INTERNATIONAL

Designation: ~~D7721 – 17~~ D7721 – 22

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*

1.1 This practice covers all types and grades of hydraulic fluids.

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

1.3 This practice provides guidelines for conducting 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~~ safety, health, and ~~health~~environmental 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 definitions and letter symbols
ISO ~~4392~~4392–1 Hydraulic fluid power—Determination of characteristics of ~~motors~~motors—Part 1: At constant low speed and constant pressure
ISO 4409 Hydraulic fluid ~~power—Positive displacement pumps—Methods~~ power—Positive-displacement pumps, motors and integral transmissions—Methods of testing and presenting basic steady state performance
ISO 5598 Fluid power systems & components—Vocabulary

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[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), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

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

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, see Terminology D4175. For additional definitions related to fluid power systems and components, see ISO 5598.

3.2 *Definitions:*

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

3.2.1.1 *Discussion*—
For purposes of this practice, the baseline oil may be a hydraulic fluid of any suitable composition.

3.2.2 *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.

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

3.2.4 *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 *energy efficiency, n*—the work output divided by the energy input; this ratio may be expressed as a percentage.

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

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

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

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

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

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

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

3.2.14 *motor volumetric efficiency, n*—ratio of the theoretical inlet flow rate to the effective inlet flow rate.

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

3.2.15.1 *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.

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

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

3.2.18 *pump volumetric efficiency, n—*ratio of the effective output flow rate to the 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 in use and the time spent operating at different levels of speed, displacement volume, torque, and pressure.

~~3.3.3 *efficiency improvement, n—*a positive change in one or more parameters measured in a system or component that may be defined as a reduction in fuel consumption, electrical power draw, 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.~~

3.3.3 *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.~~voltage; ~~*In*~~*in DC electrical circuits*, it is the energy consumed (watts) versus the product of input voltage (volts) times input current (amps).

3.3.3.1 *Discussion—*

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

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

3.3.4.1 *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 for conducting energy efficiency performance comparisons of two or more hydraulic fluids in controlled laboratory or field evaluations. It is organized in three sections.

4.2 ~~Controls and considerations based on both technical factors and practical experience are included.~~The first section describes guidelines for a dynamometer evaluation of fluids in a high-pressure positive displacement pump. Baseline and test fluids are evaluated under steady-state conditions of pump shaft speed, displacement, outlet pressure and fluid temperature. Input torque, outlet flow and case drain flow rates are measured.

4.3 ~~Requirements for test planning, testing conduct, and data analysis and reporting are described.~~ The second section describes guidelines for dynamometer evaluation of fluids in low-speed hydraulic motor testing. Baseline and test fluids are evaluated under steady-state conditions of inlet pressure, motor shaft speed, and fluid temperature. Output torque, input flow, and case drain flow rates are measured.

4.4 The third section describes guidelines for field evaluations of hydraulic fluids. Baseline and test fluids are evaluated in hydraulically powered machines. Energy consumption and duty cycle times are measured to compare the effects of fluids on machine efficiency and productivity.

4.5 Differences between baseline and test fluid performance are statistically evaluated.

5. Significance and Use

5.1 The ~~purpose~~ primary function of a hydraulic fluid is to ~~cool and lubricate fluid power components, as well as~~ transmit power. 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.~~ efficiency and productivity.

5.2 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 (lower emissions).

5.3 Differences in fluid performance may be relatively small. Consequently, it is essential that the necessary experimental controls are implemented to ensure consistency in operating conditions and duty cycle when comparing the energy efficiency 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*) statistical design of experiment and analysis, (*2*) fluid order evaluation, (*3*) equipment selection, (*4*) analysis and mitigation of the test variables, and (*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 % confidence limits.~~

6.1 ~~*Test Control*—~~*Procedure for Laboratory Evaluation of Fluids in Positive Displacement Pumps:* ~~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.~~

