpolation acceptable for the purpose of calibrating the rotor and glass cell.

3D-2.0 Test Methods:

The ASTM D 2983 test method covers the use of the Brookfield viscometer and a low-temperature bath for the determination of the low-shear-rate viscosity of lubricants. The test may operate in the viscosity range of 500 to 1,000,000 mPas (cP). The bath-controlled temperature is selected within the range of +5 °C to -40 °C (-41 °F to -40 °F).

3D-3.0 Test Procedure: Follow the procedure described in ASTM D 2983

3D-4.0 Acceptance Limits: Report per specification
Brookfield Viscosity Tester
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Viscometric Properties


3E-1.0 Scope:

This test method covers the evaluation of the shear stability of polymer-containing fluids. The test method measures the percent viscosity loss at 100 °C of polymer-containing fluids when evaluated by a diesel injector apparatus procedure that uses European diesel injector test equipment. The viscosity loss reflects polymer degradation due to shear at the nozzle.

3E-2.0 Test Procedure:

ASTM D 6278 standard test method should be followed as given.

3E-3.0 Test Methods:

ASTM D6278 Standard Test Method for Shear Stability of Polymer Containing Fluids Using a European Diesel Injector Apparatus

3E-4.0 Acceptance Limits:

Report as per specification
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Viscometric Properties

Category 3: F. Shear Stability – Shear stability by Sonic Oscillation (Also see ASTM D 2603)

3F1-1.0 Scope:

The shear stability is determined by subjecting a convenient volume of the hydraulic fluid to irradiation by sonic oscillation for a fixed period of time and the change in viscosity is determined in accordance with ASTM D 445. A standard polymer containing oil is run frequently to assure performance of the equipment. The shear stability shall be determined as follows.

3F1-2.0 Test Methods:

Using the following apparatus and according to the Procedure described below:

Apparatus: The apparatus shall consist of the following:

a. Ultrasonic generator and probe (a unit made by Wave Energy Systems, Inc., Newtown, PA, designated mode 1 WW201 with Titanium Horn has been found satisfactory).
b. Laboratory platform support, “Big Jack”) Arthur H. Thomas catalog no. 8854-J40 has been found satisfactory).
c. Sample jars, 120 mL, wide mouth (Arthur H. Thomas catalog no. 3852 or equivalent).
e. Water bath, 203 mm diameter by 67 mm deep (Arthur H. Thomas catalog no 9816-B15 or equivalent).
f. Timer, automatic, such that irradiation times can be preset in the range from 1 to 60 minutes, (Gralab model 171, Denico Gray Company, Dayton, Ohio, is suitable).

3F1-3.0 Test Procedure:

Reference fluid: A reference fluid is necessary for calibration of equipment. ASTM reference fluid A has been used as the
primary reference fluid. This fluid is a petroleum oil containing a polymer capable of being broken down by turbulence at high rates of shear. The reference fluid contains 7.8 percent by weight of polymer concentrate and the following typical properties:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Viscosity, m²/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>99°C</td>
<td>$11 \times 10^{-6}$</td>
</tr>
<tr>
<td>38°C</td>
<td>$62 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

Calibration of apparatus: The reference fluid provides a practical way of defining the performance, or level of severity, of an ultrasonic generator so that satisfactory comparisons can be made between tests run on different days with the same unit, or between tests run with different units. The procedure described below is intended to establish a repeatable performance level for a given unit.

a. With the instrument set for proper operation in accordance with the manufacturer’s instructions, make three successive runs on 30 mL samples of the reference fluid using a power setting of 40 watts, but varying the time of treatment, e.g., 10 minutes, 20 minutes, 30 minutes (samples must be cooled in ice bath during irradiation). For each run, calculate in viscosity versus time, find the irradiation time necessary to produce a stated loss in viscosity, for example 15 percent. Use this time setting for subsequent tests run that day. Future calibration work may be facilitated by adjusting the irradiation time as indicated by an initial run for this predetermined time period. This method of standardizing the operating severity level of the apparatus makes it possible to compare results obtained on different days.

b. This procedure may be used to establish severity levels appropriate for the requirements of a number of specific applications. Larger sample sizes of course will require either a higher power setting or a longer treatment time. Once the conditions for a given level of
severity has been established, it is possible to compare the shear stability of fluids at one or many irradiation times.

Test procedure: The hydraulic fluid sample shall be tested as follows:

a. Use a syringe and transfer 30 mL of the sample to a 120 mL, wide mouth glass jar. Place the jar in an ice water bath centered on the platform of the laboratory jack inside the soundproof treatment box. Raise the jack until the probe is immersed 3 to 5 mm into the sample.

b. Close the treatment box and turn on the generator unit. Adjust the total power output with the power control to 40 watts. Start the time and continue shearing for the time previously determined necessary to produce a 15 percent viscosity loss in the reference fluid.

c. When shearing is complete, shut off the unit. Open the treatment box, lower the jack and remove the jar containing the sheared sample. Wipe off probe tip with clean tissue.

d. Determine viscosity at 40 °C and at -40 °C in accordance with ASTM D 445.

e. Calculation Calculate the percentage loss of viscosity as follows:

\[
\text{Percent viscosity loss} = \left( \frac{V_o - V_f}{V_o} \right) \times 100
\]

Where:

\( V_o \) = Viscosity, cSt of oil before irradiation.

\( V_f \) = Viscosity, cSt of oil after irradiation.

3F1-4.0 Acceptance Limits: Report as per specification
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Viscometric Properties

Category 3: G. Viscosity Pressure Relationship

3G-1.0 Scope:

The viscosity and pressure—viscosity coefficient of a lubricant has a major influence on film thickness formation and shear stresses in an Elastohydrodynamic lubrication contact. It is therefore important to determine the influence of pressure and temperature on these parameters.

3G-2.0 Test Methods:

A falling-piston or falling-ball viscometer is comprised of a tube with a measured liquid, piston or ball inside the tube, an electrical magnet, and a magnetic switch. The piston or ball is made of a ferromagnetic material. It is first lifted to the top of the tube by the magnet and is then permitted to drop to the bottom of the tube under the force of gravity. The moment when the piston or ball reaches the bottom is sensed by a magnetic switch. The time required to pass the length of the tube is proportional to the viscosity. Other methods such as laser Doppler technique has also been used. The tube can be pressurized to determine impact on the viscosity as observed by the change in time for the ball to drop.

3G-3.0 Test Procedure: See description of Falling Piston Viscometer and reference table as follows:

Falling-piston or falling-ball viscometer. 1 = ferromagnetic ball, 2 = electrical magnet, 3 = magnetic switch, 4 = liquid, 5 = container.
Table for Reference Pressure-Viscosity Values

Pressure–viscosity coefficients for different oils

<table>
<thead>
<tr>
<th>Lubricant</th>
<th>Pressure–viscosity coefficient, $\alpha$ (GPa$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
</tr>
<tr>
<td>Naphthenic mineral oil</td>
<td>26.5</td>
</tr>
<tr>
<td>Mix of paraffinic/naphthenic oil, 50–50</td>
<td>23.0</td>
</tr>
<tr>
<td>Paraffinic mineral oil</td>
<td>19.8</td>
</tr>
<tr>
<td>Rapeseed oil</td>
<td>18.9</td>
</tr>
<tr>
<td>Polyglycol</td>
<td>18.7</td>
</tr>
<tr>
<td>Pine tree oil</td>
<td>17.2</td>
</tr>
<tr>
<td>TMP-ester</td>
<td>15.5</td>
</tr>
<tr>
<td>Diester</td>
<td>14.6</td>
</tr>
<tr>
<td>Polyalphaolefin</td>
<td>15.5</td>
</tr>
</tbody>
</table>

3G-4.0 Acceptance Limits: Report as per specification
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Viscometric Properties


3H-1.0 Scope:

Bulk modulus is a property that indicates the compressibility of a fluid which impacts the response time of hydraulic systems operating at high pressures. It can be described as a measure of resistance to compressibility of a fluid. Bulk modulus is the index of stiffness among the physical properties of fluid. While liquids are considered incompressible, as pressure increases all fluids compress proportional to the amount pressure applied. Also, the presence of air and evaporation of chemicals within the oil can increase compressibility. Compression of fluids causes its temperature to increase which also causes its volume to expand and in a confined space result in further increase in pressure. If compression is slow the generated heat can have time to dissipate (isothermal process). However, if compression takes place rapidly so that heat cannot dissipate (adiabatic) then the pressure increases correspondingly, which is common to most hydraulic systems.

The term Bulk Modulus refers to the reciprocal of compressibility and defined by the slope of the curve when plotted against the specific volume (at various pressures). Since specific volume is dimensionless, units of Bulk Modulus are the same as pressure like pounds per square inch (psi), bar, Pascal, or N/m². A flat slope indicates a fairly compressible fluid having a low bulk modulus. Bulk modulus is determined either under isothermal (constant temperature) or adiabatic (isentropic) condition.

There are two different ways to define the slope of pressure-specific volume curve, or the bulk modulus. Secant bulk modulus and tangent bulk modulus.
Secant bulk modulus can be calculated as the product of the original volume and the slope of the line drawn from the origin to any specified point on the curve of pressure-specific volume (or the slope of the scant line to the point). Mathematically,

\[
\text{Scant bulk Modulus} = \frac{[(\text{Volume at zero pressure}) \times \text{Pressure}]}{[(\text{Volume at zero pressure}) - (\text{Volume at desired pressure})]}
\]

Tangent bulk modulus can be calculated as the product of the original volume at any specified pressure and the derivative of fluid pressure with respect to volume at the point (the slope of the tangent line to the point). Mathematically,

\[
\text{Tangent Bulk Modulus} = V_0 \times \left(\frac{dP}{dV}\right)
\]

Sonic bulk modulus is derived from the sonic velocity in the fluid and its density. Assuming the constant density of the fluid, it is easily obtained from the propagation velocity of pressure wave, so it is widely used to measure the dynamic bulk modulus. The sonic bulk modulus has the same value of the adiabatic bulk modulus.

3H-3.0 Test Procedure: Test rigs capable of applying controlled pressure and monitoring volume and temperature are used for determination of bulk modulus.

3H-4.0 Acceptance Limits:

For some petroleum based hydraulic fluids, the isothermal secant bulk modulus of the hydraulic fluid is specified at $1.379 \times 10^6$ kilopascals (kPa) minimum, at 40 °C (104 °F) at pressures between 0 and 68,950 kPa.

While bulk modulus values in the laboratory are an indication of the fluid's performance, hydraulic fluids are quickly aerated in use and their bulk modulus changes. As a result, the test results are combined with other values to ensure proper performance. Example of ranges of the bulk modulus under Adiabatic conditions at 24 °C (76 °F):

<table>
<thead>
<tr>
<th>Pressure (PSI)</th>
<th>Bulk Modulus (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>225,000 – 235,000</td>
</tr>
<tr>
<td>100</td>
<td>240,000 – 245,000</td>
</tr>
<tr>
<td>2000</td>
<td>250,000 – 255,000</td>
</tr>
<tr>
<td>3000</td>
<td>260,000 – 270,000</td>
</tr>
</tbody>
</table>
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

CATEGORY 4

COMPATIBILITY
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

COMPATIBILITY


4A-1.0 Scope: The ASTM D 4289 and ASTM D 2240 (durometer hardness) test methods will be used to evaluate the compatibility of lubricating oils with selected elastomeric materials.

