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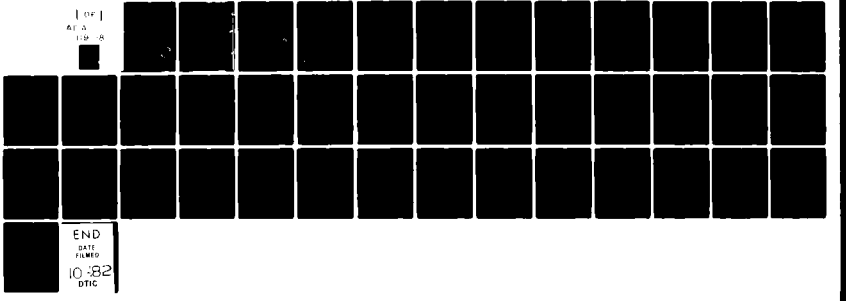

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APPLICATION OF MILITARY ENGINE OILS IN HYDRAULIC/POWER TRANSMISSION FLUID COMPONENTS AND SYSTEMS

INTERIM REPORT
AFLRL No. 159

By

H.W. Marbach, Jr.
S.J. Lestz
U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas

Under contract to

U.S. Army Mobility Equipment Research and Development Command
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Fort Belvoir, Virginia

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Today the majority of the construction equipment (CCE) and selected material handling equipment (SMHE) utilized by the Army is of the commercial or modified commercial type. Although obvious advantages exist for this policy, certain problems require resolution to make the CCE and SMHE program successful. These CCE and SMHE items have hydraulic systems that use various commercial components and frequently use commercial proprietary fluids.

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20. ABSTRACT (Continued)

Therefore, this MACI Hydraulic System and Components Program was started to perform technical evaluation and assessment of commercially available qualified and fielded military engine oils and to determine if such oils can be used as hydraulic fluids in Army CCE and SMHE.

Nine military specification engine oils; six oils qualified under MIL-L-2104C, three grade OE/HDO-10 and three grade DE/HDO-30; two available multiviscosity lubricants satisfying MIL-L-2104C engine lubricant requirements, and one oil qualified under MIL-L-46167 (Arctic) were evaluated using nine selected tests required by manufacturers and one test developed by AFLRL in conjunction with John Deere personnel. From the data developed, four MIL-L-2104C lubricants, one OE/HDO-10 lubricant, and three OE/HDO-30 lubricants passed most of the tests.

In addition, three listings were developed. One li- was of the manufacturer's hydraulic/power transmission lubricant requirements. This list was compiled to aid in the selection of the various tests performed. The second was a listing which contained all the present and planned CCE/SMHE in the Army system. The third list provided the manufacturers of the hydraulic/power transmission components, engines and drives used in each type of equipment.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, San Antonio, TX, under Contract No. DAAK70-80-C-0034 and covers the period April 1980-September 1982. The work was funded by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, VA. Contracting officer's representative was Dr. M. Kolobielski, Fuels and Lubricants Division, Energy and Water Resources Laboratory, and the technical monitor was Mr. M.E. LePera, Chief, Fuels and Lubricants Division (DRDME-GL), MERADCOM.

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I. INTRODUCTION/BACKGROUND

In many aspects, the Army's military construction mission resembles the tasks of civilian construction enterprises. These construction companies practice continuous competition through research and development. Recognizing the same need for modernization as well as being confronted with decreasing R & D budgets, the Army adopted a policy of procuring construction-type equipment (CCE) from commercial sources.(1)* In other words, the Army purchased standard "off-the-shelf" equipment to better accomplish its construction tasks. Today the majority of the construction equipment and selected material handling equipment (SMHE) utilized by the Army is of the commercial or modified commercial type. The balance is procured under government-controlled drawing packages. Although obvious advantages exist for this policy, certain problems require resolution to make the CCE and SMHE program successful. These CCE and SMHE items have hydraulic systems that use various commercial components. The fluids sed in these hydraulic systems are considered as components of the total system and are frequently provided as commercial proprietary fluids. The components vary considerably in quality, reliability, and performance. In the past, the only way to differentiate between acceptable and unacceptable components has been extensive/expensive end-item testing. This problem has existed because no standardized requirements and test methods have been available to component manufacturers or users. Therefore, this project was initiated in April 1980 as an important element in MERADCOM's overall Military Adaptation of Commercial Item (MACI) Hydraulic Systems and Component Program.

II. OBJECTIVE

The objective of the MACI program is to provide a process whereby the government may coordinate its efforts with industrial users and hydraulic/power transmission fluid (HPTF) component manufacturers, to achieve the acceptance of standardization requirements and tests to evaluate systems and components. Once adopted, test data generated by commercial laboratories

*Underscored numbers in parentheses refer to the list of references at the end of this report.

can be used by the government to verify acceptability of hydraulic components and systems. In instances where there are highly defined military specification products such as hydraulic fluids and oils, it is anticipated that adaptations may be required to ensure compatibility/ performance in commercial systems.

The MACI project provides technical data for use in end-item specifications to ensure that procurements of mobile construction and selected materials handling equipment will have hydraulic systems of the highest degree of quality and reliability. The effort is to reduce the life cycle cost of hydraulic (fluid power systems) by procuring standard commercial items with proven reliability and maintainability, and when appropriate, by defining the limits of acceptability for using military specification products.

The specific objective of the MACI program is to perform technical evaluation and assessment of commercially available qualified and fielded military engine oils and to determine if such oils can be used as hydraulic fluids in Army commercial construction equipment and selected material handling equipment.

III. TEST DETAILS

A. Lubricants

For this test program, nine lubricants were evaluated. Each lubricant was designated with a code number for laboratory use. The code number for each lubricant, along with its specification, type and description, is shown in Table 1. Some of these products were randomly selected, while others were selected because they demonstrated good performance in other engine and hydraulic system programs, qualification testing, and from actual field experience. Included in the program is lubricant 1, a MIL-L-2104C specification grade OE/HDO-10 which is the oil that met the John Deere JDM-J20A specification in an earlier program (2), and is undergoing field evaluation; lubricants 2 and 5 are also qualified under MIL-L-2104C grade OE/HDO-10 along with lubricant 3, a commercially available grade 10W-30 oil which

satisfies MIL-L-2104c; and one Arctic oil, lubricant 4, qualified under MIL-L-46167. An additional multiviscosity 10W-40 oil, lubricant 6, proposed for military use and fulfilling MIL-L-2104 requirements, was included in the program. Three oils which qualified under MIL-L-2104C, grade OE/HDO-30, lubricants 7, 8 and 9 were selected randomly from the list of grade OE/HDO-30 qualified products.

