Designation: ~~D7721 – 11~~ D7721 – 17

Standard Practice for Determining the Effect of Fluid Selection on Hydraulic System or Component Efficiency[1]

This standard is issued under the fixed designation D7721; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. ~~Scope~~ Scope*

1.1 This practice covers all hydraulic fluids.

1.2 This practice is applicable to both laboratory and field evaluations.

1.3 This practice ~~gives overall~~ provides guidelines for conducting ~~science-based~~ hydraulic fluid evaluations. It does not prescribe a specific efficiency test methodology.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *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.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4174 Practice for Cleaning, Flushing, and Purification of Petroleum Fluid Hydraulic Systems

D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants

2.2 *ISO Standards:*[3]

ISO 4391 Hydraulic fluid power—Pumps, motors and integral ~~transmissions—parameter~~ transmissions—Parameter definitions and letter symbols

ISO 4392 Hydraulic fluid power—Determination of characteristics of motors

ISO 4409 Hydraulic fluid power—Positive displacement pumps—Methods of testing and presenting basic steady state performance

ISO 5598 Fluid power systems & ~~components - Vocabulary~~ components—Vocabulary

ISO 8426 Hydraulic fluid power—Positive displacement pumps and motors—Determination of derived capacity

2.3 *Other Standards:*

VDI 2198 Type Sheets for Industrial Trucks[4]

3. Terminology

3.1 For additional definitions related to petroleum products and lubricants, ~~please refer to~~ see Terminology D4175. For additional definitions related to fluid power systems and components, ~~please refer to~~ see ISO 5598.

3.2 *Definitions:*

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.N0 on Hydraulic Fluids.

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

[3] Available from International Organization for Standardization (ISO), ~~1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20,~~ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[4] Available from Verein Deutscher Ingenieure (VDI) (The Association of German Engineers), VDI-Platz 1, 40468 Düsseldorf, Germany, www.vdi.de.

***A Summary of Changes section appears at the end of this standard**

3.2.1 *component, n*—of a hydraulic system, an individual unit, excluding piping, comprising one or more parts designed to be a functional part of a fluid power system, for example, cylinder, motor, valve, or filter.

3.2.2 *critical parts, n*—those components used in the test that are known to affect test severity.

3.2.3 *cycle time, n*—the amount of time it takes for a machine to perform a repetitive segment of an operation, typically measured as the time it takes a machine to return to the original position after completing a task.

3.2.4 *efficiency, n*—the ratio of actual work output of a component or machine to the theoretical work output calculated from the measured input power.

3.2.5 *energy consumption, n*—the total energy content consumed during a test in kWh; determined from electric power meter readings or calculated from the mass of fuel consumed and the lower heating value of the fuel.

3.2.6 *fit for use, n*—product, system, or service that is suitable for its intended use.

3.2.7 *fuel rate, n*—the rate at which fuel is consumed in L/h, normalized to the fuel density at 15 °C.

3.2.8 *grade, n*—designation given a material by a manufacturer so that it is always reproduced to the same specifications established by ~~the manufacturer.~~standards organizations such as ASTM or ISO.

3.2.9 *hydraulic fluid, n*—liquid used in hydraulic systems for lubrication and transmission of power.

3.2.10 *hydraulic system, n*—fluid power system that is an arrangement of interconnected components which generates, transmits, controls, and converts fluid power energy.

3.2.11 ~~*hydromechanical*~~ *motor hydromechanical efficiency, n*—ratio of the actual torque ~~to the derived torque.~~output of the motor to the theoretical torque output of the motor.

~~3.2.8 *hydromechanical pump efficiency, n*—ratio of the derived displacement to absorbed hydraulic torque.~~

3.2.12 *motor overall efficiency, n*—ratio of the mechanical output power to the power transferred from the liquid at its passage through the motor.

3.2.13 *motor volumetric efficiency, n*—ratio of the ~~derived~~theoretical inlet flow rate to the effective ~~outlet~~inlet flow rate.

3.2.14 *outlier, n*—result far enough in magnitude from other results to be considered not part of the set.

3.2.14.1 *Discussion*—

For purposes of this practice, classification of a result as an outlier shall be justified by statistical criteria in comparison with the valid data points.

3.2.15 *pump hydromechanical efficiency, n*—ratio of the theoretical input torque of the pump to the actual torque input of the pump.

3.2.16 *pump overall efficiency, n*—ratio of the power transferred to the liquid, at its passage through the pump, to the mechanical input power.

3.2.17 *pump volumetric efficiency, n*—ratio of the effective output flow rate to the ~~derived~~theoretical output flow rate.

3.2.18 *reference oil, n*—oil of known performance characteristics used as a basis for comparison.

3.2.18.1 *Discussion*—

For purposes of this practice, the reference oil may be a hydraulic fluid of any suitable composition.

3.2.19 *test oil, n*—any oil subjected to evaluation in an established procedure.

3.2.19.1 *Discussion*—

For purposes of this practice, the test oil may be a hydraulic fluid of any suitable composition.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *design of experiment, DOE, n*—statistical arrangement in which an experimental program is to be conducted and the selection of the levels (versions) of one or more factors or factor combinations to be included in the experiment.