4A-2.0 Method: ASTM test method ASTM D 4289 "Standard Test Method for Elastomer Compatibility of Lubricating Greases and Fluids" and D2240 "Rubber property-durometer hardness" will be used to evaluate the compatibility of lubricants with a series of specific elastomers.

Specimens of the elastomer materials are aged in the candidate oil for 1000 hours at 100°C for all of the materials specified excepting 1E0724 urethane which is aged at 80°C. A comparison of change in hardness, tensile strength, elongation, and stress at 100% elongation is made to determine the elastomer/oil compatibility.

4A-3.0 Test Procedure:

Initial properties of the elastomer samples including the hardness, tensile properties, elongation, and stress at 100% elongation must be evaluated and recorded before aging. Aging the test specimens in the candidate oil should be performed at 100°C for 1000 hours by following the procedure outlined in ASTM D 4289. Determine the change in volume, loss in tensile strength, loss in elongation and residual elongation following ASTM D 4289 and the change in the Shore A hardness by following ASTM D 2240/Report all data.

4A-4.0 Acceptance Limits:
As an example, the allowed change in hardness, relative volume change, loss in tensile strength, loss in elongation, and residual elongation for the selected elastomeric materials are given in the table below:

**Table for General Specification Requirements for Elastomer Compatibility**

<table>
<thead>
<tr>
<th>Test Temp. °C</th>
<th>Shore A Hardness Change, Pts.</th>
<th>Relative Volume %Change</th>
<th>Loss in Tensile Strength % Max</th>
<th>Loss in Elongation, % Max</th>
<th>Residual Elongation, % MIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>HNBR(1 e2719)</td>
<td>100</td>
<td>+10/−15</td>
<td>−3/+20</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>NBR (1e0741)</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FKM (1e0804)</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AU (1e0724)</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEO-PRENE (1e0809)</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

COMPATIBILITY


4B-1.0 Scope:

This test method covers twelve types of rubber hardness measurement devices known as durometers: Types A, B, C, D, DO, E, M, O, OO, OOO, OOO-S, and R. The procedure for determining indentation hardness of substances classified as thermoplastic elastomers, vulcanized (thermoset) rubber, elastomeric materials, cellular materials, gel-like materials, and some plastics is also described. It is used to determine the hardness as indication of swelling of elastomer materials after they are exposed to test oils at specified temperatures for specified periods of time, like those described in the ASTM D 471.

4B-2.0 Test Method:

This test method is based on the penetration of a specific type of indentor when forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material. The geometry of the indentor and the applied force influence the measurements such that no simple relationship exists between the measurements obtained with one type of durometer and those obtained with another type of durometer or other instruments used for measuring hardness. This test method is an empirical test intended primarily for control purposes. No simple relationship exists between indentation hardness determined by this test method and any fundamental property of the material tested. For specification purposes, it is recommended that Test Method ASTM D 785 be used for materials other than those described in 1(A-E).
FIG. 1 (a) Type A and C Indentor

FIG. 1 (b) Type B and D Indentor (continued)

FIG. 1 (c) Type O, DO, and OO Indentor (continued)
FIG. 1(d) Type M Indentor (continued)

FIG. 1(e) Type OOO Indentor (continued)
4B-3.0 Test Procedure: Follow the procedure outlined in ASTM D 2240

4B-4.0 Acceptance Limit: Report per specification

Durometer for testing ASTM D 2240 – For Testing Hardness of Elastomers
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Compatibility


4C-1.0 Scope: This procedure will provide some general guidance on seal testing as a basis for comparing different fluid types.

4C-2.0 Test Methods: SAE-AMS 3217/2B - Test Slabs, Acrylonitrile Butadiene (NBR-L), Low Acrylonitrile

4C-3.0 Test Procedure: This procedure is used to select the elastomer sample

4C-4.0 Acceptance Limits:

Measuring Weight Change Due to Elastomer Swelling (left)
Special Attachment for Weighing Rubber Sample
Table 6: Specification Requirements Elastomer Compatibility

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Conditions and Length</td>
<td>Immersion in fluid for 70 and 168 hours at 60 °C</td>
<td>60 °C and 1000 hours may be called upon for some specifications</td>
</tr>
<tr>
<td>Measurements</td>
<td>Change in volume and hardness</td>
<td>Tensile strength, elongation, and ASTM D 2240</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Durometer Standard Test may also be reported</td>
</tr>
<tr>
<td>Seal Materials</td>
<td>Standard elastomers: SRE-NBR1, HNBR, Viton, EPDM, urethane, polyacrylate, silicone, VMAC, nitrile, neoprene</td>
<td>Or others as identified by end users</td>
</tr>
<tr>
<td>Acceptance Limits</td>
<td>Change in volume: per specification</td>
<td>Report per specification</td>
</tr>
<tr>
<td></td>
<td>Change in shore A hardness: per specification</td>
<td></td>
</tr>
</tbody>
</table>
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Compatibility


4D-1.0 Scope: Compatibility with Metallic Components can be determined in existing tables that preset compatibility with various metals along with elastomers.

4D-2.0 Test Method: ASTM D 5185

4D-3.0 Test Procedure: Both base oils and the fully formulated hydraulic oil are tested and the amount of each of the following elements are listed

4D-4.0 Acceptance Limit: Report the results of each element present in the base oil and fully formulated hydraulic fluid.

Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Compatibility

Category 4: E. Compatibility with Metallic Components

4E-1.0 Scope: Compatibility with Metallic Components can be determined in existing tables that preset compatibility with various metals along with elastomers.

4E-2.0 Test Method: Using Table of Compatibility at the end of this section compatibility of base oil with metallic elements used in the hydraulic system will be listed.

4E-3.0 Test Procedure: The elemental analysis of the fluid as per Category 4D, will indicate the presence of various metallic elements.

4E-4.0 Acceptance Limit: The base oil should be compatible with the elements determined in the elemental analysis performed in Category 4D.

http://www.catpumps.com/pdfs/chem_compatibility_chart.pdf

Table of Compatibility for Category 4: E. Compatibility with Metallic Components

<table>
<thead>
<tr>
<th>CHEMICAL</th>
<th>MATERIALS</th>
<th>ELASTOMERS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BRASS</td>
<td>CAST IRON</td>
</tr>
<tr>
<td>ISOPROPYL ACETATE</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>ISO-PROPYL ALCOHOL</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>ISO-PROPYL BENZENE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>ISO-PROPYL CHLORIDE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>ISO-PROPYL ETHER</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>HYDROCARBON 60</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>JET FUEL [JP-1 THRU JP-4]</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>KEROSENE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>KETONES</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>LACQUERS</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>LACQUER THINNERS</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>LACTIC ACID (COLD)</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>LACTIC ACID (HOT)</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>LAMOLIN</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LARD (ANIMAL FAT)</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LATEX — ABRASIVE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LAVENDER OIL</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LEAD ACETATE</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>LEAD NITRATE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LEAD SULFAMATE</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>LEMON OIL</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>LIGNIN LIQUOR</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LIGROSIN</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LIME</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LIME BLEACH</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LIME SULFUR</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LINDOL</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>LINOleine ACID</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>LINSEED OIL</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>LIQUID PETROLEUM GAS [LOW SEAL L]</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LIQUOR-PULP MILL</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LIQUOR SULFATE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LITHIUM BROMIDE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LITHIUM CHLORIDE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LITHIUM HYDROXIDE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>LUBRICATING OILS</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Compatibility

Category 4: F. COMPATIBILITY WITH OTHER FLUIDS

4F.1 Scope: This test method will be used to evaluate the compatibility of different hydraulic fluid additive formulations with one another. Adapted from Caterpillar BF-1 Specification

4F.2 Test Method: The test oil is mixed with catalogue NOS. 4693, 5343 and 5235 reference oils, heated, cooled, and centrifuged to determine residue.

4F.3 Test Equipment: 100 mL centrifuge tubes high speed centrifuge capable of producing 100 000 m/s² relative centrifugal force

4F.4 Test Procedure: A 50 mL sample of the test fluid and 50 mL of one of the three reference fluids are poured into a 100 mL centrifuge tube. Shake well and heat to 204°C. Cool to room temperature. Centrifuge for 30 min at 1000 000 m/s². The tube containing the test sample and the selected fluids shall be examined for precipitation of insoluble residue and separated components. Repeat the procedure for the remaining two reference fluids.

4F.5 Acceptance Limits: No sedimentation or precipitation is allowed.

____________________________

Category 4: F-1. COMPATIBILITY WITH OTHER FLUIDS – Augmented Methods for Biobased Oils

4F-1.1 Scope: This test method will be used to evaluate the compatibility of different hydraulic fluid additive formulations with one another using a hydraulic pump test described earlier. It is based on hydraulic pump test now withdrawn modified ASTM D 7043 (formerly ASTM D 2882 and ASTM 2271) revised for this specification using Eaton 20V Pump Cartridges - Modified ASTM D 7043.
4F-1.2 Test Method: Pump Test - Based on the modified ASTM D 4073 for this specification using Eaton 20V Pump Cartridges - Modified ASTM D 7043

4F-1.3 Test Equipment:

Hydraulic pump test unit running at 1200 rpm operating a 20V vane pump, variable frequency drive preferred for ramp up starting speed, but as described in the Modified ASTM D 7043

4F-1.4 Test Procedure:

5 gallon of the biobased hydraulic oil is mixed with 5 gallon of its equivalent petroleum-based hydraulic oil as specified in the Honary Hydraulic Oil Test Recommendations’s existing specification are mixed and added to the hydraulic reservoir. The test is operated at 1000 psi for 500 hours at 79 °C (175 °F) +/- 3 degrees. Pump Cartridge weight, viscosity and total acid number are measure before and after the test. After the 500-hour test is completed, immediately after shut-down, 500 mL of the oil from the reservoir is placed in tall graduated glass beaker and placed in well lit area at room temperature [20 °C (68 °F)] for a period of 30 days.

4F-1.5 Acceptance Limits: Any of the following will constitute failure:

- More than 3% change in the viscosity of the oil as measure at 500th hour of test and compared to the initial viscosity at zero hour. Viscosity is measured at 40 °C.
- Total acid number at 500th hours exceeding 3.0 milligrams of potassium hydroxide per gram of hydraulic oil (mg KOH/g).
- Weight loss of cam ring and vanes of more than 50 mg at the end of the test.
- Presence of any visible separation, sedimentation or non-uniformity in the mixture after 30 days post pump test.

Category 4: F-2. FLUID COMPATIBILITY ASTM WK 22253 - New Practice for Evaluating Compatibility of Mixtures of Hydraulic Fluids (under development)

4F2.1. Scope: This practice covers the compatibility of mixtures of hydraulic fluids as defined by Specifications D 6158, ISO 11158, and ISO 15380.
4F-2.2 Test Method:

This practice can be used to evaluate new (unused) lubricant compatibility or the effects of adding new (replacement) lubricant to in-service (original) lubricant in the system.

To evaluate primary compatibility using this practice, the replacement fluid shall pass the ISO 13357-1 Stage II filterability test. The original fluid may either pass or fail the ISO 13357-1 filterability test, Stage II.

Primary testing is conducted on both neat, constituent fluids and mixtures in 2:98, 10:90, and 50:50 ratios using the ISO 13357-1 filterability test, Stage II.

Secondary testing is suggested when circumstances indicate the need for additional testing.