Lubricant 4 was dropped from continued testing after failing four of the first six tests. The remaining tests were performed on the additional grade 10W-40, lubricant 6.

The above specification engine oils were subjected to ten selected test requirements discussed in the following section.

TABLE 1. TEST LUBRICANTS EVALUATED

Lube No.	Grade	Specification	Description
1	OE/HDO-10	MIL-L-2104C	Army fielded oil
2	OE/HDO-10	MIL-L-2104C	Army fielded oil
3	10W-30	MIL-L-46152	Commercial Source
4	5W-20	MIL-L-46167	Army fielded oil
5	OE/HDO-10	MIL-L-2104C	Army fielded oil
6	10W-40	MIL-L-2104 Level	Commercial Source
7	OE/HDO-30	MIL-L-2104C	Army fielded oil
8	OE/HDO-30	MIL-L-2104C	Army fielded oil
9	OE/HDO-30	MIL-L-2104C	Army fielded oil

B. Test Procedures

At the present time, there is no single common specification for hydraulic and power transmission fluids. The manufacturers of commercial construction and material handling equipment issue their own proprietary specifications for hydraulic and power transmission fluids. An ASTM panel is working towards development of a uniform specification for multipurpose power transmission fluids. To aid in selection of the test procedures performed in this program, a listing was made of the various manufacturers' Requirements For

Hydraulic and Power Transmission Fluids (Table 2). This table also includes the specification requirements proposed by the ASTM panel. From this listing, nine tests were selected which were best suited to this program; these tests are shown in Table 3.

Test j is the test which AFLRL developed in conjunction with John Deere personnel and is used to evaluate wet-brake/fluid performance in Army fielded tractors.(2) The details of the tests are discussed in the following sections.

C. Listing of CCE/SMHE and Components

Results from the first year effort and past 6.2 funded R & D efforts show that numerous tests are required if all potential CCE/SMHE components are to be addressed. During the second year, two lists were prepared to help in future work. One list contains all the present/planned CCE/SMHE, and the other list provides the manufacturer of the hydraulic/power transmission components and drives used in each type of equipment.

IV. DISCUSSION OF RESULTS

Lubricants 1, 2, 3, 5, 6, and 8 were subjected to all the tests listed in Table 3; Lubricants 7 and 9 were subject to all the tests in Table 3 except for test d, THM Transmission Oil Oxidation Stability. Tests g, h, i, and j were not performed on lubricant 4. Additional or duplicate tests were performed on lubricants 6, 8 and 9, Table 4.

A summary of the overall performance of all of these tests can be seen in Table 5, and the data from the results of these tests are shown in a subsequent table.

A. TO-2 Wet Clutch Friction Retention (Caterpillar Tractor Co.).

This test makes use of the SAE No. 2 Friction Test Device which has the clutch plates totally submerged in the test fluid. The device is found in

TABLE 2. LISTING OF SUPPLIERS OF HYDRAULIC/POWER TRANSMISSION SYSTEMS FLUID REQUIREMENTS WHEELED AND/OR CRAWLER

Manufacturer Specification	Allis-Chalmers PF 821	Allison C-3	Caterpillar CD/TO-2	J.I. Case TCH145	Deutz GL-4	John Deere JDM-J21A	International Harvester B-6
K. Vis., cSt							
@ 40°C	X	X	X	NR	X	NR	NR
@ 100°C	X	X	X	X	X	X	X
Stability	NR	NR	X	X	NR	X	X
Index	NR	NR	X	X	X	NR	X
-17.8°C (0°F)	X	X	X	X	NR	X	X
(-20°F)	NR	X	NR	NR	NR	NR	X
Flash Point, °C	X	NR	X	X	X	X	X
Fire Point, °C	NR	NR	NR	X	NR	NR	NR
Pour Point, °C	X	X	X	X	X	X	X
Rust Protection	X	X	NR	X	X	X	X
Corrosion	X	NR	X	X	X	X	X
AntiFoam	X	X	X	X	X	NR	X
Rubber Compatibility	X	X	NR	X	X	NR	X
Compatibility w/other Oils	X	NR	X	X	X	X	X
Oxidation & Thermal Stability	X	X	NR	X	X	X	X
Friction, Clutch and/or Brake	NR	X	X	X	X	NR	X
Transmission Durability	X	NR	NR	NR	X	X	X
Wear Protection	X	X	NR	X	X	X	NR
Toxicity	NR	NR	NR	X	NR	NR	NR
API Gravity	NR	NR	X	NR	NR	NR	NR
Aniline Point	NR	NR	NR	NR	NR	NR	X
Color	NR	NR	NR	NR	NR	NR	X
Hydraulic Performance	NR	NR	NR	X	X	NR	X
Metals	X	NR	X	NR	NR	X	NR
Neutralization Number	NR	NR	NR	NR	NR	NR	NR
Odor	NR	NR	NR	NR	NR	NR	NR
Carbon Residue	NR	NR	X	NR	NR	NR	NR
Precipitation	NR	NR	NR	NR	NR	NR	NR
Saponification	NR	NR	NR	NR	NR	NR	NR
Stable Pour Point	NR	NR	X	NR	NR	NR	NR
Sulfated Residue	NR	NR	X	NR	NR	NR	NR
Sulfur	NR	NR	X	NR	NR	X	NR
Phosphorus	NR	NR	X	NR	NR	X	NR
Chlorine	NR	NR	X	NR	NR	X	NR
Nitrogen	NR	NR	X	NR	NR	X	NR
Low Temp Deposits	NR	NR	X	NR	NR	NR	NR
Bearing Corrosion	NR	NR	X	NR	NR	NR	NR
Ring-Sticking, Wear Deposits	NR	NR	-	NR	NR	NR	NR
Medium-Speed	NR	NR	X	NR	NR	NR	NR
High-Speed	NR	NR	X	NR	NR	NR	NR
Water Tolerance	NR	NR	X	NR	X	NR	X
Dynamic Corrosion (Sundstrand)	NR	NR	NR	NR	X	NR	NR
Cold Oil Flowability	NR	NR	NR	NR	X	NR	NR
Galvanic Protection	NR	NR	NR	NR	NR	NR	NR