6.1.1 ~~*Carryover Control*—~~*General Description*—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 pump tests shall be conducted on a hydraulic dynamometer via a modified ISO 4409 method. ISO 4409 specifies a procedure for determining the performance and efficiency of hydraulic fluid power positive displacement pumps, motors, and integral transmissions under steady-state conditions. It includes hydraulic circuit schematics, test procedures, and permissible systematic error limits. The purpose of the following procedure is D4174 provides specific recommendations to facilitate this process. The cross-contamination level in the test fluid ideally should not exceed 10 % in field trials and 1 % in laboratory evaluations. 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 to produce a statistical basis for comparing the performance of fluids in terms of pump efficiency and/or internal leakage flow losses. Modifications are required to the ISO 4409 method because fluid performance, rather than pump performance, is to be included with the test results.evaluated.

6.3.2.1 *Flushing Requirements for Surface Active Fluids (for Example, Friction Modified)*—If any of the fluids under evaluation 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.

6.1.2 *Pump Selection*—A positive displacement piston pump that is employed in construction engineering, material handling, or other off-highway vehicle applications shall be selected for testing. Load-sensing variable displacement axial piston pumps are widely used in these applications and have been found to be suitable for hydraulic fluid efficiency testing. Use of other pump designs is permitted.

NOTE 1—A calculation of the theoretical flow rate is required to determine the volumetric efficiency of a pump as shown in Eq X2.3. The theoretical flow rate is determined from the mathematical product of the pump rotational speed (r/min) and derived displacement (*Vi*).

6.1.3 *Pump Derived Displacement*—The derived displacement of the pump shall be determined in accordance with ISO 8426.

6.1.4 Internal leakage flow loss measurements shall be used to compare the effects of fluids on pump performance if the displacement is not fixed or the pump does not incorporate a swashplate position sensor.

6.1.5 Install the pump in a hydraulic circuit as shown in Fig. 1.

6.1.6 *Environmental Conditions (for Field Trials)*—*Sensors and Instrumentation*—It is important to minimizePrecision instrumentation is necessary for determining the effect of differences in environmental conditions such as ambient temperature during the conduct of a field test. This may require testing only during defined periods of the day over multiple days, or on multiple days underhydraulic fluids on pump performance. Table 1 similar weather conditions. Record ambient temperature, atmospheric

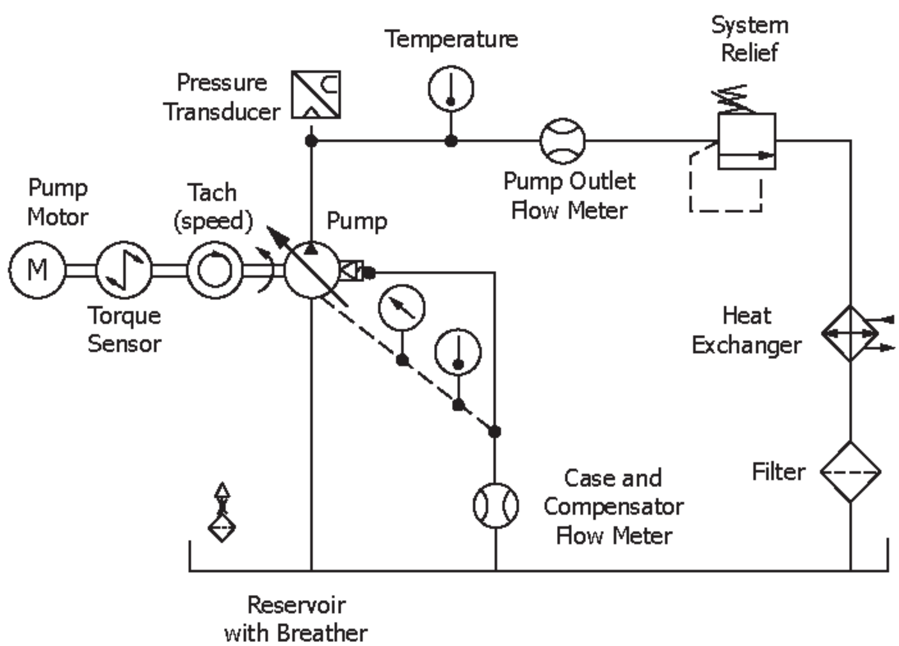

FIG. 1 Circuit Schematic for Evaluating the Effect of Fluid on Pump Performance

TABLE 1 ~~Typical~~ Systematic Measurement Error Limits as Determined During Calibration