This practice does not evaluate the wear prevention characteristics, load-carrying capacity, or the mechanical shear stability of lubricant mixtures while in service. If this is specified as anti-wear (AW) hydraulic oil, then extreme pressure (EP), or shear stability are to be evaluated, further testing of these parameters may be required.

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 limitations prior to use. There is no standard practice for evaluating the compatibility of hydraulic fluids. Increasingly conventional zinc-containing mineral-oil-based hydraulic fluids are being converted to ashless or biodegradable fluids. The amount of flushing required to convert these systems depends upon the compatibility properties of the fluid.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Compatibility

Category 4: G. Additive Stability - Augmented Method for Biobased Oils

4G-1.1 Scope:

This test method will be used to evaluate the compatibility of additive stability of a hydraulic pump test described earlier. It is based on hydraulic pump test Modified ASTM D 7043 Formerly (ASTM D 2271 and ASTM D 3882) for this specification using Eaton 20V Pump Cartridges - Modified ASTM D 7043.

4G-1.2 Test Method:

Pump Test - Based on now withdrawn Modified ASTM D7043 for this specification using Eaton 20V Pump Cartridges - Modified ASTM D 7043.

4G-1.3 Test Equipment:

Hydraulic pump test unit running at 1200 rpm operating a 20V vane pump, with variable frequency drive for ramp up starting speed, but as described in the Modified ASTM D 7043

4G-1.4 Test Procedure:

Using ASTM D 5185 test methods record the elemental content of the hydraulic oil along with its oxidation stability, viscosity, Saponification number, and Total Acid Number. Pump cartridge components are also measured according to ASTTMM D 5185 procedure. Then 10 gallons of the biobased hydraulic oil is placed in the hydraulic reservoir. The test is operated at 1000 psi for 500 hours at 79 °C (175 °F) +/- 3 degrees. Pump Cartridge weight, elemental content of the hydraulic oil along with its oxidation stability, viscosity, Saponification number, and Total Acid Number are measured immediately after the test. After the 500-hour test is completed, immediately after shut-down, 500 mL of the oil from the reservoir is placed in tall graduated glass beaker and placed in well lit area at room temperature (20 °C (68 °F) for a period of 30 days.
4G-1.5 Acceptance Limits: Any of the following will constitute failure:

- More than 10% change in the amount of any element recorded in the elemental analysis before the test and after the test.
- More than 3% change in the viscosity of the oil as measure at 500th hour of test and compared to the initial viscosity at zero hour. Viscosity is measured at 40 °C.
- Total acid number at 500th hours exceeding 3.0 milligrams of potassium hydroxide per gram of hydraulic oil (mg KOH/g).
- Weight loss of cam ring and vanes is more than 50 mg at the end of the test
- Change in saponification value greater than 3%
- Presence of any visible separation, sedimentation or non-uniformity in the mixture after 30 days post pump test.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Compatibility

Category 4: H. Panel Coker Test

4H-1.0 Scope:

The Panel Coker Test is a method for determining the relative stability of industrial lubricants in contact with hot metal surfaces.

4H.2.0 Test Equipment:

The test apparatus consists of a rectangular stainless steel reservoir, inclined 25° from horizontal, containing the test lubricant. This reservoir is covered by a machined steel piece fitting integrally into the top of the sump, and framing a 3 ½” x 1 ½” aluminum test panel. The test panel is held in place by a heating element, and thermocouple probes are used to control the temperature of the panel. A horizontal shaft containing a series of tines is positioned above the oil and rotated at 1000 rpm. During rotation of this shaft, the tines sweep through the oil and oil droplets are thrown onto the heated aluminum test panel.

4H.3.0 Test Procedure:

Operation of the apparatus consists of heating the test panel (weights measured prior to test) to the desired temperature 316 °C (600 °F) actuating the splasher motor and maintaining this temperature within close tolerances for the duration of the test. The duration of the normal test is six hours from the time the splasher is started.

On completion of the test, the heating element is turned off and the splashing is continued until the panel is cool enough to be handled. It is then removed from the holder and washed with solvent to remove all excess oil. Test panels are then weighed to determine the amount of decomposition products adhering to the surface. Weight gain of the test panel and the amount of oil consumed during the test is an indication of the lubricant’s performance under high temperature conditions.
4H.4.0 Acceptance Limits:

Report weight of deposits as per specification. For example, leaded gear oils give deposits in the range of 700-1000 mg, in contrast to the 150-200 mg obtained with the sulfur/phosphorus type.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Compatibility

Category 4: I. Separation of Insoluble Materials or Gumming of the Fluid – Augmented Method for Biobased Oils

4I-1.1 Scope:

This test method will be used to evaluate the separation of Insoluble Materials or Gumming of the Fluid of a hydraulic pump test described earlier. It is based on hydraulic pump test now withdrawn ASTM D 2271 revised for this specification using Eaton 20V Pump Cartridges - Modified ASTM D

4I-1.2 Test Method: Pump Test - Based on Modified ASTM D

4I-1.3 Test Equipment:

Hydraulic pump test unit running at 1200 rpm operating a 20V vane pump, (with variable frequency drive preferred for ramp up starting speed), but as described in the Modified ASTM D

4I-1.4 Test Procedure:

Using ASTM D 5185 test methods record the elemental content of the hydraulic oil along with its oxidation stability, viscosity, Saponification number, and Total Acid Number. Pump cartridge components are also measured according to ASTM D 5185 procedure. Then 10 gallons of the biobased hydraulic oil is placed in the hydraulic reservoir and after the first hour of operation 2% or 0.2 gallons of water added to the reservoir. The test is operated at 1000 psi for 500 hours at 79 °C (175 °F) +/- three (3) degrees; and at each of the next four 100 hour intervals another 2% or 0.2 gallons of water is added to the reservoir. Pump Cartridge weight, elemental content of the hydraulic oil along with its oxidation stability, viscosity, Saponification number, and Total Acid Number are measured immediately after the test. After the 500-hour test is completed, immediately after shut-down, 500mL of the oil removed from the reservoir is placed in tall graduated glass beaker and placed in well lit area at room temperature [20 °C (68 °F)] for a period of 30 days. In addition, 1% (5mL) water and .01% (.05mL) sulfuric acid are to be added to the sample and gently mixed.
4I-1.5 Acceptance Limits: After the requisite 30-day observation, any of the following will constitute failure:

- More than 10% change in the amount of any element recorded in the elemental analysis before the test and after the test.
- More than 5% change in the viscosity of the oil as measured at 500th hour of test and compared to the initial viscosity at zero hour. Viscosity is measured at 40 °C.
- Total acid number at 500th hours exceeding 5.0 milligrams of potassium hydroxide per gram of hydraulic oil (mg KOH/g).
- Weight loss of cam ring and vanes of more than 50 mg at the end of the test.
- Change in saponification value greater than 5%
- Presence of any visible separation, or non-uniformity in the mixture after 30 days post pump test. Some sedimentation is expected.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

CATEGORY 5

Category 5 – Storage, Storage Stability, and Shelf Life Requirements

5A. Storage Stability -- as described in Section 5A
5B. Low Temperature Storage Stability -- as described in Section 5B
5C. Long Term Storage Stability -- as described in Section 5C
5D. Shelf-Life Requirements -- as described in Section 5D
5E. Biostability
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Storage, Storage Stability, and Shelf Life Requirements

CATEGORY 5: A. STORAGE STABILITY

5A-1.0 Scope: This test method will be used to evaluate the storage stability of biobased hydraulic fluids.

5A-2.0 Test Method: As Described

5A-3.0 Test Equipment: Environmental Chamber

5A-4.0 Test Procedure:

This test would be performed on two samples side by side one exposed to open air and one topped off with nitrogen. The total acid number, oxidation stability, and viscosity of the sample should be tested and recorded before testing.

Two tall graduated cylinders with dimensions: diameter 2”, height 18” are filled with 500 mL of sample oil. One sample is topped of with nitrogen by blowing nitrogen at 3 psi through a 1/6” plastic tube for five minutes and then covered with high temperature oven safe plastic. The samples are placed inside the environmental chamber and programmed to alternate 12 hours at each of test temperatures of 60 ºC (140 ºF) and 0 ºC (32 ºF) for a period of 10 days (240 hours).

5a-5.0 Acceptance:

The samples should be inspected visually for any sign of settling or separation. Separation of any kind or settling of any component would be considered a failed product. Total acid number, oxidation stability, and viscosity should be tested following the testing. The following table is used for evaluation of these properties.
Table for Specification Requirements for Changes in OSI, TAN, and Viscosity after Storage Test

<table>
<thead>
<tr>
<th>Property</th>
<th>Initial Reading</th>
<th>After Test Reading</th>
<th>Difference</th>
<th>Pass With. Nitrogen Barrier</th>
<th>Pass W/O Nitrogen Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation Stability Index (hours)</td>
<td></td>
<td></td>
<td>Δ OSI</td>
<td>1%&lt;</td>
<td>2%&lt;</td>
</tr>
<tr>
<td>Total Acid Number (mg KOH/g)</td>
<td></td>
<td></td>
<td>Δ TAN</td>
<td>1%&lt;</td>
<td>2%&lt;</td>
</tr>
<tr>
<td>Viscosity in cSt at 40 °C (104°F)</td>
<td></td>
<td></td>
<td>Δ Viscosity</td>
<td>1%&lt;</td>
<td>2%&lt;</td>
</tr>
</tbody>
</table>

**Typical Environmental Chambers for Exposing Sample Oils to Changing Climates** (left) and **Graduated Glass Cylinders**
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Storage, Storage Stability, and Shelf Life Requirements

CATEGORY 5B. LOW TEMPERATURE STORAGE STABILITY

5B-1.0 Scope: This test method will be used to determine the low temperature storage stability of hydraulic fluids.

5B-2.0 Test Method: Proposed

5B-3.0 Test Procedure: Environmental Chamber

5B-4.0 Acceptance Limit:

This test would be performed on two samples side by side one exposed to open air and one topped off with nitrogen. The total acid number, oxidation stability, and viscosity of the sample should be tested and recorded before testing.

Two tall graduated cylinders with dimensions: diameter 2”, height 18” are filled with 500 mL of sample oil. One sample is topped off with nitrogen by blowing nitrogen at 3 psi through a 1/6” plastic tube for five minutes and then covered with high temperature oven safe plastic. The samples are placed inside the environmental chamber and programmed to alternate 12 hours at each of test temperatures of -40 °C (40 °F) and 60 °C (140 °F) for a period of 100 hours.

5B-5.0 Acceptance:

The samples should be inspected visually for any sign of settling or separation. Separation of any kind or settling of any component would be considered a failed product.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Storage, Storage Stability, and Shelf Life Requirements

CATEGORY 5: C.  LONG TERM STORAGE STABILITY

5C-1.0 Scope:

This test method will be used to evaluate the storage stability of biobased hydraulic fluids.

5C-2.0 Test Method:

As Described

5C-3.0 Test Equipment:

Environmental Chamber

5C-4.0 Test Procedure:

This test would be performed on two samples side by side one exposed to open air and one topped off with nitrogen. The total acid number, oxidation stability, and viscosity of the sample should be tested and recorded before testing.

Two tall graduated cylinders with dimensions: diameter 2”, height 18” are filled with 500 mL of sample oil. One sample is topped off with nitrogen by blowing nitrogen at 3 psi through a 1/6” plastic tube for five minutes and then covered with high temperature oven safe plastic. The samples are placed inside the environmental chamber and programmed to alternate 12 hours at each of test temperatures of 60 °C (140 °F) and 0 °C (32 °F) for a period of 100 days (2,400 hours).