X = To be determined
NR = Not required

TABLE 2. LISTING OF SUPPLIERS OF HYDRAULIC/POWER TRANSMISSION SYSTEMS FLUID REQUIREMENTS WHEELED AND/OR CRAWLER (Cont'd)

Manufacturer Specification	Massey-Ferguson M1136	Minneapolis Moline 35301	Oliver/White S-3727-B	Versatile JDM-J20A	Fiat-Allis GM-6137-M	Ford M2C134-A	ASTM Proposed
K. Vis., cSt							
@ 40°C	NR	X	X	NR	NR	NR	NR
@ 100°C	X	X	X	X	X	X	X
Stability	X	X	NR	X	NR	X	X
Index	X	X	NR	NR	NR	NR	NR
-17.8°C (0°F)	X	X	NR	X	X	X	X
(-20°F)	NR	NR	NR	NR	X	NR	X
Flash Point, °C	NR	X	X	X	X	X	X
Fire Point, °C	NR	X	NR	NR	X	X	NR
Pour Point, °C	X	X	X	X	NR	X	NR
Rust Protection	X	X	NR	X	X	X	X
Corrosion	X	X	X	X	X	X	X
AntiFoam	X	X	X	X	X	X	X
Rubber Compatibility	X	X	NR	X	X	X	X
Compatibility w/other Oils	NR	X	NR	X	X	X	NR
Oxidation & Thermal Stability	X	X	NR	X	X	X	X
Friction, Clutch and/or Brake	NR	X	X	X	X	X	X
Transmission Durability	X	X	NR	X	X	X	NR
Wear Protection	X	X	NR	X	X	X	X
Toxicity	X	X	NR	NR	X	X	NR
API Gravity	NR	X	NR	NR	NR	NR	NR
Aniline Point	NR	X	NR	NR	NR	NR	NR
Color	NR	NR	X	NR	NR	NR	NR
Hydraulic Performance	NR	NR	NR	X	X	NR	X
Metals	NR	NR	NR	NR	NR	X	NR
Neutralization Number	NR	X	X	NR	NR	NR	NR
Odor	NR	X	NR	NR	NR	X	NR
Carbon Residue	NR	NR	NR	NR	NR	NR	NR
Precipitation	NR	X	NR	NR	NR	NR	NR
Saponification	NR	NR	X	NR	NR	NR	NR
Stable Pour Point	NR	NR	NR	NR	NR	NR	NR
Sulfated Residue	NR	NR	NR	NR	NR	NR	NR
Sulfur	NR	X	NR	NR	NR	NR	NR
Phosphorus	NR	NR	NR	NR	NR	NR	NR
Chlorine	NR	NR	NR	NR	NR	NR	NR
Nitrogen	NR	NR	NR	NR	NR	NR	NR
Low Temp Deposits	NR	NR	NR	NR	NR	NR	NR
Bearing Corrosion	NR	NR	NR	NR	NR	NR	NR
Ring-Sticking, Wear Deposits	NR	NR	NR	NR	NR	NR	NR
Medium-Speed	NR	NR	NR	NR	NR	NR	NR
High-Speed	NR	NR	NR	NR	NR	NR	NR
Water Tolerance	NR	NR	NR	X	X	NR	X
Dynamic Corrosion (Sundstrand)	NR	NR	NR	NR	NR	NR	X
Cold Oil Flowability	NR	NR	NR	X	NR	NR	NR
Galvanic Protection	NR	NR	NR	NR	NR	NR	X

X = To be determined
NR = Not required

TABLE 3. LUBRICANT PERFORMANCE TESTS

TEST	TEST DESCRIPTION
a.	Wet Clutch Friction Retention (Caterpillar, TO-2)
b.	Wet Clutch Friction Retention (Detroit Diesel Allison, C-3)
c.	Vane Pump Wear (DDA, C-3)
d.	THM Transmission Oil Oxidation Stability (DDA, C-3)
e.	Seal Compatibility (DDA, C-3)
f.	Vickers Vane Pump Wear (ASTM, D 2882)
g.	Dynamic Corrosion (Sundstrand axial piston pump water contamination) JDM-J21A Tentative.
h.	Wet Brake Chatter (Massey Ferguson 1135 In-Vehicle)
i.	Water Sensitivity (John Deere JDM-J20A 4.6)
j.	Wet-Brake Chatter and Hydraulic System Performance (John Deere 410 In-Vehicle)

TABLE 4. DUPLICATE TEST RESULTS

Lube No.	Test No.
6 and 8	f. Vickers Vane Pump Wear (ASTM D2882)
8	b. Wet Clutch Friction (DDA, C-3)
8 and 9	a. TO-2 Wet Clutch Friction (Caterpillar).

TABLE 5. OVERALL PERFORMANCE OF THE MILITARY ENGINE OILS

TEST		LUBRICANT OILS 1	2	3	4	5	6	7	8	9
A.	TO-2 Wet Clutch Friction Retention	P	F	F	F	P	P	P	P/F	P/F
B.	C-3 Wet Clutch Friction Retention	P	P	P	F	P	P	P	P	P
C.	C-3 Vane Pump Anti-Wear	P	P	P	F	BP	P	P	P	P
D.	C-3 THM Transmission Oxidation	P	P	P	P	P	P	ND	P	ND
E.	C-3 Seal Compatibility	P	P	P	P	P	P	P	P	P
F.	Vickers Vane Pump Wear (D 2882)	P	P	P	F	F	BP	P	P	P
G.	Dynamic Corrosion (JDM-J20A Tent.)	P	P	P	ND	F	P	P	P	P
H.	Wet-Brake Chatter (MF)	BP	P	F	ND	F	BP	P	P	P
I.	Water Sensitivity (JDM-J20A)	P	P	P	ND	P	P	P	P	P
J.	Wet-Brake Chatter and Hydraulic Performance (AFLRL)	P	BF	BF	ND	BF	BF	P	P	P

