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Single Hydraulic Fluid for Army Ground Combat and Tactical Vehicles and Equipment

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The objective of this study was to address the perceived problems of low temperature operability and seal incompatibility which have prevented the conversion of all Army vehicles and equipment to MIL-H-46170 (FRH) hydraulic fluid. This was accomplished by performing a literature search of all test reports pertaining to FRH and surveying users of FRH to gather all information concerning these and any other problems. It was learned that FRH does not perform well at temperatures of −25°C and below, although whether this is a problem or not depends on the hydraulic system. There are no seal problems when FRH is used with new seals. A list of several courses of action to accomplish conversion of all Army vehicles and equipment to a single hydraulic fluid is provided.

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EXECUTIVE SUMMARY

This study provides relevant data for Army decisionmakers in order to select the best course of action in the conversion of all Army ground vehicles and equipment to a single hydraulic fluid. This would eliminate many supply, procurement, and logistics problems and would provide the best possible hydraulic fluid. The two leading choices for this single hydraulic fluid are:

- MIL-H-46170 (FRH), a fire resistant hydraulic fluid which was developed and partially adopted by the Army in the early 1970s in response to serious flammability complaints with MIL-H-6083 (OHT), the petroleum based hydraulic fluid, then most commonly used.
- A new, improved fire resistant hydraulic fluid having excellent low temperature properties, but slightly more flammable than FRH and less flammable than OHT.

First, it was necessary to determine the magnitude and severity of the complaints about FRH (low temperature operability and seal compatibility) to eliminate impediments to FRH adoption by all Army ground vehicles and equipment. A literature and user survey was conducted and the results are summarized in this report.

It was found that all vehicles tested experienced some degree of hydraulic system sluggishness at temperatures below 0°F with some clear deficiencies occurring at –25°F, although whether or not this presented a problem depended on the hydraulic system. However, criteria have not been established giving the permissible degree of hydraulic system sluggishness yet still permitting satisfactory performance of weapons and weapons support systems.

There were no reported seal leakage problems, although some seal leakage in hydraulic systems is accepted as normal. Excessive leakage may be attributed to worn or defective seals, a changeover from OHT to FRH using the same seals, or an inadequacy of the elastomer material, and not from an inability of FRH to sufficiently swell the elastomer and thus prevent leakage.

Because no single hydraulic fluid perfectly meets the needs of all Army ground vehicles and equipment, prioritization of requirements is necessary. Four suggested courses of action to expedite the hydraulic fluid standardization effort are:

- Conversion of all vehicles to FRH
- Continued usage of both OHT and FRH
- Conversion of all vehicles to a new, improved hydraulic fluid
- Usage of FRH and the new hydraulic fluid to replace OHT.

Additional work is still needed in this effort. Field testing of vehicles using FRH, OHT, and/or the new hydraulic fluid should be performed to compare the performance of these fluids and determine the requirements of vehicle hydraulic systems. Development of the improved hydraulic fluid and flammability testing of this fluid should be completed to determine if this fluid meets the flammability requirements of Army vehicles and equipment.

SECTION I. INTRODUCTION

The maintenance of a large stock of different lubricants, fluids, and associated products—many of which are used in relatively small quantities—has caused the Army serious procurement, supply, and logistics problems. In order to reduce this proliferation of lubricants and to monitor the entry of nonstandard lubricants within the military supply system, the Belvoir Research, Development and Engineering (RD&E) Center has the assigned responsibility of coordinating all Lubrication ("Lube") Orders and other Lubrication Instructions (Army Materiel Command Regulation 750-11, *Use of Lubricants, Fluids, and Associated Products,* 15 June 1986).

To reduce the number of hydraulic fluids being used in ground combat and tactical vehicles and equipment, this Center is seeking to standardize a single hydraulic fluid. The primary hydraulic fluids currently in use in these vehicles and equipment are:

- MIL-H-46170 (FRH), *Hydraulic Fluid, Rust Inhibited, Fire Resistant, Synthetic Hydrocarbon Base,* 18 August 1982
- MIL-H-6083 (OHT), *Hydraulic Fluid, Petroleum Base, for Preservation and Operation,* 14 August 1986
- MIL-H-5606 (OHA), *Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance,* 29 August 1980.

In addition, several obsolete hydraulic fluids and at least one proprietary hydraulic fluid are still referenced in lubrication instructions for Army vehicles and equipment.