5C-5.0 Acceptance:

The samples should be inspected visually for any sign of settling or separation. Separation of any kind or settling of any component would be considered a failed product. Total acid number, oxidation stability, and viscosity should be tested. The following table is used for evaluation of these properties.
<table>
<thead>
<tr>
<th>Property</th>
<th>Initial Reading</th>
<th>After Test Reading</th>
<th>Difference</th>
<th>Pass With. Nitrogen Barrier</th>
<th>Pass W/O Nitrogen Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation Stability Index (hours)</td>
<td></td>
<td></td>
<td>Δ OSI</td>
<td>3%&lt;</td>
<td>5%&lt;</td>
</tr>
<tr>
<td>Total Acid Number (mg KOH/g)</td>
<td></td>
<td></td>
<td>Δ TAN</td>
<td>3%&lt;</td>
<td>5%&lt;</td>
</tr>
<tr>
<td>Viscosity in cSt at 40 °C (104°F)</td>
<td></td>
<td></td>
<td>Δ Viscosity</td>
<td>3%&lt;</td>
<td>5%&lt;</td>
</tr>
</tbody>
</table>
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Storage, Storage Stability, and Shelf Life Requirements

Category 5: D. SHELF-LIFE STABILITY

5D-1.0 Scope:

This test method will be used to evaluate the storage stability of biobased hydraulic fluids.

5D-2.0 Test Method: As Described

5D-3.0 Test Equipment: Environmental Chamber

5D-4.0 Test Procedure:

This test would be performed on two samples side by side one exposed to open air and one topped off with nitrogen. The total acid number, oxidation stability, and viscosity of the sample should be tested and recorded before testing.

Two tall graduated cylinders with dimensions: diameter 2”, height 18” are filled with 500 mL of sample oil. One sample is topped off with nitrogen by blowing nitrogen at 3 psi through a 1/6” plastic tube for five minutes and then covered with high temperature oven safe plastic. Both samples will contain 1 gram of soft iron (Spec to be inserted). The samples are placed inside the environmental chamber and programmed to alternate 12 hours at each of test temperatures of 60 °C (140 °F) and 0 °C (32 °F) for a period of 180 days (4,320 hours).

5D-5.0 Acceptance:

The samples should be inspected visually for any sign of settling or separation. Separation of any kind or settling of any component would be considered a failed product. Total acid number, oxidation stability, and viscosity should be tested. The following table is used for evaluation of these properties.
### Table for Specification Requirements for Changes in OSI, TAN, and Viscosity after Storage Test

<table>
<thead>
<tr>
<th>Property</th>
<th>Initial Reading</th>
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<th>Difference</th>
<th>Pass With. Nitrogen Barrier</th>
<th>Pass W/O Nitrogen Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation Stability Index (hours)</td>
<td>Δ OSI</td>
<td>5%&lt;</td>
<td>10%&lt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Acid Number (mg KOH/g)</td>
<td>Δ TAN</td>
<td>5%&lt;</td>
<td>10%&lt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity in cSt at 40 °C (104°F)</td>
<td>Δ Viscosity</td>
<td>5%&lt;</td>
<td>10%&lt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Storage, Storage Stability, and Shelf Life Requirements


5E-1.0 Scope:
While hydraulic oils contain demulsifiers to prevent water oil emulsifications, for those fluid used off-shore, test of biostability will be required to ensure biobased hydraulic oils in the presence of sea water do not lose biostability. This practice addresses the evaluation of the relative inherent bioresistance of water-miscible metalworking fluids, the bioresistance attributable to augmentation with antimicrobial pesticides or both. It replaces Methods ASTM D 3946 and E 686.

5E-2.0 Test Method: ASTM E2275

5E-3.0 Test Procedure:
In this practice relative bioresistance is determined by challenging metalworking fluids (in this case biobased hydraulic fluids) with a biological inoculum that may either be characterized (comprised of one or more known biological cultures) or uncharacterized (comprised of biologically contaminated metalworking fluid or one or more unidentified isolates from deteriorated metalworking fluid). Challenged fluid bioresistance is defined in terms of resistance to biomass increase, viable cell recovery increase, chemical property change, physical property change or some combination thereof.

5E-4.0 Acceptance Limit:
Changes in pH, Total Acid Number, biomass, viscosity, and sludge formation will be reported and compared to specification limits for each product.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

CATEGORY 6

Environmental Properties and Compliance
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Environmental Properties and Compliance

Category 6: A. Biodegradability – OECD 301 F - ASTM D 6731 - Standard Test Method for Determining the Aerobic, Aquatic Biodegradability of Lubricants or Lubricant Components in a Closed Respirometer

6A-1.0 Scope:

OECD 301 F - ASTM D 6731 is used to determine the biodegradability of fluids by monitoring under test condition the amount of oxygen consumption and/or carbon dioxide evolution due to bacterial activity in the sample in 28 days. It measures the rate at which an organism consumes a test material.

6A-2.0 Test Methods:

301 F - ASTM D 6731

6A-3.0 Equipment Used:

**Electrolytic respirometer:** When the inoculums begin to metabolize the test sample, the microbes consume the existing oxygen inside the sample container and release carbon dioxide. The CO2 is absorbed by the KOH trap, which causes a slight negative pressure in the sealed vessel. This slight vacuum triggers the electrolytic cell to supply oxygen via the electrolysis of a diluted acid solution until the pressure is equilibrated.

6A-4.0 Procedure:

For this test a known concentration of test material is placed into a closed flask containing a mineral medium and microbes; the solution is maintained at a constant temperature and continuously stirred for up to 28 days. Evolved carbon dioxide is absorbed by a potassium hydroxide solution, while oxygen is fed into the flasks at a at an equivalent rate. The amount of oxygen consumed by the inoculums during biodegradation of the test is measured through a computer, so at the conclusion of the test the Biological Oxygen Demand (BOD) can be calculated,
expressed as mg oxygen per mg test compound. The Theoretical Oxygen Demand (ThOD) is calculated via elemental analysis, and expressed in mg as the amount of oxygen required to oxidize a substance completely. Using these values the % Biodegradation of a sample is achieved.

6A-5.0 Test Acceptability: Minimum 50% biodegradability is required for all biobased products. Each individual specification may require different than 50% biodegradability.

Electrolytic Respirometer for Tests of Biodegradability
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Environmental Properties and Compliance

Category 6: B. Aquatic Toxicity – Using *Daphnia Magna* - ASTM D6081 Standard Practice for Aquatic Toxicity Testing of Lubricants: Sample Preparation Results Interpretation

6B-1.0 Scope:
Aquatic toxicity measures the effect a test material has on a population of aquatic organisms. The mortality of the populations are documented, and a lethal load % is calculated.

6B-2.0 Test Methods: ASTM D6081

6B-3.0 Equipment Used: Controlled water bath for the test specimens

6B-4.0 Procedure:
To adapt this test to poorly water soluble lubricants, the solutions are mechanically dispersed for 24 hours, and then the Water Accommodated Fraction (WAF- the portion of sample that is water soluble) is decanted. This aliquot is tested for toxicity. Specific organisms (ex. neonatal *Daphnia Magna*) are then exposed to the various concentrations of sample WAF’s, and the mortality rate of organisms is documented after 24 and 48 hours. A lethal load 50 is calculated, which is a statistically estimated loading rate of test material that is expected to be lethal to 50% of organisms.

6B-5.0 Test Acceptability: Toxicity levels (LC50) of greater than 1000 PPM for amounts measured at 48 hours.
Daphnia Magna Used as a Test of Aquatic Toxicity
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Environmental Properties and Compliance

Category 6: C. Aquatic Toxicity – Using Fish – OECD 203 Standard Practice for Aquatic Toxicity Testing of Lubricants: Sample Preparation Results Interpretation

6C-1.0 Scope:

Aquatic toxicity measures the effect a test material has on a population of aquatic organisms. The mortality of the populations are documented, and a lethal load % is calculated.

6C-2.0 Test Methods:

OECD 203 Guidelines for Testing of Chemicals are periodically reviewed to ensure that they reflect the best available science. In the revision of this Guideline (originally adopted in 1981, updated in 1984 and 1992), special attention was given to possible improvements in relation to animal welfare concerns in order to avoid unnecessary testing in laboratory animals.

According to this updated version of Guideline 203, prior to undertaking the described fish acute toxicity test it should be evaluated whether the Threshold Approach provided as Annex 2 to this guideline is applicable. The Threshold Approach takes into consideration EC50 values from relevant algae and acute invertebrate (e.g. daphnia) tests.

LIMIT TEST

Using the procedures described in this Guideline, a limit test may be performed at 100 mg (active ingredient)/liter or at the Threshold Concentration (derived as described in Annex 2 to this guideline) in order to demonstrate that the LC50 is greater than this concentration. The limit test should be performed using a minimum of 7 fish, with the same number in the control(s). (Binomial theory dictates that when 10 fish are used with zero mortality, there is a 99.9 % confidence that the LC50 is greater than 100 mg/l. With 7, 8 or 9 fish, the absence of mortality provides at least 99% confidence that the LC50 is greater than the concentration used in the limit test.) If any...
mortalities occur, a full study should be conducted. If sub-lethal effects are observed, these should be recorded.

6C-3.0 Equipment Used: Controlled water bath for the test specimens

6C-4.0 Procedure:
Follow the OECD 203 as described in the standard

6C-5.0 Test Acceptability: Toxicity levels (LC50) of greater than 1000 PPM for amounts measured at 48 hours.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Environmental Properties and Compliance


6D-1.0 Scope:

Terrestrial toxicity measures the effect of sample substance on test organism in soil.

6D-2.0 Test Method:

**ASTM E1963 - (OECD 208)**

6D-3.0 Procedure:

Seeds are planted in various concentrations of sample material blended in soil, and grown for twice the test organism’s normal germination period. Seedling emergence, death rate, as well as shoot and root growth are documented during the test period.

6D-4.0 Acceptance Limit:

Report the results according to the standard. In general growth rate less than 50% of the control sample is considered the minimum pass requirement. Individual tests may require more stringent results.
Plant Growth Chamber (left) – Sample Plants (right)
Category 6-E. Human Toxicity: ASTM E2552 - 08 Standard Guide for Assessing the Environmental and Human Health Impacts of New Energetic Compounds

OSHA Occupational Exposure Limit for Mineral oil Mists

6E-1.0 Scope:

This guide is intended to determine the relative environmental influence of new munition constituents, consistent with the research and development (R&D) level of effort and is intended to be applied in a logical, tiered manner that parallels both the available funding and the stage of research, development, testing, and evaluation. Specifically, conservative assumptions, relationships, and models are recommended early in the research stage, and as the munition technology is matured, empirical data will be developed and used. Munition constituents may include fuels, oxidizers, explosives, binders, stabilizers, metals, dyes, and other compounds used in the formulation to produce a desired effect. Munition systems range from projectiles, grenades, rockets/missiles, training simulators, smokes and obscurants. Given the complexity of issues involved in the assessment of environmental fate and effects and the diversity of the munition systems used, this guide is broad in scope and not intended to address every factor that may be important in an environmental context. Rather, it is intended to reduce uncertainty at minimal cost by considering the most important factors related to the environmental impacts of energetic materials. This guide provides a method for collecting data useful in a relative ranking procedure to provide the munition scientist with a sound basis for prospectively determining a selection of candidates based on environmental and human health criteria.