P = Pass
F = Fail
BP = Borderline Pass
BF = Borderline Fail
ND = Not Determined

most petroleum research and development laboratories, as well as independent testing laboratories. The standard SAE No. 2 Friction-Test Device is modified (3) to provide oil flow through the clutch pack to an external oil reservoir and oil cooler. Also, the clutch pack lock-up time was controlled to 1.8 seconds. Bronze-on-steel friction materials were used because most Caterpillar-built power transmissions use these materials. The results compare very favorably with the full scale Caterpillar power shift transmission. The test criteria for a satisfactory TO-2 Friction Retention Performance are:

- Maximum Wear - bronze discs 0.25 mm (0.010 in.) total
  - steel plate 0.1 mm (0.004 in.) total
- Test Cycles - minimum cycles 15,000
- Maximum slip time increase - 20% for Grade 10
- Maximum slip time increase - 15% for all others

Lubricants 1, 5, 6, and 7 passed all phases of this test. Lubricants 2, 3, and 4 failed the maximum slip time increase. Lubricants 1, 4, 5, 6, 7, 8 and 9 completed the minimum test cycles. Lubricants 1, 3, 6, 7, 8 and 9 passed both the bronze disc and steel plate wear. Lubricants 8 and 9 were run in duplicate, and each gave one passing and one failing result of the slip time parameter. These two lubricants will be tested for a third time in the next phase of this program. The average of the three tests for each lubricant will indicate the acceptance level, in accordance with the requirement of the proponent of this test.(3) Data from this test, as well as other tests mentioned in Table 3, are included in Table 6.

B. C-3 Wet Clutch Friction Retention (Detroit Diesel Allison, DDA)

This test (4) also makes use of the SAE No. 2 Friction Test Device. Cooling is controlled by water flowing around the outside of the test cavity. The clutch discs are of standard resin graphite with steel plates. Except for clutch discs and fixtures, all changes were machine settings only. The C-3 test results compare favorably with full-scale DDA off-highway power shift transmissions. The test criteria for satisfactory C-3 Friction Retention performance are:

TABLE 6. SUMMARY OF COMPLETED TEST RESULTS

Code	Test Procedure	Lubricant Code 1	2	3	4
		OE/HDO-10	OE/HDO-10	10W/30	5W/20
a	TO-2 FRICTION CHARACTERISTIC TEST (CAT)				
	Percent Change, 15% Max	13.18	52.50	23.26	31.6
	4-Bronze Discs Avg Wear, 0.010 Max	0.0064	0.0523	0.0047	0.0081
	5-Steel Plates Avg Wear, 0.004 Max	0.0034	0.0049	0.0032	0.0042
	Test Cycles, 15000 Min	15,000	4,500	10,900	15,000
b	C-3 FRICTION RETENTION TEST (DDA)				
	Max Slip Time at 5500 Cycles, 0.85 Sec.	0.79	0.79	0.78	0.85
	Min Torque at 0.2 Sec Slip Time at 5500 Cycles, 75 ft-lb	88	86	90	67
	Difference in Torque at 0.2 Sec Slip Time Between 1500 and 5500 Cycles, 30 ft-lb max	26	16	0	40
c	C-3 PUMP ANTI-WEAR TEST (DDA)				
	Cam Rig Grinding Patter Remaining, %	96 to 98	91 to 95	88 to 91	60+
	Scuffing, Scoring or Chattering	Trace	Trace	Trace	Light
	Pressure and Thrust Plate	Trace	Trace	Trace	Trace
d	C-3 THM TRANSMISSION OXIDATION TEST (DDA)				
	% Viscosity Increase at 210°F, 15% Max	5.43	1.45	-16.76	-2.05
	O_2 Concentration at 300 hr, not less than 2%	10.5	10.0	10.0	9.6
	Sludge	Trace	Trace	Trace	Trace
	Varnish	Trace	Trace	Trace	Trace
	Spot Test	Pass	Pass	Pass	Pass
e	C-3 SEAL COMPATIBILITY TEST (DDA)				
	Total Immersion				
	Volume Change	+0.84	+1.67	+3.27	+0.36
	Hardness Change	+1	+2	+2	+1
	Dip Cycle				
	Volume Change	+3.12	4.08	+5.42	+4.40
	Hardness Change	-2	-2	-2	-2
	Tip Cycle				
	Volume Change	+2.90	+3.71	+3.84	+3.15
	Hardness Change	-2	-2	-3	-3
f	VICKER VANE PUMP WEAR (ASTM D 2282)				
	Ring Wt Loss, mg	30.1	30.8	26.6	210.0
	Vanes Wt Loss, mg	3.6	3.0	0.0	2.5
	Total (100-Hr Ford M2C143-A, 50 mg Max)	33.7	33.8	26.6	212.5
g	Dynamic Corrosion (Sundstrand Axial Piston Water Contamination)				
	Flow Degradation, 10% Max.	1.3	0.6	-1.3	ND
	Pump Parts Condition, Good Min.	Good	Good	Good	ND
h	WET BRAKE CHATTER IN MASSEY FERGUSON 1135 Tractor: Average of Ref. Runs				
	Min 08	35	26	53	ND
	Max 53	48	44	61	ND
	Avg 24	41	35	57	ND
i	WATER SENSITIVITY (JDM-J20A)				
	Sediment, vol%, 0.1 Max	0.02	0.075	0.5	ND
	Additive Loss, No. Mass, 15 Max				
	Ca	9.6	0.05	0.11	ND
	P	0.12	0.06	0.08	ND
	Zn	---	0.09	0.12	ND
j	USAFLRL WET BRAKE CHATTER AND HYDRAULIC PERFORMANCE IN JD 410 JDM-20A FLUID				
	Wet-Brake Chatter = 158	156	180	193	ND
	Front Bucket Dump at 1500 rpm, sec = 2.7	2.6	3.4	4.1	ND
	Backhoe Bucket Retract at 1500 rpm sec = 3.0	3.1	3.9	4.7	ND