~~Parameter~~	~~Permissible Systematic Measuring Instrument Errors for Each Class of Measurement Accuracy~~		
Parameter	Permissible Systematic Measuring Instrument Errors for Each Class of Measurement Accuracy		
	A	B	C
~~Rotational Frequency (%)~~	~~±0.5~~	~~±1~~	~~±2~~
Rotational Frequency (%)	±0.5	±1.0	±2.0
~~Flow Rate (%)~~	~~±0.5~~	~~±1.5~~	~~±2.5~~
Flow Rate (%)	±0.5	±1.0	±2.5
Torque (%)	±0.5	±1.0	±2.0
~~Pressure, where p < 0.15 MPa (1.5 bar) gauge~~	~~±0.001 (±0.01)~~	~~±0.003 (±0.03)~~	~~±0.005 (±0.05)~~
Pressure, where p < 0.15 MPa gauge (MPa)	±0.001	±0.003	±0.005
~~Pressure, where p ≥ 0.15 MPa (1.5 bar) gauge~~	~~±0.05 (±0.5)~~	~~±0.15 (±1.5)~~	~~±0.25 (±2.5)~~
Pressure, where p ≥ 0.15 MPa (%)	±0.25	±0.5	±1.0
~~Test Fluid Temperature (°C)~~	~~±0.5~~	~~±1~~	~~±2~~
Test Fluid Temperature (°C)	±1.0	±2.0	±4.0

~~pressure, and sea level at the beginning of each test sequence.~~lists the systematic measuring instrument error limits for hydraulic fluid testing during calibration. Sensors that comply with Class A requirements are recommended.

~~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.~~

6.1.7 ~~*Oil Temperature*—~~*Calibration—*~~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 inlet.~~The calibration of all instruments shall be verified. Pressure transducers in particular are susceptible to damage as a result of hydraulic pressure spikes.

6.1.8 ~~*Oil Viscosity*—~~*Flow Meter Selection—*~~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~~ Positive displacement gear type flow meters are recommended for dynamometer testing. In vehicle testing, it may be necessary to use another type of flow meter to avoid excessive pressure losses that affect machine performance and efficiency.

6.1.9 *Baseline Oil*—The baseline fluid shall be selected by agreement of the responsible parties.

6.1.10 ~~*Oil Pressure*—~~*Pump Run-in—*~~Oil pressure has a strong influence on hydraulic pump efficiency. It is important to ensure that the~~New pumps shall be run-in for 24 h with the baseline fluid following the test sequence outlined in Table 2~~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.~~. After the initial 3 h warm up (stages 1 – 5), run-in the component for 20 h at rated pressure and speed (stage 6). Total time for run-in shall be 24 h, including the 1 h cool down cycle (stage 7). Any mechanical issues arising during run-in shall be fixed as necessary, with the run-in continuing where left off.

6.1.11 *Fluid Flushing*—A triple flush method shall be employed to reduce carry over between fluids. Flush and drain the system three times. Change the oil filter. Fill the system and perform fluid Run-in.

6.1.12 *Fluid Run-in*—New baseline and candidate fluids shall be run-in 500-turns of the reservoir at 50 °C and maximum system pressure.

TABLE 2 24 h Run-in Sequence for New Hydraulic Pumps

Stage	Time, h	Mode	Speed, % of rated max	Pressure, % of rated max	Displacement, % of rated max	Pump Inlet Temp, °C
1	0.5	Warm up	50	25	100	Ambient
2	0.5	Warm up	50	50	100	50 nominal
3	0.5	Warm up	75	50	100	50 nominal
4	0.5	Warm up	75	75	100	80 nominal
5	1.0	Warm up	100	75	100	80 nominal
6	20.0	Run-in	100	100	100	80 ± 1
7	1.0	Cool down	75	25	100	Ambient

NOTE 2—Fluid Run-in is performed to stabilize viscosity and tribological surface conditions. Shearing of the fluid is more severe at 50 °C than 80 °C, hence fluid run-in is performed at the lower of these two temperatures (50 °C).