6E-2.0 Test Method: ASTM E2552

6E-3.0 Test Procedure:

The purpose of this guide is to provide a logical, tiered approach in the development of environmental health criteria coincident with level and
effort in the research, development, testing, and evaluation of new energetic materials. Various levels of uncertainty are associated with data collected from previous stages. Following the recommendation in the guide should reduce the relative uncertainty of the data collected at each developmental stage. At each stage, a general weight of evidence qualifier shall accompany each exposure/effect relationship. They may be simple (for example, low, medium, or high confidence) or sophisticated using a numerical value for each predictor as a multiplier to ascertain relative confidence in each step of risk characterization. The specific method used will depend on the stage of development, quantity and availability of data, variation in the measurement, and general knowledge of the dataset. Since specific formulations, conditions, and use scenarios are often not known until the later stages, exposure estimates can be determined only at advanced stages (for example, Engineering and Manufacturing Development). Exposure data can then be used with other toxicological data collected from previous stages in a quantitative risk assessment to determine the relative degree of hazard.

Data developed from the use of this guide are designed to be consistent with criteria required in weapons and weapons system development (for example, programmatic environment, safety and occupational health evaluations, environmental assessments/environmental impact statements, toxicity clearances, and technical data sheets).

Information shall be evaluated in a flexible manner consistent with the needs of the authorizing program. This requires proper characterization of the current problem. For example, compounds may be ranked relative to the environmental criteria of the prospective alternatives, the replacement compound, and within bounds of absolute environmental values. A weight of evidence (evaluation of uncertainty and variability) must also be considered with each criterion at each stage to allow for a proper assessment of the potential for adverse environmental or occupational effects; see 6.8.

This standard approach requires environment, safety, and occupational health (ESOH) technical experts to determine the risk and energetic materials researchers to evaluate the acceptability of the risk. Generally, the higher developmental stages require a higher managerial level of approval.

6E-4.0 Acceptance Criteria:

Report any toxicity test results
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Hydraulic Fluids - Environmental Compliance

CATEGORY 6: F. Other environmental requirements. The following tests are available for environmental Considerations.

OECD SECTION 2 - EFFECTS ON BIOTIC SYSTEMS

Ecotoxicology

OECD 201 Alga, Growth Inhibition Test
OECD 202 *Daphnia* sp. Acute Immobilization Test (adopted as *Daphnia* sp.14-day Reproduction Test including an Acute Immobilization Test)
OECD 203 Fish, Acute Toxicity Test
OECD 204 Fish, Prolonged Toxicity Test Study
OECD 205 Avian Dietary Toxicity Test
OECD 206 Avian Reproduction Test
OECD 207 Earthworm, Acute Toxicity Tests
OECD 208 Terrestrial Plants, Growth Test
OECD 209 Activated Sludge, Respiration Inhibition Test
OECD 210 Fish, Early-Life Stage Toxicity Test
OECD 215 Fish, Juvenile Growth Test
OECD 216 Soil Microorganisms: Nitrogen Transformation Test
OECD 217 Soil Microorganisms: Carbon Transformation Test
OECD 222 Earthworm Reproduction Test (*Eisenia fetida/Eisenia andrei*)
OECD 224 Determination of the activity of anaerobic bacteria - reduction of gas production from anaerobically sewage sludge
OECD 227 Terrestrial Plant Test: Vegetative Vigor Test

OECD SECTION 3 - DEGRADATION AND ACCUMULATION

OECD 301 Ready Biodegradability
OECD 301A : DOC Die-Away Test
OECD 301B : Co2 Evolution Test
OECD 301C : Modified MITI Test (I)
OECD 301D : Closed Bottle Test
OECD 301E : Modified OECD Screening Test
OECD 301F : Manometric Respirometry Test
OECD 304A Inherent Biodegradability in Soil
OECD 306 Biodegradability in Seawater
OECD 307 Aerobic and Anaerobic Transformation in Soil
OECD 310 Ready Biodegradability - CO2 in sealed vessels (Headspace Test)
OECD 311 Anaerobic Biodegradability of Organic Compounds in Digested Sludge: by Measurement of Gas Production
OECD 312 Leaching in Soil Columns

**OECD SECTION 4 - HEALTH EFFECTS**

OECD 401 Acute Oral Toxicity 12 May 1981
OECD 402 Acute Dermal Toxicity 403 Acute Inhalation Toxicity
OECD 404 Acute Dermal Irritation/Corrosion
OECD 405 Acute Eye Irritation/Corrosion
OECD 406 Skin Sensitization
OECD 407 Repeated Dose 28-Day Oral Toxicity Study in Rodents 408 Repeated Dose 90-Day Oral Toxicity Study in Rodents
OECD 409 Repeated Dose 90-Day Oral Toxicity Study in Non-Rodents
OECD 410 Repeated Dose Dermal Toxicity:90- Day
OECD 411 Sub-chronic Inhalation Toxicity: 90- Day
OECD 412 Repeated Dose Inhalation Toxicity: 28/14-Day
OECD 413 Sub-chronic Inhalation Toxicity: 90-Day
OECD 414 Prenatal Developmental Toxicity Study
OECD 415 One-Generation Reproduction Toxicity
OECD 416 Two-generation Reproduction Toxicity Study
OECD 417 Toxicokinetics
OECD 420 Acute Oral toxicity – Acute Toxic Class Method
OECD 421 Reproduction/Developmental Toxicity Screening Test
OECD 422 Combined Repeated Dose Toxicity Study with the Reproduction/Developmental Toxicity Screening Test
OECD 423 Acute Oral Toxicity – Acute Toxic Class Method
OECD 424 Neurotoxicity Study in Rodents
OECD 425 Acute Oral Toxicity: Up-and-Down Procedure
OECD 427 Skin Absorption: In Vivo Method
OECD 428 Skin Absorption: In Vitro Method
OECD 429 Skin Sensitization: Local Lymph Node Assay
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

CATEGORY 7

TRIBOLGICAL PROPERTIES (FRICTION AND WEAR PROTECTION)
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

Category 7. PUMPS TESTING - EATON (VICKERS) 20V – Modified ASTM D 7043 – 100-Hour Test at 2000 PSI and 65 °C (+/- 3) (149 °F) (1000 PSI for fluids with lower than 20 cSt viscosity)

7A-1.0 Scope: This test method will be used to evaluate the ability of a biobased hydraulic fluid to provide acceptable fluid pump anti-wear characteristics.

7A-2.0 Test Method: EATON (Vickers®) "Pump Test procedure for evaluation of anti-wear fluids for mobile systems". Has been replaced by modified ASTM D 7043.

7A-3.0 Test Procedure: The test should be run at 1200 rpm with an inlet temperature 65 °C (+/-3) or (149 °F) and an outlet pressure of 20.7 Mpa.

7A-4.0 Acceptance Limits: Total weight loss of all vanes from individual cartridges tested should be less than 50 mg (not including intra-vanes). Weight loss of ring from individual cartridge tested should be less than 50 mg.
Category 7: B. PUMPS TESTING - EATON (VICKERS) 20V – Modified ASTM D 7043 – 1000-Hour Test at 1000 PSI and 79 °C (+/- 3) (500 PSI for fluids with lower than 20 cSt viscosity)

7B-1.0 Scope: This test method will be used to evaluate the ability of a biobased hydraulic fluid to provide acceptable fluid pump anti-wear characteristics.

7B-2.0 Test Method: EATON (Vickers®) "Pump Test procedure for evaluation of anti-wear fluids for mobile systems". Has been replaced by modified ASTM D 7043.

7B-3.0 Test Procedure: The test should be run at 1200 rpm with an inlet temperature 79 °C (+/- 3) and an outlet pressure of 1000 PSI.

7B-4.0 Acceptance Limits:

Total weight loss of all vanes from individual cartridges tested should be less than 50 mg (not including intra-vanes). Weight loss of ring from individual cartridge tested should be less than 50 mg. The real reason for this test is to monitor the viscosity, Total Acid Number, and other properties during the 1000 hours of test.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

Category 7: C. PUMPS TESTING-VICKERS 35 VQ-25 – ASTM D 6973 Vane Pump

7C-1.0 Scope: This test method will be used to evaluate the ability of a biobased hydraulic fluid to provide acceptable fluid pump anti-wear characteristics.

7C-2.0 Test Method: Vickers® "Pump Test procedure for evaluation of anti-wear fluids for mobile systems" ASTM D 6973.

7C-3.0 Test Procedure: Vickers® test method and procedure in the EATON (Vickers®) will be used to evaluate the performance of biobased hydraulic fluids. The test should be run at 2400 rpm with an inlet temperature 93 °C +/- 3 °C (200 °F) and an outlet pressure of 3000 PSI (20.7 Mpa) for fluids with viscosity of 32 cSt and higher. One, two or three 50-hour tests may be performed provided that at least two consecutive tests can pass the weight loss requirements of the oil.

7C-4.0 Acceptance Limits:

Total weight loss of all vanes from individual cartridges tested should be less than 15 mg (not including intra-vanes). Weight loss of ring from individual cartridge tested should be less than 75 mg.

Regardless of weight loss measurements, the pump parts, especially the rings, should not have evidence of unusual wear or stress in contact areas. Examples of acceptable and unacceptable rings are shown in the Vickers® publication form M-2952-S. There may be instances when unsatisfactory performance is indicated even though the weight loss is low; for example galling or excessive burning might not show excessive weight loss, but would be unacceptable.

Viscosity change from the beginning to the end of each 50-hour test should not be more than 3% of the viscosity at the start of the test.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

Category 7: D. PUMPS TESTING - DENISON HF - Modified ASTM D 6973 Piston Pumps

7D-1.0 Scope: This test method will be used to evaluate the ability of a biobased hydraulic fluid to provide acceptable fluid pump anti-wear characteristics.

7D-2.0 Test Method: DENISON HF-0 Modified ASTM D 6973"Pump Test procedure for evaluation of anti-wear fluids for mobile systems".

7D-3.0 Test Procedure: DENISON HF-0 test method

7D-4.0 Acceptance Limits: Per Pump Manufacturer’s latest pass-fail specification

Viscosity change from the beginning to the end of each 50-hour test should not be more than 3% of the viscosity at the start of the test.

Test Stand Set Up for Dennison HF Series Tests
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

Category 7: E. PUMPS TESTING - OTHER PUMP TESTS AS CALLED FOR BY ORIGINAL EQUIPMENT MANUFACTURERS (OEMs)

7E-1.0 Scope: This test method will be used to evaluate the ability of a biobased hydraulic fluid to provide acceptable fluid pump

7E-2.0 Test Method: Pump tests as specified by the OEMs for specific equipment

7E-3.0 Test Procedure: Test as specified by the OEMs for specific equipment

7E-4.0 Acceptance Limits: As specified by the OEMs for specific equipment
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties

Friction and Wear Protection

Category 7: F. FZG RATING

7F-1.0 Scope: This test method will be used to evaluate the scuffing load capacity of biobased hydraulic oils.

7F-2.0 Test Method: ASTM D5182

7F-3.0 Test Procedure: ASTM D5182 standard test method will be used to evaluate the scuffing load capacity of biobased hydraulic fluids when used in hydraulic applications.

7F-4.0 Acceptance Limits:

The test must achieve a passing rating through a minimum of 11 load stages. Failure criteria is reached when the total sum of the width of scuffing, scoring, and adhesive wear damage from each of the 16 gear teeth is equal to or exceeds one gear tooth width (20 mm).