5	6	6	7	8	8	9	9
OE/HDO-10	10W/40	RERUN	OE/HDO-30	OE/HDO-30	RERUN	OE/HDO-30	RERUN
6.90	8.67	ND	5.45	12.66	28.57	17.5	8.52
0.0126	0.0053	ND	0.0029	0.0035	0.0049	0.0034	0.0051
0.0046	0.0025	ND	0.0029	0.0029	0.0030	0.0028	0.0035
15,000	15,000	ND	15,000				
0.81	0.74	ND	0.74	0.72	0.75	0.72	ND
79	95	ND	108	115	93	118	ND
14	0	ND	8	4	17	8	ND
+75	85 to 88	ND	95 to 98	84 to 87	ND	89 to 92	ND
Trace	Trace	ND	Trace	Trace	ND	Trace	ND
Trace	Trace	ND	Trace	Trace	ND	Trace	ND
0.28	-19.58	ND	ND	3.43	ND	ND	ND
15.4	9.5	ND	ND	6.8	ND	ND	ND
Trace	Trace	ND	ND	Trace	ND	ND	ND
Trace	Trace	ND	ND	Trace	ND	ND	ND
Pass	Pass			Pass			
+0.82	+0.72	ND	+1.66	-0.19	ND	+2.24	ND
+1	+1	ND	+1	+2	ND	+2	ND
+4.91	+4.05	ND	+4.33	+3.15	ND	+4.84	ND
-2	-2	ND	-1	-1	ND	-2	ND
+3.20	+3.07	ND	+2.18	+1.79	ND	+2.34	ND
-3	-2	ND	-3	-2	ND	-3	ND
110.8	51.1	56.2	11.5	46.1	42.1	13.5	ND
13.4	7.2	2.9	2.0	1.1	1.1	3.0	ND
124.2	58.3	59.1	13.5	47.2	43.2	16.5	ND
21.2	0.6	ND	7.8	2.7	ND	1.3	ND
Good	Good	ND	Good	Good	ND	Good	ND
53	31	ND	22	29	ND	31	ND
57	42	ND	53	45	ND	44	ND
57	42	ND	38	39	ND	36	ND
Trace	Trace	ND	Trace	NONE	ND	0.025	ND
---	0.26	ND	---	---	ND	5.8	ND
0.09	0.08	ND	---	---	ND	11.1	ND
0.12	0.11	ND	---	---	ND	---	ND
182	197	ND	126	136	ND	139	ND
3.2	3.8	ND	5.2	4.9	ND	4.6	ND
3.6	4.3	ND	4.8	4.5	ND	4.5	ND

- Maximum slip time at 5500 cycles, 0.85 sec
- Minimum torge at 0.2 sec slip time at 5500 cycles, 75 ft-lb
- Maximum difference in torque at 0.2 sec slip time between 1500 and 5500 cycles, 30 ft-lb

Lubricants 1, 2, 3, 5, 6, 7, 8 and 9 passed all phases of the test. Lubricant 4 failed two of the three phases, and Lubricant 8 was run in duplicate and passed all phases of the test.

C. C-3 Vane Pump Antiwear (DDA)

The test determines the fluid antiwear properties in a motor-driven Saginaw power steering pump at 2950 rev/min at 900 psi for 50 hours. The test criteria for satisfactory performance are:

> Pump cam ring shall still show the grinding pattern for 360°, and shall be free from scuffing, scoring, or chatter wear marks, Pressure and Thrust plate wear.

As noted in Reference 5, good performing lubricants do not fall below the 80-percent level. Lubricants 1, 2, 3, 6, 7, 8 and 9 were acceptable, with lubricant 4 considered as a fail. Lubricant 5 was considered a marginal pass.

D. C-3 THM Transmission Oxidation (DDA).

This test (4) uses a General Motors Hydraulic THM-350 transmission and is driven at 1755 rev/min, under no output load, at 163°C (325°F) convertor-out temperature, for 300 hours. Air is introduced at a rate of 30 cm^3/min to determine the oxidation resistance and thermal stability of automatic and power shift transmission fluids. The test criteria for satisfactory performance are:

> Percent viscosity increase at 210°F, 15% max
> Oxygen concentration at 300 hours, not less than 2%
> Sludge
> Varnish
> Oil spot test

All those lubricants tested (1, 2, 3, 4, 5, 6 and 8) passed this test. Lubricants 7 and 9 were not tested in an effort to cut costs. It has been AFLRL experience that all fielded MIL-L-2104C lubricants have passed this test.

E. C-3 Seal Compatibility (DDA)

For this test (4), three different seal materials are used. Buna-N seal compound is subjected to hot transmission fluid, and measurements of volume and hardness are made before and after test. Silicone and polyacrylate seal compound is subjected to hot transmission oil and to a hot air/hot oil vapor atmosphere, and measurements of volume and hardness are made before and after test. The test pass or fail criteria for fluid performance are:

	SAE 10	SAE 30
Total Immersion		
Volume Change	+0.96 to 6.9%	-0.75 to 6.9%
Hardness Change	-5 to +5 pts.	-5 to +5 pts.
Dip Cycle		
Volume Change	0 to +10%	
Hardness Change	-4 to +1%	
Tip Cycle		
Volume Change	+1.5 to 6.5%	
Hardness Change	0 to -10 pts.	

All the lubricants (1, 2, 3, 4, 5, 6, 7, 8 and 9) passed all phases of the seal compatibility test.

F. Vickers Vane Pump (ASTM D 2882)

This test consists of a rotary vane pump operating at 1200 rpm, at 2000 psi, circulating 3 gallons of oil at a temperature of 65.6°C (150°F) or 79.5°C (175°F) for 100 hours. Pump wear total, consisting of cam ring and vane weight losses during test, are the results obtained. The performance criteria vary among manufacturers.

Ring Weight Loss, mg
Vanes Weight Loss, mg
Total Weight Loss, 50 mg max

This method has a relatively poor precision as indicated by high values of

the repeatability and reproducibility random errors.(6) The manufacturers' requirement limit of 50 to 100 mg maximum weight loss is much smaller than the testing error. In this program, the 50 mg limit was assumed as performance criterion following the tentative specification for hydraulic fluid developed by the ASTM panel (Appendix A). Lubricants 1, 2, 3, 7, 8 and 9 passed the test. Lubricants 4 and 5 failed, giving high values of the total weight loss. Lubricant 6 was run in duplicate, and the average value of 58.7 mg indicates a borderline pass.