6.1.13 *Calculation of the Run-in Time*—The minimum run-in duration shall be calculated as shown in Eq 1:

$$\theta = (q_r * 500)/(Vi\ (n) * 60) \quad (1)$$

where:

θ = minimum fluid run-in duration in hours,
q_r = volume of oil in the reservoir in liters,
Vi = pump displacement in liters per revolution, and
n = rotational frequency of the pump in r/min.

6.1.14 ~~*Operator Differences*—~~*Pump Test Sequence*—~~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~~ Each evaluation shall consist of two segments: an initial fluid baseline and a candidate fluid 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 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.~~

6.1.15 ~~*Electric Power Quality*—~~*Pump Test Conditions*—~~In systems drawing power from a common source such as plant equipment, changes~~ The high-pressure pump testing shall consist of operating a variable displacement piston pump at maximum pressure and 80 °C under the conditions shown in Table 3~~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.~~. Each of the twelve test points shall be evaluated during a single run. A minimum of five runs of data shall be collected. The testing stage sequences may be altered to help with temperature control.

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

6.1.16 ~~*Fuel Measurement*—~~*Test Validation*—~~Fuel gauges on commercial~~Verify that inputs (Table 3 ~~hydraulic machines are designed to indicate when fuel replenishment is necessary. Consequently, fuel gauge accuracy is insufficient for efficiency studies. Fuel levels may be determined by using an auxiliary tank and weighing the amount of fuel~~) comply with the limits provided in Table 1~~consumed or using fuel flow sensors.~~.

TABLE 3 Pump Test Parameters

Stage	Time	Mode	Pump speed, % of max	Pressure, % of max	Displacement, % of max	Pump Inlet Temp, °C
	0.1 h	Warm up	40 – 50	20 – 30	100 nominal	Ambient
	0.1 h	Warm up	50 – 60	50 – 60	100 nominal	50 nominal
	0.3 h	Warm up	60 – 70	70 – 80	100 nominal	80 nominal
	0.5 h	Warm up	100	100	100 nominal	80 nominal
1	≥5 s	Testing	100	100	100	80
2	≥5 s	Testing	100	100	80	80
3	≥5 s	Testing	100	100	60	80
4	≥5 s	Testing	100	90	100	80
5	≥5 s	Testing	100	90	80	80
6	≥5 s	Testing	100	90	60	80
7	≥5 s	Testing	90	100	100	80
8	≥5 s	Testing	90	100	80	80
9	≥5 s	Testing	90	100	60	80
10	≥5 s	Testing	90	90	100	80
11	≥5 s	Testing	90	90	80	80
12	≥5 s	Testing	90	90	60	80

~~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.~~

6.1.17 *Test Measurements*—Record the following:

6.1.17.1 Input torque,

6.1.17.2 Input shaft speed,

6.1.17.3 Inlet temperature,

6.1.17.4 Inlet pressure,

6.1.17.5 Outlet pressure,

6.1.17.6 Outlet flow rate, and

6.1.17.7 Pump case, pressure compensator, and motor drainage flow rates.

6.1.18 Evaluate the results as described in 7.1.

6.2 ~~*Subject Equipment Selection*—~~*Procedure for Laboratory Evaluation of Fluids in Positive Displacement Motors:* ~~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.~~

6.2.1 *General Description*—Hydraulic motor tests shall be conducted on a hydraulic dynamometer via a modified ISO 4392-1 method. This part of ISO 4392 describes a method of determining the low-speed characteristics of positive displacement rotary fluid power motors, of either fixed or variable displacement types. The method involves testing at constant low-speed and high-pressure conditions. The purpose of the following procedure is to produce a statistical basis for comparing the performance of fluids in terms of hydraulic motor efficiency and/or torque losses. Modifications are required to the ISO 4392 method because fluid performance, rather than motor performance, is to be evaluated.