FZG Test Rig (left) and Test Specimens, Load Arm Installed (top right) and Gear Specimens Installed
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

CATEGORY 7: G. FOUR-BALL WEAR TEST ASTM D 4172

7G-1.0 Scope: This test method will be used to evaluate the relative wear preventative properties of biobased hydraulic fluids in sliding contact.

7G-2.0 Test Method: ASTM D 4172

7G-3.0 Test Procedure: ASTM D4172 standard test method will be used to evaluate the wear preventative properties of biobased hydraulic fluids when used in hydraulic applications. The required test conditions are as follows: 40 kg load, 93 °C +/- 3 (200), 600 RPM, and 30 Minutes test duration. Some Honary Hydraulic Oil Test Recommendations hydraulic fluids may require smaller loads and as a result requiring smaller scar diameters.

7G-4.0 Acceptance Limits:

The measured wear scar length must not exceed 0.50 mm or as specified in carious hydraulic oil specifications.

Four Ball Wear Tester and Test Specimens (left) with Microscope for Scar Diameter Measurement
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

CATEGORY 7:  H. FOUR-BALL EXTREME PRESSURE TEST -- Four Ball Extreme Pressure Test—ASTM D 2596, ASTM D 2783, and ASTM D 2672

7H-1.0 Scope: This test method will be used to evaluate the relative wear preventative properties of biobased hydraulic fluids in sliding contact.

7H-2.0 Test Method: Four Ball Extreme Pressure Test—ASTM D 2596, ASTM D 2783, and ASTM D 2672

7H-3.0 Test Procedure: Four Ball Extreme Pressure Test—ASTM D 2596, ASTM D 2783, and ASTM D 2672 test method will be used to evaluate the extreme pressure properties of biobased hydraulic fluids when used in hydraulic applications in various department products. The required test conditions are as follows: variable kg loads, 20 °C (68 °F), 1750 RPM, and 10 Second test durations.

7H-4.0 Acceptance Limits: Depending on the fluids viscosity and the intended use, various weld point in Kg are specified.
Four Ball Extreme Pressure Tester – Cup and Chuck and Balls Welded (right) 4-bal specimens and Chuck
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

CATEGORY 7: 1. TIMKEN O.K. LOAD TEST Timken OK Load Test – ASTM D 2509

7I-1.0 Scope: This test method will be used to evaluate the relative Extreme Pressure properties of biobased hydraulic fluids in sliding contact.

7I-2.0 Test Method: – ASTM D 2509

7I-3.0 Test Procedure:

ASTM D 2509 standard test method will be used to evaluate the extreme pressure properties of biobased hydraulic fluids when used in hydraulic applications in various department products.

7I-4.0 Acceptance Limits: Pass on two specimens at min. 100 lbs.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

CATEGORY 7: J. Pin & Vee Block Test – ASTM D 3233 Also referred to as Film thickness

7J-1.0 Scope: This test method will be used to evaluate the relative Extreme Pressure properties of biobased hydraulic fluids in sliding contact.

7J-2.0 Test Method: ASTM D 3233

7J-3.0 Test Procedure:
ASTM D 3233 standard test method will be used to evaluate the extreme pressure or film thickness properties of biobased hydraulic fluids when used in hydraulic applications in various department products.

7J-4.0 Acceptance Limits:
Base oils used in the biobased hydraulic oil depending on viscosity and intended use various loads ranging from 1000 to 4000 lbs of force are specified.

Pin & Vee Test Machine (left) and Pin and V Block Specimens Used (top) and Unused (bottom)
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

CATEGORY 8

Other Requirements
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)

Category 8 – Other Requirements

8a. Carcinogenicity:

The Occupational Safety and Health Administration (OSHA) definition of a carcinogen (see 3.5.2) is a chemical or process that is:

a. Regulated by OSHA as a carcinogen.
b. Listed under the category "known to be carcinogens" or "reasonably anticipated to be carcinogens" in the latest Annual Report on Carcinogens published by the National Toxicology Program (NTP).
c. Listed under Group 1, 2A and 2B by the International Agency for Research on Cancer (IARC).
Category 8 – Other Requirements

8b. Storage Stability: Store a sample of one liter of the hydraulic fluid, under nitrogen, for three months at 150 ± 3 °C (302 °F). Following the storage period, visually examine the hydraulic fluid and perform the tests of and report any separation as well perform oxidation stability test and report the results. Any cloudiness, sediment, suspended matter, discoloration or other change in homogeneity, or the failure of any of the tests specified above, shall constitute failure of this test.

OSI values should be within 10% of the original OSI before the start of the test. For example, if the OSI of the hydraulic oil before the test is 100 hours, the OSI after the three month test is not less than 90 hours, then the oil has passed this storage stability test.
HONARY HYDRAULIC OIL TEST RECOMMENDATIONS

Biobased Hydraulic Fluids Requirements

Tribological Properties (Friction and Wear Protection)


This test is intended to measure the thermal stability of hydraulic oils. Copper and steel rods are placed together in the oil which is heated to 135°C for one week. The condition of the metal specimens is reported according to the Cincinnati Milacron color chart, total sludge in mg/100 ml oil, and viscosity change can also be reported.
8d. Acquisition, Packaging and Labeling

8e. Storage Stability:

Store a sample of the hydraulic fluid for six months under nitrogen at 100 ± 3 °C (212 °F) method 3465 of FED-STD-791. Following the storage period, visually examine the hydraulic fluid and perform Oxidation Stability Index (OSI) test. Any cloudiness, sediment, suspended matter, discoloration or other change in homogeneity, or the failure of any of the tests specified above, shall constitute failure of this test.

OSI values after the test should not decrease more than 10% of the original OSI before the test. For example, if the OSI of the hydraulic oil before the test is 100 hours, the OSI after the six-month test is not less than 90 hours then the oil has passed this storage stability test.

8f. Verification of Various Operating Environments

8g. Material Safety Data Sheet

MISC. EXAMPLE OF VENDOR GENERATED SPECIFIC REQUIREMENTS

Friction Properties USING REFERENCE SOFTWARE – There are specific requirements from some vendors e.g. Caterpillar BF-1 test requirements for biodegradable hydraulic fluids, that would require accommodation to ensure vendor warrantee. Since, Caterpillar is one of the likely vendors to the Department; attempts will be made to match tests that would be equivalent to the following test procedure.

SUMMARY OF TEST METHOD USED BY CATERPILLAR, INC. FOR CERTIFICATION OF CATERPILLAR BIODEGRADABLE HYDRAULIC OILS

SCOPE

The procedure defined here as an example, defines the test methods for evaluation of the lubrication and friction performance characteristics of a biodegradable oil used in caterpillar hydraulic friction mechanisms.

SUMMARY OF TEST METHOD:
The procedure for this test utilizes the LINK MODEL 1158 Oil/Friction Test Machine which is an inertia dynamometer in which kinetic energy of a freely rotating mass is absorbed by the reaction of a rotating friction disc and an opposing stationary steel plate. A flywheel is accelerated to predetermined speeds and brought to stop by bringing the disk and plate together at various engagement pressures.

This apparatus is used to measure the characteristics listed below

a. Average dynamic coefficient of friction

9.2.2.2 INSTRUCTIONS FOR GENERATING THE LIMIT FILES TO BE USED WITH A SPECIFIC KIT.

Before a 137-1271 kit is used for certification testing of candidate oils, a reference test must be done using parts from the kit and reference oil supplied by the OEM and SEQFRRET runs will be made. At the completion of these runs, the limit files are to be generated or updated as follows:

Go to the print report menu.

Select the reference test

Select one of the seven runs which has been completed. This will define the sequence name, disc and plate used in the run.

Select the limit file for that friction material.

Select the report format for that friction material.

Press F7 and enter. The limit file will be automatically updated using the factors defined in figure 3. (These factors are stored as part of the software in limit generation reference files) The update of the limit file will also put the run number of the reference run into the description of the limit file.

9.2.2.3 A lab can repeat any of the reference runs on another disc and plate from the kit if they desire, realizing that fewer complete sets will remain for the testing of candidate oils. The final reference runs made will be used to establish the baseline.

9.2.3 An oil, to be certified as a BF-1 oil, must have performance characteristics relative to those of the reference oil as defined in figure 3.

Sequence SEQ1274 with 137-1274 clutch group (118-7181 disc and 1Y-0726 plate)
Sequence SEQFRRET with 137-1274 clutch group (118-7181 disc and 1Y0726 plate)

9.2.4 The energy limit must not occur at (during an engagement from) a speed lower than 28 m/s.

9.2.5 Total wear of the friction disc must not exceed 0.07 mm.

9.2.6 Successful completion means that for each sequence the coefficients stay above the specified minimum, the energy limit is at a speed at or above the minimum, and the total wear is less than or equal to the maximum allowable. If the first attempt in any run is unsuccessful, two succeeding successful completions of that run will meet the requirement.

9.2.7 Except as described in 9.3 (multiple run averaging), any one of the following conditions constitutes failure of a candidate oil; -any of the plotted points of static or average dynamic coefficient of friction fall outside of the allowable ranges as shown by the limit lines on the coefficient plots. -The energy limit, as determined by the limit detection option of the software, is reached and the sequence is stopped at a speed lower than that indicated by the vertical limit line on the coefficient vs speed plot. -The disc wear is greater than the allowable maximum for any of the seven runs. - The disc or plate becomes dished or warped at a speed less than the minimum acceptable energy limit even if the energy limit is not detected. -The friction material is structurally damaged by erosion or chemical or mechanical forces during the test.

9.3 Multiple run averaging is allowed as follows for the values of friction coefficient:

9.3.1 If the friction data for any of the runs with a candidate oil are slightly outside of the limits, a second run with that material may be made and the average coefficient values of the two runs (calculated by the M1158 machine) may be plotted against the two-run limit -- which presents the same performance level as does the single run limit with a single run. The friction level of the oil with that material is considered passing if the plotted points are within the limits.

9.3.2 If the averaged friction data of two runs of a given material with a candidate oil are slightly outside of the two-run limits, a third run with that material may be made and the average coefficient values of the three runs (calculated by the M1158 machine) may be plotted against the three-run limit--which represents the same performance level as does the single run limit with a single run. The friction level of the oil with that material is considered passing if the plotted points are within the limits.

9.3.3 Neither the values of energy limit nor the speed at which warpage might occur, nor total wear are subject to multiple-run averaging.
9.3.4 The limit files and report format files identified in the following table are to be used in printing the respective test reports. The limit files are generated on command by the M1158 machine based on the performance of the reference runs.

<table>
<thead>
<tr>
<th>CLUTCH GP</th>
<th>SEQUENCE</th>
<th>1 - RUN</th>
<th>2 - RUN</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 - RUN</td>
<td>1 - RUN</td>
<td>MULTIPLE</td>
<td></td>
</tr>
<tr>
<td>137-1274</td>
<td>SEQ1274</td>
<td>LIM1274</td>
<td></td>
</tr>
<tr>
<td>2LIM1274</td>
<td>3LIM1274</td>
<td>REP1274</td>
<td></td>
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<tr>
<td>MULT1274</td>
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<tr>
<td>137-1274</td>
<td>SEQFRRET</td>
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<td>2LIMFRRET</td>
<td>3LIMFRRET</td>
<td>REPFRRET</td>
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</tr>
<tr>
<td>MULTFRET</td>
<td></td>
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</tr>
</tbody>
</table>

9.4 TEST DISCONTINUATION

Any one of the following conditions, if the results are otherwise satisfactory and neither the friction disc nor the reaction plate show damage or warping, would constitute sufficient reason to abort a run without classifying it as a failure of the oil.