G. Dynamic Corrosion (Sundstrand Axial Piston Pump Water Contamination)

The test determines the percent flow loss due to water contamination in a Sundstrand 22 Series Axial Piston Pump (variable displacement) using one-half of full stroke at 3100 RPM ± 100 using 5000 PSI, a reservoir temperature of 150°F ± 10°F, a loop temperature of 180° ± 10°F, 5 in. Hg. maximum inlet vacuum and 1% distilled water for 200 hours. This is preceded by a 25-hour start-up and break-in period with no distilled water present. The reported test data are:

Flow Loss at 5000 PSI, 10% max.
Pump Parts Condition, Good min.
Viscosity at 100°F
Viscosity at 210°F
Water Percent
Acid No.
Wear Metals, ppm
  Iron
  Copper
  Chrome
  Lead

Lubricants 1, 2, 3, 6, 7, 8 and 9 passed the % flow degradation, and all the pump parts were in good condition. Lubricant 5 passed the pump parts condition phase of the test but failed the % flow degradation phase; therefore, this oil is considered a fail. This lubricant had a good flow until the 130-hour period, at which time the flow decreased steadily. In addition, the case pressure was hard to maintain when it reached 200 hours. There also appeared to be no corresponding increase or decrease in water %, acid number, viscosity, or wear metals. Lubricant 4 was not tested.

H. Wet Brake Chatter (Massey-Ferguson 1135 In-Vehicle)

The test tractor is a Massey-Ferguson Model 1135 and is equipped with a six-speed transmission incorporating a two-speed auxiliary transmission. The test procedure consists basically of a drain-flush-refill with test oil, and repetitive applications of left and right brakes with a recording of brake chatter under various gear-speed conditions. The analysis of the chatter recording is then made to provide a comparison and ranking of the test oils. Test criteria for the reported data are:

Low Chatter	10 - 20
Medium Chatter	20 - 40
High Chatter	40 - 50
Heavy Chatter	50 and above, fail

Lubricants 2, 7, 8 and 9 fell in the medium chatter range, with lubricants 1 and 6 falling in the high chatter range. Lubricants 3 and 5 fell in the heavy (fail) chatter range.

I. Water Tolerance (John Deere JDM-J20A)

A mixture of 199.2 cm^3 of oil and 0.8 cm^3 deionized water is mixed in a blender for 60 seconds, maintaining 12,000 to 14,000 rpm. The mixture is transferred to a centrifuge tube and stored in a light-tight chamber for 7 days. The sample is centrifuged, and the percent volume of sediment is reported. The top oil phase is analyzed for metallic constituents of additives. The test criteria for a satisfactory performance are:

Sediment, Vol%, 0.1 max
Additive Loss, % mass, 15 max

All lubricants tested passed this test. Lubricant 4 was not tested.

J. Wet Brake Chatter and Hydraulic Performance (AFLRL)

This test is performed in a John Deere Model 410 front loader/backhoe tractor. The tractor is equipped with a four-speed transmission incorporating a two-speed auxiliary transmission. The test procedure consists basically of

testing the tractor with John Deere JDM-J20A lubricant, then drained, flushed, and refilled with test oil, repetitive applications of left-turn--left brake and right-turn--right brake at 57°C (135°F) and 74°C (165°F) with a recording made of that chatter with the transmission in 1st gear, second auxiliary range (fifth gear) and then a comparison analysis of the chatter recording is made with the JD fluid. The front loader and backhoe operations are timed, and brake lock-up and operating valves are evaluated to provide a comparison ranking. The test criteria for satisfactory performance are:

Wet Brake Chatter compared to JDM-J20A fluid
Front loader performance
Backhoe performance
Pressure Control Valve performance
Panic Brake lock-up

In this test, four lubricants (1, 7, 8 and 9) had a lower wet-brake chatter than the John Deere Reference fluid. All four were MIL-L-2104C lubricants, one was lubricant 1, an OE/HDO-10, and the other three were OE/HDO-30 lubricants. Lubricants 2, 3, 5, and 6 had more brake chatter than did the John Deere reference fluid. Lubricants 1, 2 and 5 had the fastest response time, with the multigrade lubricants 3 and 6 and lubricants 7, 8 and 9 (OE/HDO-30) having the slowest response times. None of the lubricants that had slower response times and more wet-brake chatter was considered to be excessive to the point that it would substantially hinder operation of the vehicles.

K. Field Evaluation

The three John Deere Model 410 front loader/backhoe tractors in the field evaluation at the 62nd Construction Engineer BN in Ft. Hood, Texas were evaluated for wet-brake chatter and hydraulic performance every 4 months. The results from the initial start of test and December 1981 are summarized in Table 7. One tractor uses the baseline lubricant, which meets the John Deere JDM-J20A specification; two tractors use the test oil, a fielded MIL-L-2104C grade OE/HDO-10 (NSN 9150-01-090-5753) lubricant.

TABLE 7. JD-410 VEHICLE WET-BRAKE AND HYDRAULIC PERFORMANCE

Company	Fluid	Hours		Brake Chatter		Front Loader	Backhoe
		12/78	12/81	12/78	12/81		
B	OE/HDO-10	722	1441	132	216	Slow-Smooth	Slow-Smooth
C	OE/HDO-10	894	1607	128	187	Mod-Jerky	Mod-Smooth
D	JDM-20A	776	1690	135	189	Slow-Jerky	Mod-Smooth

The front loader and backhoe of the tractor in "B" Company [using the MIL-L-2104C OE/HDO-10] performed slowly but smoothly. The wet-brakes had more chatter than did the tractor in "D" Company, which uses the baseline JD proprietary fluid. The right brake pedal had to be pumped with each use, while the left brake performed satisfactorily. When the panic stop was made, only the left wheel would skid.

The tractor in "C" Company, which also uses the OE/HDO-10 grade oil, performed moderately fast and slightly jerky in the front loader but quite smoothly with the backhoe. The wet-brakes had less chatter than did the baseline tractor in "D" Company. Both brake pedals were well adjusted. During the panic stop, both wheels made a skidding stop.