6.2.2 *Motor Selection*—A positive displacement piston motor that is employed in construction engineering, material handling, or other off-highway vehicle applications shall be selected for testing. A Poclain MSE02 Radial Piston Motor and a Danfoss Series 90 Axial Piston Motor have been found to be suitable. Use of other motor designs is permitted.

NOTE 3—A calculation of the theoretical torque is required to determine the hydromechanical efficiency of a motor as shown in Eq X2.5. Theoretical torque is determined from the mathematical product of the motor differential pressure and derived displacement (*Vi*).

6.2.3 The derived displacement of the motor shall be determined in accordance with ISO 8426.

6.2.4 Install the pump in a hydraulic circuit as shown in Fig. 2.

6.2.5 See 6.1.6 – 6.1.8 for sensor, calibration, and flow rate requirements.

6.2.6 *Baseline Oil*—The baseline fluid shall be selected by agreement of the responsible parties.

6.2.7 *New Motor Run-in*—New motors shall be run-in according to manufacturer recommendations with the baseline fluid. Performing a run-in sequence is necessary to stabilize the performance of the motor in low-speed testing. If run-in procedure is not available from the manufacturer, use the run-in sequence listed in Table 4.

6.2.8 *Fluid Flushing*—A triple flush method shall be employed to reduce carry over between fluids. Flush and drain the system three times. Change the oil filter. Fill the system and perform fluid run-in.