Following the Korean War, the Army replaced OHA with OHT as the standard operational hydraulic fluid to preclude the corrosion problems which occurred when OHA was used in the hydraulic systems of ground equipment. OHA does not contain corrosion inhibitors and should not be used in Army ground vehicles and equipment. Nevertheless, there are at least 40 Army vehicles/equipment which still use OHA according to current Lubrication Orders/Instructions.

As a result of the October 1973 Arab/Israeli conflict, General Abrams expressed alarm over the high number of reported losses of M60 tanks and associated crew casualties due to fires. These fires, which reportedly occurred in the turret environment, were attributed in part to the highly flammable OHT hydraulic fluid. Consequently, by mid-1974, all of the most vulnerable armored vehicles (M60, M60A1, M60A1(AOS), M60A2, M48A3, M728, and M551) were directed to have their OHT replaced with the newly developed, less flammable FRH. The remaining armored combat vehicles and other self-propelled artillery (identified as the *Phase 2 Conversion*) were to be retrofitted at a later date; however, this retrofitting did not occur. At least 29 vehicles/equipment currently list OHT as their correct hydraulic fluid. The more recently fielded M1 Abrams Tanks and M2 Bradley Fighting Vehicles use FRH in recognition of its improved flammability characteristics. However, only 15 Lubrication Orders list FRH as the correct hydraulic fluid. Some vehicles/equipment use both OHT and FRH since OHT is recommended for extreme low temperature operations while FRH is the primary hydraulic fluid. The mandated usage of FRH as the single hydraulic fluid for ground combat and tactical vehicles and equipment would reduce the vulnerability of each vehicle and decrease the logistic burden.

The reasons given for not converting the remaining armored combat vehicles and other Army vehicles from OHT to FRH were:

- Low temperature operability deficiencies;
- Perceived seal incompatibilities; and
- Concern over increased cost.

SECTION II. LITERATURE STUDY AND USER SURVEY

In order to eliminate the impediments of converting all ground vehicles and equipment to a single hydraulic fluid, all reported FRH deficiencies required assessment. A literature study was conducted of all available previously conducted low temperature and seal compatibility testing of OHT, OHA, FRH and MIL-H-83282, *Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft,* NATO Code Number H-537, 14 February 1982. MIL-H-83282 is a synthetic hydraulic fluid identical to FRH except that it does not contain corrosion inhibitors. It can be assumed that FRH acts the same as MIL-H-83282 in cold temperature testing and in its interaction with elastomer materials. Similarly, OHT and OHA are identical except for the corrosion inhibitors in OHT. In addition, a letter requesting information about low temperature and seal deficiencies of FRH was sent to Army testing facilities and to representatives of the major Army users of FRH (US Army Armament Research, Development, and Engineering Center; US Army Armament, Munitions, and Chemical Command; US Army Tank-Automotive Command; US Army Test and Evaluation Command; and the Program Executive Office for Close Combat Vehicles). A telephone survey of the major program offices was also conducted to ensure that all FRH "complaints" were represented in this study. Based upon this search, the following reports were first reviewed, and then divided between *Low Temperature Operability Problems* and *Seal Leakage, Seal Compatibility Problems.*

LOW TEMPERATURE OPERABILITY PROBLEMS

Although OHT and FRH possess very similar characteristics (see Table 1), FRH has higher viscosities at low temperatures. Thus, a possibility exists that the performance of FRH at low temperatures will not be as good as that of OHT. Low temperature testing on various systems has been performed with results in general agreement that FRH is more sluggish at low temperatures than OHT. Whether or not this results in an operational deficiency depends on the system and its requirements.

Table 1. Comparison of Hydraulic Fluid Properties*

CHARACTERISTICS	MIL-H-6083	MIL-H-46170	PROPOSED FLUID
Viscosity, cSt:			
@ 40°C	13, min	19.5, max	—
@ 100°C (min)	—	3.4	2.2
@ –40°C (max)	800	2,600	550
@ –54°C (max)	3,500	report	2,500
Pour point, °C (max)	–59	–54	–59
Evaporation loss, % (max)	70.0	5.0	20.0
Flash point, °C (min)	82	218	160
Fire point, °C (min)	—	246	170
Autoignition temp, °C (min)	—	343	360
Swelling of synthetic rubber, %	19.0 – 28.0	15.0 – 25.0	18.0 – 30.0
Lubricity, scar diameter, mm (max):			
10 kg load	–	0.30	0.30
40 kg load	1.0	0.65	0.65
Cost, per gallon (February 1989)	$5.50	$7.52	$7.50