The tractor in "D" Company, which uses the baseline proprietary JD fluid, performed slowly and a little jerky when using the front loader, while the backhoe operated moderately and smoothly. There was some leak-down in the frontloader and backhoe. This leak-down was probably caused by the leak in the backhoe bucket hydraulic line. Also, the left brake pedal was very soft and would not lock up the brake. The right brake was acceptable. The panic stop, when applied, would only skid the right wheel.

Each of these three vehicles has had the forward clutch pack replaced during the field evaluation along with broken hydraulic lines, numerous fitting leaks, etc., as shown in Table 8. The clutch replacements and the other hydraulic problems are not attributed to the lubricants, but appear to the operational and maintenance related.

TABLE 8. MAINTENANCE PROBLEMS DURING FIELD EVALUATION

	B Company	C Company	D Company
Lubricant	MC-606	MC-606 [b]	JD-20A
Date Placed on Test	3-9-79	7-14-78	8-24-78
Condition of Vehicle When Put on Test	Fair	Poor	Good
Leak in Hydraulic Lines	Y	Y	Y
Forward Clutch Pack Replaced	Y [c]	Y [d]	Y
Rear Axle Seal Leak	N	N	Y
Broken Axle	Y [e]	N	Y
Bad Brake One Side	Y	Y	Y
Transmission Leak	Y	N	N
Reverser Valve	Y	N	N
Left Brake Assembly	Y [f]	N	N
Hours of Test	1441	1607	1690

Y = Yes
N = No
a was placed on test late due to oil leaks, bad brakes, and broken tachometer.
b was using MC-88 OE/HDO-10 when put on test because the JD fluid was not available.
c had forward clutch problem before put on test.
d had two clutches, one due to improper adjustment.
e vehicle was driven into a tree.
f had left brake problems before put on test.

It appears from the results of these three vehicles that the wet-brake chatter and overall hydraulic performance of MIL-L-2104C OE/HDO-10 grade oil is as good as the JD fluid with the possible exception that there was a small increase in wet-brake chatter in the tractor in "B" Company.

L. Multipurpose Power Transmission Fluid

The Army's concern about proliferating HPTF requirements was brought to the attention of the American Society of Testing and Materials and the Society of Automotive Engineers in 1974 with a request to consider development of a multipurpose hydraulic fluid. (7) The Society of Automotive Engineers could

obtain no agreement because each equipment manufacturer preferred its own proprietary fluid and again stated that MIL-L-2104C engine oils would produce problems if used. However, in late 1975, ASTM approved a panel to develop a multipurpose power transmission fluid specification. Personnel from AFLRL have met with this panel many times, and in October 1981 a tentative multipurpose power transmission fluid specification was approved. Appendix A is a first draft of the specification in SAE-recommended practice format.

M. Listing of CCE/SMHE and Components

Appendix B lists the CCE/SMHE in present and proposed Army inventory. The density of the equipment in the Army ranges considerably from two well drilling machines, (6 in. at 1500 ft) to 999 fork lifts (4000 lb). Also 1163 fork lifts, (6000 lb R & T) and as few as 9 elevating scrapers (9 cu yd) are proposed to be purchased for the Army inventory.

Appendix C shows the manufacturers of the various different components. There are approximately nine different manufacturers of engines, including fuel and electric, ten manufacturers of transmissions; six manufacturers of torque convertors; eleven manufacturers of hydraulic pumps; 12 manufacturers of power steering units; ten manufacturers of rear drive units, and five manufacturers of front drive units.

V. CONCLUSIONS

From the presented data, and from the summarized results (Table 5), it can be seen that not all eight of the fielded MIL-L-2104C and MIL-L-46167 lubricants passed all the bench performance tests and in-vehicle tests. This is particularly unusual with the Caterpillar and Detroit Diesel Allison tests, because these manufactueres design their power transmissions to operate with MIL-L-2104C and MIL-L-46167 engine specification lubricants. The three grade OE/HDO-30 oils were selected randomly. Two of these oils are scheduled to complete their triplicate TO-2 friction test. Assuming satisfactory

performance results of the TO-2 test, these oils will have passed all the bench tests. It appears that all grade 30 MIL-L-2104C oil may pass all the bench tests and will be potential hydraulic fluids for use in Army commercial construction and material-handling equipment. Among grade OE/HDO-10 oils, only lubricant 1 passed all the bench performance tests. In previous work, lubricant 1 had passed the John Deere JDM-J20A specification and is on a field evaluation. In addition, all lubricants passed three of the tests: d. THM Transmission Oil Oxidation Stability (C-3), e. Seal Compatibility (C-3) and i. Water Tolerance (JDM-J20A). Not all lubricants passed the Wet-Brake Chatter (Massey-Ferguson, In-vehicle) and the Wet-Brake Chatter and Hydraulic Performance (John Deere In-Vehicle) tests. However, those lubricants that had slower response times and more wet-brake chatter were not considered excessive to the point that it would substantially hinder operation of the vehicles.

VI. RECOMMENDATIONS

Results from this program and past 6.2-funded R&D efforts show that numerous tests are required if all potential CCE components are to be addressed. The list of procured and proposed CCE shows a broad range of equipment representing many different suppliers. It is desirable that any lubricant selected for use in the CCE/HPTF systems be acceptable for use in the Army combat/tactical fleet engines and HPTF systems. The question then prevails as to whether or not military specification lubricants MIL-L-2104C/D, MIL-L-46152A/B, and MIL-L-46167 can protect all the different brands and types of component systems during the service life of the equipment, particularly after the warranty period. Because of the magnitude of the overall problem* and the continued uncertainty of whether or not the Army's lubricants will provide minimum protection in CCE/HPTF systems, the following work plan is recommended:

(a) Since MIL-L-46152A has been upgraded to MIL-L-46152B, two of these new lubricants, probably the 15W-40's, should be evaluated. These

* Numerous manufacturers and suppliers have different lubricant requirements.

lubricants are not tactical but are used extensively throughout the Army. Two lubricants have also passed all the testing of the new MIL-L-2104D specification. Because these tactical lubricants will probably begin to appear in late 1982, it is advantageous to establish their performance in the CCE HPTF systems. In addition, new products have been qualified under MIL-L-46167 specification. Also, it would be advantageous and of interest to evaluate one of the MIL-L-21260B preservative lubricants. The evaluation of these lubricants will aid in selection of lubricants in section (f) below. These products should be those which demonstrate most favorable performance in other engine and hydraulic system programs, qualification testing, and from actual field experience. The tests to be conducted are shown in Table 3.