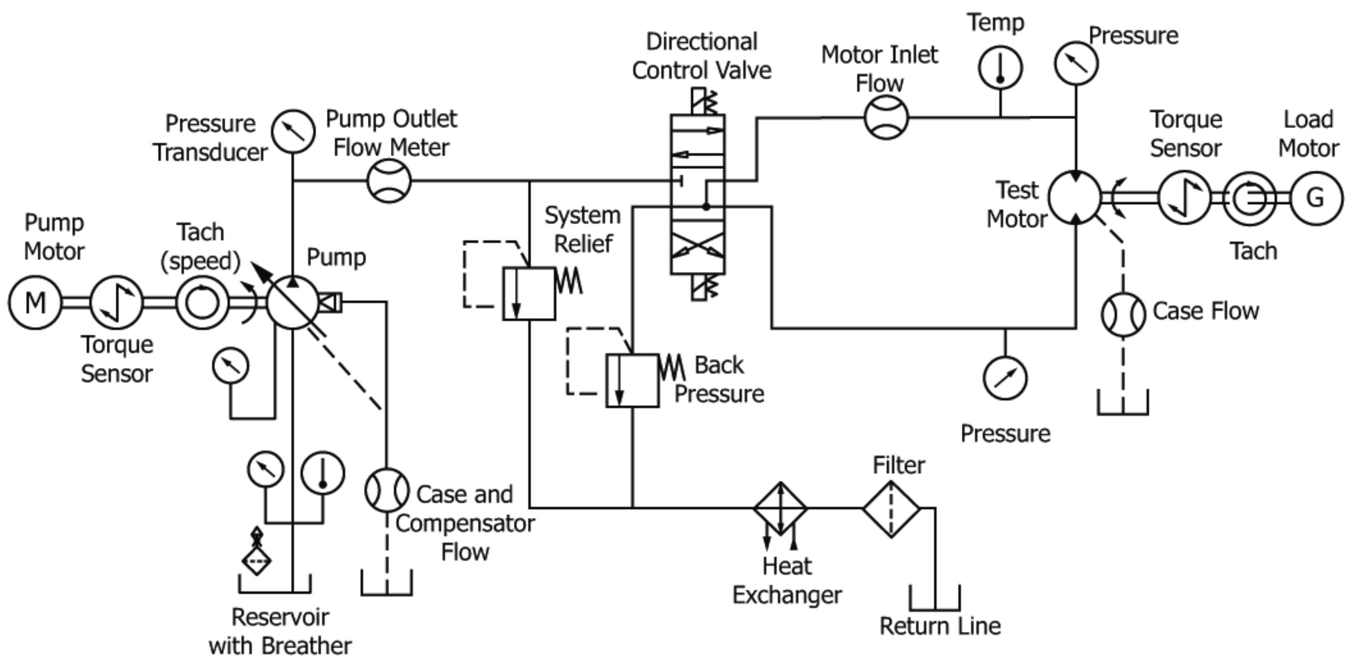

FIG. ~~1~~2 ~~Schematic of Fuel Measurement System~~Circuit Schematic for Evaluating the Effect of Fluid on Motor Performance

TABLE 4 24 h Run-in Sequence for New Hydraulic Motors

Stage	Time, h	Mode	Speed, % of rated max	Pressure, % of rated max	Motor Inlet Temp, °C
1	1.0	Warm up	25 %	25 %	50 nominal
2	1.0	Run-in	50 %	50 %	50 nominal
3	1.0	Run-in	75 %	75 %	50 nominal
4	4.0	Run-in	100 %	100 %	80 nominal
5	4.0	Run-in	75 %	100 %	80 nominal
6	4.0	Run-in	50 %	100 %	80 nominal
7	4.0	Run-in	10 %	100 %	80 nominal
8	4.0	Run-in	5 %	100 %	80 nominal
9	1.0	Cool down	75 %	25 %	Ambient

6.2.9 *Fluid Run-in*—New baseline and candidate fluids shall be run-in 500-turns of the reservoir at 50 °C and maximum system pressure.

6.2.10 *Calculation of the Run-in Time*—The minimum run-in duration shall be calculated as shown in Eq 1.

6.2.11 *Motor Test Sequence*—Each evaluation shall consist of two segments: an initial fluid baseline and a candidate fluid evaluation.

6.2.12 *Motor Test Conditions*—The low-speed high-torque motor test shall be conducted under the conditions shown in Table 5.

TABLE 5 Motor Test Parameters

Stage	Time	Mode	Speed, % of rated max	Speed, r/min	Pressure, % of rated max	Pump Inlet Temp, °C
	0.1 h	Warm up	25		25	Ambient
	0.1 h	Warm up	50		50	50 nominal
	0.3 h	Warm up	75		75	80 nominal
	0.5 h	Warm up	100		100	80
1	15 s	Testing		1	25.0	80
2	15 s	Testing		1	37.5	80
3	15 s	Testing		1	50.0	80
4	15 s	Testing		1	62.5	80
5	15 s	Testing		1	75.0	80
6	15 s	Testing		1	87.5	80
7	15 s	Testing		1	100.0	80

Each of the seven test points shall be evaluated during a single run. A minimum of five runs of data shall be collected. The testing stage sequences may be altered to help with temperature control.

6.2.13 *Test Validation*—Verify that inputs (Table 5) comply with the limits provided in Table 1.

6.2.14 ~~*Breaking-in of Equipment*—~~*Data Collection*—~~To reduce mechanical variability in new equipment, it is recommended that appropriate equipment break-in procedures shall be followed until stable conditions are obtained.~~Collect 15 s of data at each test point under steady-state conditions.

NOTE 4—The motor rotates one-quarter revolution in 15 s during 1 r ⁄min testing. A shorter sample duration my lead to excessive variability in the test results.

6.2.15 *Test Measurements*—Record the following motor input and output parameters:

6.2.15.1 Input flow rate,

6.2.15.2 Inlet temperature,

6.2.15.3 Inlet pressure,

6.2.15.4 Outlet pressure,

6.2.15.5 Output torque,

6.2.15.6 Output shaft speed, and

6.2.15.7 Motor case drainage flow rate.

6.2.16 Evaluate the results as described in 7.2.

~~6.5 *Equipment Selection/Matching*—Efficiency tests may be run in a single hydraulic system or in matched hydraulic systems of identical design that have been constructed using components of the same make and model. In either case, in the test plan, any variations in the operating conditions or differences in the relative efficiency of the different hydraulic units need to be addressed. For example, data runs in matched hydraulic systems may need to be alternated to ensure consistent results as described in 6.3.1.~~