* *Values given are specification requirements and not typical inspection properties.*

1. A comparative study of OHT and FRH was performed in 1976 in M60A1 and M60A2 turret hydraulic systems.[1] Performance of both turret systems at -25°F was inferior with FRH compared to OHT. Both turret systems were more effective with either hydraulic fluid in the stabilized mode than in the nonstabilized mode. With FRH, recoil times were slow and recoil lengths were short at –25°F and –50°F. It was recommended that FRH fluid be considered acceptable for use in the turret hydraulic and recoil systems of both the M60A1 and M60A2 tanks.

2. Testing was conducted to verify acceptability of MIL-H-83282 in the landing gear shock struts of a Navy aircraft (S-3A main landing gear) at temperatures as low as –65°F.[2] OHA was also tested for comparison. The quantitative differences between performance tests of OHA and MIL-H-83282 were negligible except that the strut service time was twice as long for MIL-H-83282 and a higher fill pressure was required. MIL-H-83282 was recommended as an acceptable substitute for OHA in high performance landing gear shock struts.

3. In testing the M1E1 (XM256) gun mount, it was found that the recoil cycle time generally decreased as the system warmed up.[3] The initial cycle time changed significantly with ambient temperatures: about 0.35 seconds at +125°F; about 20 seconds at –50°F; and 40 to 80 seconds at –65°F.

4. According to the March 1988 Initial Production Test of the M1A1, the performance of the M1A1 is currently classified as a deficiency under low temperature conditions for several reasons.[4] One problem was that main gun tube oscillations occurred at 0°F with the system in normal mode, so that a 15 minute warm-up period in the emergency mode was required. In previous tests, oscillations did not occur until temperatures were in the –10°F to –15°F range. Despite this deficiency and since fire survivability is a top priority for the Abrams, FRH continues to be the recommended hydraulic fluid. Design changes, such as the use of a small heater in the manifold, have been made to accommodate the use of FRH.

5. The 1981 Current Production Test of the M901 included testing of OHA (the fluid currently required in the M901) and FRH.[5] At –25°F, both fluids required slave starting. The firing sequence was successful with OHA after it was warmed up. A first firing sequence was unsuccessful with FRH; the launcher required excessive time (25 seconds) to erect and the weapon station could not be traversed. A second (repeated) firing sequence at low temperatures was successful. The initial firing sequence failure was related to frozen condensation on critical control mechanisms. When the test was repeated with the ice

problem eliminated, system performance improved, but was still sluggish and the pump sounded "funny", presumedly from the high viscosity FRH.[6] At higher temperatures, the firing scenario was successful with FRH.

6. In 1985, testing of the Light Armored Vehicle (LAV) for the Marine Corps also revealed problems with FRH at low temperatures.[7] The turret traverse rate at –25°F was well below the level required to fully support tactical operations because of inability of the hydraulic system to function satisfactorily with FRH. Although no criteria were given, turret traversing rates were considered marginal at 0°F. The turret traverse rate improved substantially after 30 minutes of operation.

7. Additional cold room testing of the LAV provided more information about the exact temperatures at which the systems cannot function.[8] The targeting head could not be erected at –25°F. When the temperature was raised to –15°F, the targeting head still could not be raised. The hydraulic system pressure was 2,400 psi, but no movement was noted. At 0°F, the turret subsystem functioned, although marginally, when compared to operation at ambient temperatures. At –5°F, the performance characteristics of the turret were approximately the same as at 0°F. Since FRH is the recommended hydraulic fluid for the LAV because of vulnerability considerations, a redesign of the turret system to allow for adequate performance at low temperatures was recommended.

SEAL LEAKAGE, SEAL COMPATIBILITY PROBLEMS

There have been contradictory reports about increased seal leakage with the use of FRH. Leakage is prevented by the swelling of the elastomeric seals, which is caused by the hydraulic fluid. OHT causes somewhat greater elastomer swell than FRH, but it has been assumed that FRH-induced elastomer swell is adequate to prevent leakage.

It is difficult to ascertain the cause of seal leakage. For example, in addition to insufficient swelling of the seal, seal leakage can be caused by—

- A poorly designed seal that does not meet the specified tolerances,
- Degradation of the seal by particulate contamination of the hydraulic fluid, or
- Wearing of the seal by mechanical means.