3.3.2 *duty cycle, n*—time interval devoted to starting, running, stopping, and idling when a device is ~~used for intermittent duty~~ in use and the time spent operating at different levels of ~~rated capacity.~~speed, displacement volume, torque, and pressure.

3.3.3 *efficiency improvement, n*—~~difference in system or component behavior between two fluids and this difference can~~ a positive change in one or more parameters measured in a system or component that may be defined as ~~an improvement~~a reduction in fuel consumption, ~~work produced,~~ electrical power draw, ~~flow rate, temperature reduction, and so forth.~~or temperature, an increase in work produced or flow rate, or any combination of these or other parameters.

3.3.3.1 *Discussion—*

This improvement is expressed as a percent increase that is obtained by dividing the test oil performance by the reference oil performance and multiplying by 100 or, if appropriate, for example, temperature, then actual values can be reported.

3.3.4 *power factor, n*—in AC electrical circuits, the ratio of actual electric power dissipated by the circuit to the product of the root mean square values of current and voltage. In DC electrical circuits, it is the energy consumed (watts) versus the product of input voltage (volts) times input current (amps).

3.3.4.1 *Discussion—*

The power factor is the dimensionless ratio of energy used compared to the energy flowing through the wires.

3.3.5 *system overall efficiency, n*—in fluid power systems, the ratio of the output power of the system to the input power of the system.

3.3.5.1 *Discussion—*

For integral transmissions and open-loop hydraulic circuits that drive a hydraulic motor, system overall efficiency is the ratio of the output mechanical power at the hydraulic motor shaft to the input mechanical power at the pump shaft. Methods ISO 4391 and ISO 4409 provide additional details for determining system efficiency in circuits with boost pumps.

4. Summary of Practice

4.1 The purpose of this practice is to define minimum technical requirements needed statistically to validate for conducting energy efficiency performance comparisons of two or more hydraulic fluids in controlled laboratory or field evaluations.

4.2 Controls and considerations based on both technical factors and practical experience are included.

4.3 Requirements for test planning, testing conduct, and data analysis and reporting are described.

5. Significance and Use

5.1 The purpose of a hydraulic fluid is to cool and lubricate fluid power components, as well as transmit power. Several standard test methods are available to measure the lubrication performance of hydraulic fluids. This practice provides uniform guidelines for comparing fluids in terms of their power-transmitting abilities as reflected in their effect on hydraulic system or component efficiency. Standard test methods ISO 4409 and ISO 4392 provide specifications for evaluating the steady state performance of hydraulic pumps and motors but do not address technical requirements specific to hydraulic fluid testing.

5.2 *General*—Energy efficiency benefits of hydraulic fluids are the differences between two large numbers. Differences in fluid performance may be relatively small. Consequently, it is essential to ensure that the differences observed are statistically valid (within defined confidence limits, typically 95%) and that proper precautions to ensure the that the necessary experimental controls have been put in place to compare are implemented to ensure consistency in operating conditions and duty cycle when comparing the energy efficiency performance of two or more different hydraulic fluids under identical operating conditions. of different hydraulic fluid formulations.

5.3 Practical advantages of enhanced hydraulic system efficiency may include increased productivity (faster machine cycle time), reduced power consumption (electricity or fuel), and reduced environmental impact (lowered emissions).

5.4 This practice implies no evaluation of hydraulic fluid quality other than its effect on hydraulic system efficiency.

6. Procedure

6.1 *Protocol*—A successful outcome is dependent on an evaluation of goals and methods at the outset along with an assessment of potential sources of error. Such an evaluation requires a clearly defined test protocol that shall include: (1)*(1)* statistical design of experiment and analysis, (2)*(2)* fluid order evaluation, (3)*(3)* equipment selection, (4)*(4)* analysis and mitigation of the test variables, and (5)*(5)* appropriate data collection methods. This ensures that both the reference and test oils are evaluated in exactly the same way, thus ensuring a valid comparison is made.

6.1.1 *Site Coordinator/Personnel Training*—Because of the complexity of field trials, it is recommended that a designated site coordinator be used to ensure any questions or concerns from site personnel are addressed and that test protocols are being followed.

6.2 *Statistical Design of Experiment (DOE)*—A statistical DOE system shall be used to account for any test variability and ensure any differences observed are significant to 95%95 % confidence limits.

6.3 *Test Control*—There are a number of test variables that can significantly influence efficiency measurements and shall be controlled.

6.3.1 *Fluid Order*—To account for the potential impact of machine drift/bias and lubricant carryover effects, it is highly recommended that the efficiency of the reference fluid (A) be evaluated before and after each test fluid (B) evaluation. Alternating the reference fluid and test fluid in an ABA or ABAB test sequence is satisfactory. When operator or test equipment variables may have a significant impact on the test outcome, the operators and test equipment should also be alternated in a systematic manner.