~~6.6 *Data Collection Equipment Selection*—Instrumentation for measuring rotational frequency, flow rate, pressure, temperature, and torque are routinely required in hydraulic efficiency tests. It is essential to ensure that the sensitivity and precision of measurements are sufficient to detect performance differences, if they exist. Table 1 lists the typical systematic measuring instrument error limits for hydraulic instruments. Instruments that comply with Class A requirements are recommended. The calibration of all instruments shall be verified. Pressure transducers in particular are susceptible to damage as a result of hydraulic pressure spikes. Positive displacement or turbine flow meters are acceptable. Positive displacement flow meters are generally more accurate, however the pressure drop across the meter may affect machine performance or efficiency.~~

6.3 ~~*Data Collection:*~~*Field Testing:*

6.3.1 *General Description*—Field tests shall be conducted on equipment that is predominantly hydraulicly powered. Typical examples include crawler excavators, mining excavators, wheel loaders, hydraulic forge lifts, hydraulic presses, injection molding and die casting machines.

NOTE 5—Plastic injection molding machines and medium sized excavators in the 20 to 50 ton range have been extensively studied. Example test protocols for these types of machines are provided in Appendix X3.

6.3.2 *Equipment Selection*—Select equipment that is fit for use.

6.3.2.1 Inspect the candidate machine to ensure that all critical mechanical and hydraulic functions (propulsion, extension, retraction, pressure, and flow control) are operating properly.

6.3.2.2 Air conditioning and other auxiliary systems may be disabled or locked into a fixed operating condition to reduce the impact of ambient temperature and unrelated conditions on energy consumption.

6.3.3 *Sensors and Instrumentation*—Equip the machine with the necessary sensors to measure changes in energy consumption and productivity. It is recommended that the following parameters be measured.

6.3.3.1 Ambient temperature,

6.3.3.2 Atmospheric pressure,

6.3.3.3 Hydraulic fluid temperature,

6.3.3.4 Hydraulic pump outlet pressure,

6.3.3.5 Energy consumption:
(1) Fuel consumption,
(2) Fuel temperature,
(3) Engine or motor speed, and
(4) Electric power consumption current and voltage.

6.3.3.6 Cooling device operation mode and power consumption,

NOTE 6—If it is not possible to fix the cooling conditions it is necessary to measure the fan speed and cooling water temperature and flow rate.

6.3.3.7 Cycle time, and

6.3.3.8 Mass of material processed or moved per cycle.

6.3.4 *Data Acquisition*—The parameters are recorded over time with an appropriate data recorder. Real time data shall be recorded with high time resolution. A sample frequency of 2.4 kHz or higher is recommended for evaluating electrical efficiency in short-cycle time applications like injection molding.

6.3.5 *Test Fluids:*

6.3.5.1 *Baseline Fluid ("A")*—The baseline fluid shall be selected by agreement of the responsible parties.

6.3.5.2 *Test Fluid ("B")*—The test fluid shall be selected by agreement of the responsible parties.

6.3.5.3 *Fluid Properties*—Measure the viscosity, viscosity index, shear stability, and density of the baseline and candidate fluids.

6.3.6 *Test Sequence*—Use an "ABA" or "BAB" test fluid.

6.3.7 *Fluid Change Procedure*—Start the machine and operate all functions until the oil temperature has equilibrated close to the typical operating temperature.

NOTE 7—Warming of the fluid facilitates the proper draining of the hydraulic fluid.

6.3.7.1 Collect an oil sample for analysis.

6.3.7.2 Retract all hydraulic cylinders to minimize the volume of fluid trapped in the system.

6.3.7.3 Drain the oil reservoir completely.

NOTE 8—Install a quick disconnect or ball valve at the lowest point of the reservoir to facilitate oil changes. If a bottom drain port is not available, then the oil may be removed by pumping it out of the reservoir from a top access port.