In addition, laboratory duplication of seal problems is more difficult since the composition of each seal is unknown and seals with the same part number may be entirely different chemically.

1. **Finding: No seal problems.** The 1976 initial testing of FRH and OHT in the M60A1 turret hydraulic systems and the M140 and the M162 gun mount stated that there was no evidence of leaking or seeping of seals.[1]

2. **Finding: Major seal problem, but no longer relevant.** Because of reports of excessive seal leakage in the M140 gun mounts of the M60A1, additional testing of the M140 gun mount's Greene-Tweed T-seals with OHT and FRH was conducted in 1975.[9] Both fluids produced very slight and equal effects on the tensile strength, elongation, hardness, and compression set of the rubber after immersion for 70 hours at 275°F. That report concluded that FRH was an extracting fluid (extracts plasticizers from the Greene-Tweed elastomer) under certain conditions. OHT does not extract plasticizers to the same degree. Since OHT swelled the elastomer and FRH often shunk the elastomer, it was quite likely that FRH caused excessive leakage in M140 gun mounts containing Greene-Tweed seals. In response to these seal leakage problems, the formulation of FRH was changed in 1976, increasing the amount of the ester component which causes the seal swell. Therefore, these test results are not relevant to current FRH.

3. **Finding: No seal problems.** A report prepared in 1980 after testing the M162 gun mount seals predicted that seals made from the currently used seal compound would swell much less in FRH than in OHT.[10] Because of the partial exchange of plasticizers from the elastomer and the elastomer swell agents in the fluid, both the elastomer and the hydraulic fluid will change with time. Based upon this report, seal changes were recommended when the fluid was changed from OHT to FRH.

4. **Finding: No seal problems.** Additional testing to elucidate the causes for the failure of M140 gun mount seals in the presence of FRH was performed from 1981 to 1983.[11] The conclusions were that the Greene-Tweed (GT-160) seals swell significantly less in FRH than OHT. Also, fluid/seal interactions alter the nature and behavior of an elastomer due to the changes in the composition of the materials within the elastomer/polymer network. So, unless the given fluids have equivalent additive packages, consecutive fluid substitutions would be expected to cause composition changes within the elastomer network which would be reflected in the elastomer's physical properties and the ability to provide a reliable seal. These problems could be alleviated by using identical or equivalent ester-additive packages in the seal and fluids when fluid changes are anticipated. In addition, since the seal

plasticizer is leached out by the hydraulic fluids, it may not be necessary to include it in the seals. Since the ester-additive packages of OHT and FRH are not identical, the seals should be changed when there is a changeover from OHT to FRH.

5. **Finding: Probable seal problems; may be caused by the sealant material.** Another study of two types of Greene-Tweed elastomers (GT-160 and GT-599) was performed by Belvoir RD&E Center in 1989.[12] These Greene-Tweed elastomers were selected since they are used extensively in the systems of Army vehicles and equipment. The two types of elastomers were immersed in several samples of OHT and FRH from different manufacturers for 2 weeks at 100°C. It was found that elastomer swell occurred with OHT and elastomer shrinkage occurred with FRH. Consequently, both elastomer types were characterized as initially unacceptable because of their "low swell" properties.

SECTION III. CONCLUSIONS

Based upon the low temperature performance testing of FRH, it can be concluded that FRH does not perform satisfactorily at temperatures below 0°F, with clear deficiencies occurring at –25°F in some systems tested. The Marine Corps LAV had the most serious low temperature problems with FRH, although FRH is still recommended because of flammability considerations. All Army users of FRH acknowledge some degree of low temperature sluggishness, but this is tolerated since a short warm-up period sufficiently warms the hydraulic fluid to eliminate any sluggishness and also since flammability considerations are of a higher priority. Unfortunately, low temperature operability criteria have not been established which would define the degree of hydraulic system sluggishness that will still permit satisfactory performance of weapons and weapons support systems.

There are no reported seal leakage problems when FRH is used with new seals. However, it is normal for most hydraulic systems to experience some leakage, which is not reported. Since there are no current seal leakage complaints attributed to FRH, it can be assumed that FRH is acceptable with respect to elastomer swell. Past problems may be attributed to hydraulic fluid changeover from OHT to FRH without an accompanying seal change, or to the original, inadequate FRH formulation, which may not have provided sufficient seal swell.