The machine is shut down because of low oil level. (The M1158 calls this a spurious fault, stops the run and turns off the circulating pump.)

The energy limit of the friction material is exceeded because a feedback or instrumentation problem causes the input force or input speed to be far greater than the desired amount.

The air supply fails, making it impossible to achieve the required pressures. The drive motor does not achieve the required speeds.

10. REPORT
Glossary

**Additive:** Any material added to base stock to change its properties, characteristics, or performance.

**Anhydrous:** A lubricating grease without water (as determined by ASTM D 128).

**Aniline Point:** The lowest temperature at which equal volumes of aniline and hydrocarbon fuel or lubricant base stock are completely miscible. A measure of the aromatic content of a hydrocarbon blend, used to predict the solvency of a base stock or the cetane number of a distillate fuel.

**Apparent Viscosity:** A measure of the viscosity of a non-Newtonian fluid under specified temperature and shear rate conditions.

**Bactericide:** Additive to inhibit bacterial growth in the aqueous component of fluids, preventing foul odors.

**Bases:** Compound that react with acids to form salts plus water. Alkalis are water-soluble bases, used in petroleum refining to remove acidic impurities. Oil soluble bases are included in lubricating oil additives to neutralize acids formed during the combustion of fuel or oxidation of the lubricant.

**Base Number:** The amount of acid (perchloric or hydrochloric) needed to neutralize all or part of a lubricant’s basicity, expressed as KOH equivalents.

**Base Stock:** The base fluid, usually a refined petroleum fraction or a selected synthetic material, into which additives are blended to produce finished lubricants.

**Blending:** Blending is the process of mixing fluid lubricant components for the purpose of obtaining desired physical properties.

**Boundary Lubrication:** Lubrication between two rubbing surfaces without the development of a full fluid lubricating film. It occurs under high loads and requires the use of antiwear or extreme-pressure (EP) additives to prevent metal-to-metal contact.

**Bright Stock:** A heavy residual lubricant stock with low pour point, used in finished blends to provide good bearing film strength, prevent scuffing, and reduce oil consumption. Usually identified by its viscosity, SUS at 210°F or cSt at 100°C.

**Brookfield Viscosity:** Measure of apparent viscosity of a non-Newtonian fluid as determined by the Brookfield viscometer at a controlled temperature and shear rate.
**Cetane Number:** A measure of the ignition quality of a diesel fuel, as determined in a standard single cylinder test engine, which measures ignition delay compared to primary reference fuels. The higher the Cetane Number, the easier a high-speed, direct-injection engine will start, and the less “white smoking” and “diesel knock” after start-up.

**Cloud Point:** The temperature at which a cloud of wax crystals appears when a lubricant or distillate fuel is cooled under standard conditions. Indicates the tendency of the material to plug filters or small orifices under cold weather conditions.

**Coefficient of Friction:** Coefficient of static friction is the ratio of the tangential force initiating sliding motion to the load perpendicular to that motion. Coefficient of kinetic friction (usually called coefficient of friction) is the ratio of the tangential force sustaining sliding motion at constant velocity to the load perpendicular to that motion.

**Copper Strip Corrosion:** A qualitative measure of the tendency of a petroleum product to corrode pure copper.

**Corrosion:** The wearing away and/or pitting of a metal surface due to chemical attack.

**Corrosion Inhibitor:** An additive that protects lubricated metal surfaces from chemical attack by water or other contaminants.

**Demulsibility:** A measure of the fluid’s ability to separate from water.

**Density:** Mass per unit volume.

**Dispersant:** An additive that helps keep solid contaminants in a crankcase oil in colloidal suspension, preventing sludge and varnish deposits on engine parts. Usually nonmetallic (“ashless”), and used in combination with detergents.

**Dry Film Lubricant:** A low shear-strength lubricant that shears in one particular plane within its crystal structure (such as graphite, molybdenum disulfide and certain soaps).

**Elastohydrodynamic Lubrication (EHD):** A lubricant regime characterized by high unit loads and high speeds in rolling elements where the mating parts deform elastically due to the incompressibility of the lubricant film under very high pressure.

**Emulsifier:** Additive that promotes the formation of a stable mixture, or emulsion, of oil and water.

**Evaporation Loss:** The loss of a portion of a lubricant due to volatization (evaporation). Test methods include ASTM D 972 and ASTM D 2595.

**Extreme Pressure Property:** That property of a grease that, under high applied loads, reduces scuffing, scoring, and seizure of contacting surfaces. Common laboratory tests are Timken OK Load (ASTM D 2509 and ASTM D 2782) and Four-Ball Load Wear Index (ASTM D 2596 and ASTM D 2783).
**Flash Point:** Minimum temperature at which a fluid will support instantaneous combustion (a flash) but before it will burn continuously (fire point). Flash point is an important indicator of the fire and explosion hazards associated with a petroleum product.

**Friction:** Resistance to motion of one object over another. Friction depends on the smoothness of the contacting surfaces, as well as the force with which they are pressed together.

**Fuel Ethanol:** Ethanol (ethyl alcohol, \(\text{C}_2\text{H}_5\text{OH}\)) with impurities, including water but excluding denaturants.

**Hydrolytic Stability:** Ability of additives and certain synthetic lubricants to resist chemical decomposition (hydrolysis) in the presence of water.

**Kinematic Viscosity:** Measure of a fluid’s resistance to flow under gravity at a specific temperature (usually 40°C or 100°C).

**Lubricating Grease:** A solid to semifluid dispersion of a thickening agent in liquid lubricant containing additives (if used) to impart special properties.

**Naphthenic:** A type of petroleum fluid derived from naphthenic crude oil, containing a high proportion of closed-ring methylene groups.

**Neutralization Number:** A measure of the acidity or alkalinity of an oil. The number is the mass in milligrams of the amount of acid (\(\text{HC}_1\)) or base (\(\text{KOH}\)) required to neutralize one gram of oil.

**Neutral Oil:** The basis of most commonly used automotive and diesel lubricants, they are light overhead cuts from vacuum distillation.

**Newtonian Behavior:** A lubricant exhibits Newtonian behavior if its shear rate is directly proportional to the shear stress. This constant proportion is the viscosity of the liquid.

**Newtonian Flow:** Occurs in a liquid system where the rate of shear is directly proportional to the shearing force. When shear rate is not directly proportional to the shearing force, flow is non-Newtonian.

**Non-Newtonian Behavior:** The property of some fluids and many plastic solids (including grease), of exhibiting a variable relationship between shear stress and shear rate.

**Oxidation:** Occurs when oxygen attacks petroleum fluids. The process is accelerated by heat, light, metal catalysts and the presence of water, acids, or solid contaminants. It leads to increased viscosity and deposit formation.

**Oxidation Inhibitor:** Substance added in small quantities to a petroleum product to increase it oxidation resistance, thereby lengthening its service or storage life; also called antioxidant.
**Oxidation Stability:** Resistance of a petroleum product to oxidation and, therefore, a measure.

**Paraffinic:** A type of petroleum fluid derived from paraffinic crude oil and containing a high proportion of straight chain saturated by hydrocarbons; often susceptible to cold-flow problems.

**Poise:** Measurement unit of a fluid’s resistance to flow, i.e., viscosity, defined by the shear stress (in dynes per square centimeter) required to move one layer of fluid along another over a total layer thickness of one centimeter at a velocity of one centimeter per second. This viscosity is independent of fluid density and directly related to flow resistance.

**Pour Point:** An indicator of the ability of an oil or distillate fuel to flow at cold operating temperatures. It is the lowest temperature at which the fluid will flow when cooled under prescribed conditions.

**Pour Point Depressant:** Additive used to lower the pour point or low-temperature fluidity of a petroleum product.

**Rheology:** The deformation and/or flow characteristics of grease in terms of stress, strain, temperature, and time (commonly measured by penetration and apparent viscosity).

**Rust Preventative:** Compound for coating metal surfaces with a film that protects against rust. Commonly used to preserve equipment in storage.

**Saponification:** The formation of a metallic salt (soap) due to the interaction of fatty acids, fats, or esters generally with an alkali.

**Sludge:** A thick, dark residue, normally of mayonnaise consistency, that accumulates on nonmoving engine interior surfaces. Generally removable by wiping unless baked to a carbonaceous consistency, its formation is associated with insolubles overloading of the lubricant.

**Stoke (St):** Kinematic measurement of a fluid’s resistance to flow defined by the ratio of the fluid’s dynamic viscosity to its density.

**Synthetic Lubricant:** Lubricating fluid made by chemically reacting materials of a specific chemical composition to produce a compound with planned and predictable properties.

**Tribology:** Science of the interactions between surfaces moving relative to each other, including the study of lubrication, friction, and wear.

**Viscosity:** A measure of a fluid’s resistance to flow.

**Viscosity Index:** Relationship of viscosity to temperature of a fluid. High viscosity index fluids tend to display less change in viscosity with temperature than low viscosity index fluids.

**Viscosity Modifier:** Lubricant additive, usually a high molecular weight polymer, that reduces the tendency of an oil’s viscosity to change with temperature.
**White Oil**: Highly refined lubricant stock used for specialty applications such as cosmetics and medicines.
Conversion Factors for Commons Units

Density

Density of Water

1,000 kg/m$^3$ = 62.43 Lbs./Cu.Ft = 8.33 Lbs./Gal. = 0.1337 Cu.Ft./Gal.

1 lb/ft$^3$ = 16.018 kg/m$^3$ = 0.016 g/cm$^3$ = 0.00926 oz/in$^3$ = 2.57 oz/gal (Imperial) = 2.139 oz/gal (U.S.) = 0.0005787 lb/in$^3$ = 27 lb/yd$^3$ = 0.161 lb/gal (Imperial) = 0.134 lb/gal (U.S.) = 0.0121 ton/yd$^3$

1 slug/ft$^3$ = 515.379 kg/m$^3$

1 kg/l = 62.43 lb/ft$^3$

1 kg/m$^3$ = 0.001 g/cm$^3$ = 0.0005780 oz/in$^3$ = 0.16036 oz/gal (Imperial) = 0.1335 oz/gal (U.S.) = 0.0624 lb/ft$^3$ = 0.000036127 lb/in$^3$ = 1.6856 lb/yd$^3$ = 0.010022 lb/gal (Imperial) = 0.008345 lb/gal (U.S.) = 0.0007525 ton/yd$^3$

Force

1 N (Newton) = 0.1020 kp = 7.233 pdl = 7.233/32.174 lb$\ell$ = 0.2248 lb$\ell$ = 1 (kg m)/s$^2$ = 10$^5$ dyne = 1/9.80665 kgf