6.3.2 *Carryover Control*—Hydraulic systems may retain a significant amount of residual fluid after they have been drained. This residual fluid can create cross-contamination. The level of cross-contamination between test fluids shall be kept to a minimum. In preparation for the evaluation of each fluid, the hydraulic system should be filled, flushed, and drained of the test fluid at least once. Practice D4174 provides specific recommendations to facilitate this process. The cross-contamination level in the test fluid ideally should not exceed ~~10%~~10 % in field trials and ~~1%~~1 % in laboratory evaluations. ~~the~~The amount of cross-contamination should be determined using an appropriate test method such as elemental analysis, mass balance, infrared spectroscopy, or viscosity. This information is to be included with the test results.

6.3.2.1 *Flushing Requirements for Surface Active Fluids (for ~~example,~~Example, Friction Modified)*—If any of the fluids under evaluation ~~contain~~contains surface-active friction-reducing materials (for example, friction modifiers), then extra precautions to minimize carryover effects may be required. One of these precautions shall be to use a flush oil that is capable of removing such surface-active additives.

6.3.3 *Environmental Conditions (for ~~example, Temperature, Humidity, and Precipitation)—~~Field Trials)—*It is important to minimize the effect of differences in environmental conditions such as ambient temperature during the conduct of a field test. This may ~~include~~require testing only during defined periods of the day over multiple days, or on multiple days under similar weather ~~conditions, or collecting temperature data for subsequent analysis or correction during data analysis.~~conditions. Record ambient temperature, atmospheric pressure, and sea level at the beginning of each test sequence.

6.3.3.1 Precipitation shall be avoided as much as possible during testing as it is difficult to account for variation in traction.

6.3.3.2 The recommended ambient temperature for machine testing is 15 °C to 30 °C.

6.3.4 *Oil Temperature*—Oil temperature can have a significant influence on fluid performance and, therefore, should be monitored to account for its influence on efficiency. Oil temperatures shall be measured as accurately as possible both in the reservoir and at the ~~pump.~~pump inlet.

6.3.5 *Oil Viscosity*—Oil viscosity can have a significant influence on fluid efficiency and, therefore, should be monitored from start to end of test to account for its influence on efficiency.

6.3.6 *Oil Pressure*—Oil pressure has a strong influence on hydraulic pump efficiency. It is important to ensure that the equipment is operating at comparable pressures during identical test operations between oils under test. If pressure changes as a result of factors other than the work load (that is, leakage, pump wear) occur, the results will not be valid.

6.3.7 *Operator Differences*—It is usually preferable in mobile equipment to test reference and candidate oils using the same operator. When not possible, procedures should be included to minimize the effects of any differences, for example, account for differences in DOE—randomized testing and machine evaluation.

6.3.8 *Operating Conditions (Speed, Load, Duty Cycle)*—The test procedure should define as specifically as practical such variables as speed of operation, sequence of steps, and load. Also, the duty cycle shall be defined to hold as consistently as possible between the test and reference oils. Where possible, standard duty cycles such as found in VDI 2198 should be employed.

6.3.9 *Fuel Quality*—Differences in fuel characteristics can contribute to changes in efficiencies during field testing. It is ~~highly~~ preferable to conduct field evaluations using a single batch of fuel. When this is not possible, comparable fuel quality shall be included in the test protocol.

6.3.10 *~~Electronic (Controlled for Power Factor)—~~Electric Power Quality—*In systems drawing power from a common source such as plant equipment, changes in load separate from the test equipment can affect electrical power quality. In systems that may be affected, comparable power quality (for example, amps, watts, and power factor) shall be included in the test protocol.

6.3.11 ~~An accurate location to measure~~The recommended location for measuring electrical power consumption is between the ~~motor and motor starter.~~variable frequency drive (or starter in an across-the-line application) and the electric motor.

6.3.12 *Fuel Measurement*—Fuel gauges on commercial hydraulic machines are designed to indicate when fuel replenishment is necessary. Consequently, fuel gauge accuracy is insufficient for efficiency studies. Fuel levels may be ~~more accurately controlled by being careful to refuel on a level surface and using a dipstick, or by determining the weight of fuel added to the tank.~~determined by using an auxiliary tank and weighing the amount of fuel consumed or using fuel flow sensors.

6.3.12.1 In high pressure common rail diesel engines, a portion of the fuel flow is recirculated to cool the system. The fuel consumption rate may be continuously measured using the system depicted in Fig. 1. This system measures the fuel sent to the injection pump and isolates the unused fuel returned to the tank.

6.3.12.2 The energy content of fuel is affected by temperature due to the impact of thermal expansion on density. Fuel flow sensors must be able to account for changes in fuel temperature and density as well as the volume of fuel consumed.

6.4 *Subject Equipment Selection*—The equipment selected should be both fit for use (that is, representative of the type to which the testing will be applied) and having all critical parts maintained in good working order.

6.4.1 *~~Breaking in~~ Breaking-in of Equipment*—To reduce mechanical variability in new equipment, it is recommended that appropriate equipment break-in procedures shall be followed until stable conditions are obtained.