The additional question of whether or not seal leakage will occur after changeover from OHT to FRH has not been answered conc'.sively. Research currently in progress within the Belvoir RD&E Center is directed to answering this question by studying seal swell of different typical seal materials in OHT and FRH. Testing of the seals when immersed in OHT followed by FRH and in FRH followed by OHT is included to ascertain if a seal change is needed when there is an OHT-FRH changeover.

It appears that the only impediments to the use of F".H as the single hydraulic fluid for ground combat and tactical vehicles and equipment are the low temperature performance of FRH and the possible costs involved with a fluid conversion (hydraulic fluid, labor, and possibly new seals).

It will be necessary to prioritize the .equirements for a decreased logistical burden, fire survivability, low temperature operability, and cost to decide which course to choose in standardizing hydraulic fluid in Army ground combat and tactical vehicles and equipment. Table 2 provides courses of action in expediting the hydraulic fluid standardization effort.

Table 2. Decision Factors in Comparing Courses of Action for Achieving Single Hydraulic Fluid

The Decision Factors in the table are points to consider in deciding which hydraulic fluid should be used in Army vehicles and equipment. No attempt has been made to weigh these considerations and they are not of equal importance. Options A, B, C, and D are described below the table. The + sign means that the hydraulic fluid option selected has a positive impact. For example, if Option A (conversion of all Army ground vehicles and equipment to FRH) is selected, the vulnerability of all Army ground vehicles and equipment will be improved—a positive consideration. The – sign means that the factor has a negative impact. With Option A, all Army ground vehicles and equipment may experience some low temperature operability ("negative") problems. The ? symbol means that data is not yet available to make the determination.

HYDRAULIC FLUID TO BE USED FOR ARMY VEHICLES

DECISION FACTOR	OPTION A FRH	OPTION B FRH & OHT	OPTION C New Fluid	OPTION D FRH & New Fluid
Low Temperature Operability	–	+	+	+
Flammability (Vulnerability)	+	–	?	?
Logistic Burden	+	–	+	–
Cost Required for Conversion	+	+	–	–
Cost Required for R&D	+	+	–	–
Wear Prevention	+	–	+	+

Option A Convert all Army vehicles and equipment from OHT to FRH, thus accepting a moderate degree of low temperature sluggishness and utilizing equipment modifications (auxiliary heaters, etc.) and warm-up procedures to accommodate the use of FRH, if necessary. An added consideration in the conversion from OHT to FRH is that FRH has superior anti-wear characteristics to OHT so vehicles and equipment using FRH should experience less wear over the life of the system.

Option B Continue usage of both FRH and OHT (*status quo*). (The use of OHA must be phased out because OHA does not contain corrosion inhibitors). This course of action is discouraged since it does not alleviate the logistical burden of two or more fluids being required and the flammability of OHT remains a problem for all users.

Option C Replace both OHT and FRH with a new hydrocarbon-based hydraulic fluid (compatible with FRH, OHT, and existing seals in existing systems) having satisfactory low temperature and flammability characteristics which are better than OHT, but not as good as FRH (refer to Table 1, page 3). The Air Force has developed an improved hydrocarbon-based, fire-resistant hydraulic fluid with excellent low temperature properties intended to replace OHA in aircraft operating in cold climactic conditions.[13, 14, 15, 16] For Army usage, the Air Force-developed hydraulic fluid would require the addition of corrosion inhibitors.

Option D Replace OHT with the new hydraulic fluid described in Option C which has improved flammability characteristics, and continued usage of FRH in vehicles where the superior flammability characteristics of FRH are essential.

SECTION IV. RECOMMENDATIONS AND ADDITIONAL TESTING

It is recommended that the single hydraulic fluid effort be continued. The following testing is necessary to continue this effort:

1. Perform controlled low temperature testing in the field using FRH and OHT in test and control groups of vehicles which do not currently use FRH to determine:

- The performance of FRH, whether major or minor problems occur;
- Low temperature performance acceptability criteria for various hydraulic systems; and
- Whether all Army vehicles and equipment may be converted to FRH or, if not, whether an improved, low temperature hydraulic fluid is needed.

2. Complete development of the corrosion inhibited version of the new hydrocarbon-based, low temperature hydraulic fluid.

3. Perform flammability testing of the new hydrocarbon-based, low temperature hydraulic fluid so that vulnerability assessments can be made.

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