1 lb$\ell$ (Pound force) = 4.44822 N = 0.4536 kp = 32.17 pdl = 4.448x10$^5$ dyn

1 dyn = 1 (g cm)/s$^2$

1 kg has a weight of 1 kp

1 kp (Kilopond) = 9.80665 N = 2.205 lb$\ell$ = 70.93 pdl

1 pdl (Poundal) = 0.13826 N = 0.01409 kp = 0.03108 lb$\ell$

Frequency

1 hertz = 1 cycle/sec

Heat flow rate

1 Btu/sec = 1,055.1 W

1 kW (kJ/s) = 102.0 kpm/s = 859.9 kcal/h = 3,413 Btu/h = 1.360 hk = 1.341 hp = 738 ft lb/s = 1,000 J/s = 3.6x10$^6$ J/h
1 kpm/s = 9.8067x10^{-3} kW = 8.432 kcal/h = 32.47 Btu/h = 0.01333 hk = 0.01316 hp = 7.237 ft lb/s
1 kcal/h = 1.163x10^{-3} kW = 0.1186 kpm/s = 3.969 Btu/h = 1.582x10^{-3} hk = 1.560x10^{-3} hp = 0.8583 ft lb/s
1 Btu/h = 2.931x10^{-4} kW = 0.0299 kpm/s = 0.252 kcal/h = 3.986x10^{-4} hk = 3.939x10^{-4} hp = 0.2163 ft lb/s
1 kcal/h = 1.16x10^{-3} kW
1 hk (metric horse power) = 0.735499 kW = 75.00 kpm/s = 632.5 kcal/h = 2,510 Btu/h = 0.9863 hp = 542.8 ft lb/s
1 hp = 0.74570 kW = 76.04 kpm/s = 641.2 kcal/h = 2,545 Btu/h = 1.014 hk = 550.3 ft lb/s
1 ft lb/s = 1.35501 kW = 0.1382 kpm/s = 1.165 kcal/h = 4.625 Btu/h = 1.843x10^{-3} hk = 1.817x10^{-3} hp

**Heat transfer coefficient**

1 Btu/ft² h °F = 5.678 W/m² K = 4.882 kcal/h m² °C
1 W/m²K = 0.85984 kcal/h m² °C = 0.1761 Btu/ ft² h °F
1 kcal/h m² °C = 1.163 W/m²K = 0.205 Btu/ ft² h °F

**Mass, weight**

pounds, kilograms, grams, ounces, grains, tons (long), tons (short), tons (metric), carat, grain, ounce mass, pound mass (lbₘ), slug, tonne

1 kg = 1,000 gram = 2.2046 lb = 6.8521x10^{-2} slug
1 lb = 16 oz = 0.4536 kg = 453.6 g = 7000 grains = 0.03108 slug
1 slug = 14.594 kg = 32.174 lbₘ
1 grain = 0.000143 lb = 0.0648 g
1 g = 15.43 grains = 0.0353 oz = 0.002205 lb
1 qt = 0.9464 liters
1 metric ton (or tonne) = 1 tonne métrique = 1000 kg = 10⁶ g = 10⁹ mg = 0.907 short tons
1 short ton = 2000 lbs = 907.18474 kg
1 long ton = 2240 pounds = 1,016.0469088 kg
1 oz (ounce) = 28.35 g = 437.5 grains = 0.0625 lb = 0.0000279 long ton (UK) = 0.00003125 long ton (US) = 0.000558 long hundredweight (UK) = 0.000625 long hundredweight (US) = 0.004464 stone = 16 dram
1 troy pound = 12 troy ounces
1 scruple = 20 grains
1 dram = 3 scruples
1 apothecary ounce = 8 drams
1 apothecary pound = 12 apothecary ounces
1 pennyweight = 24 grains
Density, Specific Weight and Specific Gravity - An introduction and definition of density, specific weight and specific gravity. Formulas with examples.

Specific Volume

1 m$^3$/kg = 16.02 ft$^3$/lb$\text{m}$ = 27680 in$^3$/lb$\text{m}$ = 119.8 US gal/lb$\text{m}$ = 1000 liter/kg
1 liter/kg = 0.016 ft$^3$/lb$\text{m}$ = 27.7 in$^3$/lb$\text{m}$ = 0.12 US gal/lb$\text{m}$ = 0.001 m$^3$/kg
1 ft$^3$/lb$\text{m}$ = 1728 in$^3$/lb$\text{m}$ = 7.48 US gal/lb$\text{m}$ = 62.43 liter/kg = 0.062 m$^3$/kg
1 US gal/lb$\text{m}$ = 0.134 ft$^3$/lb$\text{m}$ = 231 in$^3$/lb$\text{m}$ = 8.35 liter/kg = 0.0083 m$^3$/kg

Temperature

Celsius, Rankine, Kelvin, Centigrade, Fahrenheit,

$1 \degree C = 1.8 \degree F$
$1 \degree F = 0.555 \degree C$

0 \degree C corresponds to 32 \degree F, 273.16 K and 491.69 R

$T(\degree R) = \frac{9}{5}T(K)$
$T(\degree F) = \frac{T(\degree C)}{9/5} + 32$
$T(\degree F) = [T(K) - 273.15](9/5) + 32$
$T(\degree C) = \frac{5}{9}[T(\degree F) - 32]$

Thermal conductivity

$1 \text{ W/(m K)} = 0.85984 \text{ kcal/(h m } ^\circ \text{ C)} = 0.5779 \text{ Btu/(ft h } ^\circ \text{ F)}$
$1 \text{ Btu/(ft h } ^\circ \text{ F)} = 1.731 \text{ W/(m K)} = 1.488 \text{ kcal/(h m } ^\circ \text{ C)}$
$1 \text{ kcal/(h m } ^\circ \text{ C)} = 1.163 \text{ W/(m K)} = 0.6720 \text{ Btu/(ft h } ^\circ \text{ F)}$

Dynamic Viscosity

$1 \text{ lb/(ft s)} = 1.4879 \text{ Pa s} = 14.88 \text{ P} = 1,488 \text{ cP} = 0.1517 \text{ kp s/m}^2$
$1 \text{ cP (Centipoise)} = 10^{-3} \text{ Pa s} = 0.01 \text{ Poise} = 1.020 \times 10^{-4} \text{ kp s/m}^2 = 6.721 \times 10^{-4} \text{ lb/(ft s)} = 0.00100 \text{ (N s)/m}^2 = 0.01 \text{ gram/(cm sec)} = 2.4191 \text{ lb/(ft hr)}$
$1 \text{ kg/(m s)} = 1 \text{ (N s)/m}^2 = 0.6720 \text{ lb/ft s} = 10 \text{ Poise}$
$1 \text{ P (Poise)} = 0.1 \text{ Pa s} = 100 \text{ cP} = 1.020 \times 10^{-2} \text{ kp s/m}^2 = 6.721 \times 10^{-2} \text{ lb/(ft s)} = 0.1 \text{ kg/ms}$
$1 \text{ Pa s (N s/m}^2) = 10 \text{ P (Poise)} = 10^{-3} \text{ cP} = 0.1020 \text{ kp s/m}^2 = 0.6721 \text{ lb/(ft s)}$
$1 \text{ kp s/m}^2 = 9.80665 \text{ Pa s} = 98.07 \text{ P} = 9,807 \text{ cP} = 6.591 \text{ lb/(ft s)}$
1 reyns = 1 lb s/in² = 6894.76 Pa s

Kinematic Viscosity

1 ft²/s = 0.0929 m²/s
1 ft²/h = 2.581x10⁻⁵ m²/s
1 St (Stokes) = 1x10⁻⁴ m²/s = 100 cSt = 1.076x10⁻³ ft²/s
1 m²/s = 10⁻⁴ St = 10⁶ cSt = 10.764 ft²/h
1 cSt (Centistoke) = 10⁻⁶ m²/s = 0.01 Stokes = 10⁻⁶ ft²/s
When cSt is bigger than 50, the conversion is as follows: SSU = 4.55 * cSt,

Volume

1 ft³ = 0.02832 m³ = 28.32 dm³ = 0.03704 yd³ = 6.229 Imp. gal (UK) = 7.481 gal (US) = 1,728 cu inch = 2.296x10⁻⁵ acre foot = 12 board foot (timber) = 0.7786 bushel (UK) = 0.8036 bushel (US, dry) = 0.00781 cord (firewood) = 0.0625 cord foot (timber) = 28316.8 cu centimeter = 6.42851 gallon (US, dry) = 7.48052 gallon (US, liq) = 28.3168 liter = 996.614 ounce (UK, liq) = 957.506 ounce (US, liq) = 51.4281 pint (US, dry) = 59.84442 pint (US, liq) = 25.714 quart (US, dry) = 29.922 quart (US, liq)
1 in³ = 1.6387x10⁻⁵ m³ = 1.639x10⁻² dm³ (liter) = 16.39 cm³ = 16390 mm³ = 0.000579 ft³
1 Gallon (U.S.) = 3.785x10⁻³ m³ = 3.785 dm³ (liter) = 231 in³ = 0.13368 ft³ = 4.951x10⁻³ yd³ = 0.8327 Imp. gal (UK) = 4 Quarts = 8 Pints
1 Imp. gallon (UK) = 4.546x10⁻³ m³ = 4.546 dm³ = 0.1605 ft³ = 5.946x10⁻³ yd³ = 1.201 gal (US)
1 dm³ (Liter) = 10⁻³ m³ = 0.03532 ft³ = 1.308x10⁻³ yd³ = 0.220 Imp gal (UK) = 0.2642 Gallons (US) = 1.057 Quarts = 2.113 Pints
1 barrel (UK) = 1.5 bag (UK) = 1.41541 barrel (US, dry) = 1.37251 barrel (US, liq) = 4.5 bushel (UK) = 4.64426 bushel (US, dry) = 5.77957 cu ft = 0.16366 cu meter = 36 gallon (UK) = 163.6592 liter
1 barrel beer = 31.5 gallons beer
1 barrel (US, oil) = 1.33 barrel (US, liq) = 5.61458 cu foot = 42 gallons (US, liq) = 158.9873 liters
1 barrel (US, dry) = 0.969696 barrel (US, liq) = 3.28122 bushel (US, dry) = 4.0833 cu ft = 7056 cu inch = 0.11563 cu meter = 104.999 quart (US, dry)
1 barrel (US, liq) = 1.03125 barrel (US, dry) = 0.75 barrel (US, oil) = 4.2109 cu foot = 7276.5 cu inch = 0.11924 cu meter = 26.22924 gallon (UK) = 31.5 gallon (US, liq) = 119.24 liter = 1 bushel = 1.2445 Cu.Ft. = 32 Quarts (Dry) = 64 Pints (dry) = 4 Pecks
1 bushel (UK) = 0.3333 bag (UK) = 1.03206 bushel (US) = 36368.7 cu cm = 1.28435 cu foot = 2219 cu inch = 8 gallon (UK) = 36.3687 liter

Test Methods Relevant to Biobased Hydraulic Oil by Professor Lou Honary – Page 166
1 bushel (US, dry) = 0.30476 barrel (US, dry) = 0.96894 bushel (UK) = 35239.07 cu cm = 1.24446 cu foot = 2150.42 cu inch = 0.03524 cu meter 0.04609 cu yard = 8 gallon (US, dry) = 9.30918 gallon (US, liq) = 35.23907 liter = 1191.57 ounce (US, liq) = 4 peck (US) = 64 pint (US, dry) = 32 quart (US, dry) = 37.23671 quart (US, liq)

1 quart (qt) = 2 pints = 57.75 in³ = 1/8 dry quarts
1 fluid ounce (fl. oz.) = 2 tablespoons = 1.805 in³ = 29.574 milliliters

\[ t \text{ (in °C)} \begin{array}{cccccc} 188 & 216 & 196 & 218 & 196 & 218 & 221 & 246 \end{array} \]