(b) Using the previously developed list of present and proposed hydraulic/power transmission systems component manufacturers, identify equipment items which it is claimed cannot properly operate with military lubricants, to include MIL-L-2104C/D and MIL-L-46167 products.

(c) Identify tests and criteria used for evaluating component acceptability. Also obtain available performance data with above-mentioned military specification products in these components.

(d) From the components identifyied in (b) above, establish a list of critical items. The criteria to be used in preparation of the list should include, but not be limited to, consideration of the item density within the system, severity of operation, such as loading, temperature and duration of running, and equipment critical during military field application.

(e) Select those tests identified in (c) above which are applicable for evaluating performance of the critical items listed in (d).

(f) Using selected military specification lubricants, conduct the applicable test(s) to determine performance of the selected lubricants in each of the critical components.

(g) Data from the test matrix of (f) above should be evaluated to select lubricants for field testing. The selection should be based on the pass/fail criteria established in (c) above. Lubri-

cants demonstrating marginal/poor performance should be given consideration in the selection process in order to determine if slight trade-offs in performance can be tolerated in actual field operation. Consideration should also be given to lubricants tested in previous programs.

(h) Full-scale vehicle testing should be conducted to identify minimal acceptability of selected products for field application. The types of vehicles to be tested should be minimized based on critical components identified from the test matrix.

(i) Based on the results of the full-scale testing, the suitability of various military specification lubricants for use in fielded equipment would be determined.

VII. LIST OF REFERENCES

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7. Letter, MERADCOM, STSFB-GL, ASTM D2, Technical Div. B-11, Automatic Transmission Fluids, 13 August 1974.

APPENDICES

APPENDIX A. PROPOSED ASTM MULTIPURPOSE POWER TRANSMISSION FLUID SPECIFICATION

Property/Performance	Limits		Test Method
VISCOSITY--NEW	Individual Equipment manufacturers will recommend viscosity		
a) Centistokes/100°C	grades for various ambient tem-		ASTM D 445
b) Centipoise	peratures specifying grades		ASTM D 2602
c) Borderline Pumping Temperature, °C	using the SAE J-300D Sept 80 viscosity classification system.		ASTM D 3299
VISCOSITY--SHEARED	Report the viscosity obtained at the end of D 2882 and the		D 445 D 2882
a) Kinematic/100°C, cSt	Dynamic Corrosion* Test		Dynamic Corrosion Test*
FLASH POINT, °C	Report		D 92
FOAMING CHARACTERISTICS	Dry	With 0.5 vol% Water Added	D 892, Option A
Sequence 1, cm^3	25/0	25/0	
Sequence 2, cm^3	50/0	50/0	
Sequence 3, cm^3	25/0	25/0	
SEAL COMPATIBILITY/ GM BUNA/N			D 471
Volume Change, %	0 to +6		
Hardness Change, Points	0 to ±5		
RUST RESISTANCE Spots per Length	No more than six per any 25 mm after 100 hours		IH BT-9*
WATER TOLERANCE Add 0.5 V% Water Sediment, %	0.1 maximum		JD J20A 4.6*
DYNAMIC CORROSION TEST Flow Loss, %	10.0 maximum		Sundstrand water contamination test*
VANE PUMP TEST Weight Loss, mg	50 maximum		D 2882
GEAR WEAR PROTECTION Micrometers Wear	Equal to or better than Ref TF-8		Modified JD J20A 5.4*
GEAR EP PROTECTION Weight Loss, mg	75 maximum		Chevron modified FZG* run at 120°C

APPENDIX A. PROPOSED ASTM MULTIPURPOSE POWER TRANSMISSION FLUID SPECIFICATION (CONTINUED)

OXIDATION PROTECTION		DDA Test 122*
Equipment and Fluid Evaluation	- No significant varnish or sludge on transmission parts - No blacking or flaking of copper containing parts - Oil shall not gain more than 15% in viscosity at 100°C	
COPPER PROTECTION		D 130
Strip Rating	1b maximum	3 hours/150°C
GALVANIC PROTECTION		FSM 791B
Specimen Evaluation	No corrosion after 10 days.	Method 5322.1*
FRICTION PTO		JD J20A 5.3*
a) Dynamic Coefficient of Friction	0.10 minimum for at least three out of five readings	
b) Stall Time, Seconds	3.00 maximum	
c) Wear, mm	0.16 maximum	
FRICTION/SINTERED BRONZE PADS		JD J20A 5.1*
Capacity, Kilo Newton Meters	125 minimum	
Chatter	Equal to or better than Ref. TF-8	
BRAKING SAFETY AND CAPACITY	Candidate fluid must meet Class A limits using IH Model 4586	SAE J 1041

* These tests will be proposed as ASTM standards

APPENDIX B. ARMY PRESENT AND PLANNED CCE/SMHE

SSN	DESCRIPTION	MANUFACTURER	MODEL	NSN	TOTAL TO DATE	82	83	84	85	86
R021	Distributor, Bituminous, 1500 Gal.	E D. Etnyre AM General	D-60	3895-01-028-4390	150 54					
R030	Truck, Dump, 20 Ton	IHC AM General	F-S070 F-S070	3805-01-028-4389	770 167					
R020	Crane, Truck Mounted, HYD, 25-Ton	Harnischfeger Corp. Grove Mfg.	MT-250 TMS-300	386-00-018-2021 3810-01-054-9779	389 109					
R035	Roller, Steel Wheel, 10-14 Ton	Hyster Co.	C35080	3895-00-578-0372	87					
R039	Loader, Scoop, 4 1/2-5 CU YD	Clark Eq. Co. IH	175B H100C	3805-00-602-5006 3805-01-052-9043	258 167		Planned	Planned		
R044	Tractor, Crawler, T-H	CAT CAT	D-8K D-8K	2410-00-574-7597 2410-00-574-7597	267 40					
R040	Tractor, Wheeler, w/front Loader and Backhoe	John Deere & Co. John Deere & Co.	JD-410 JD-410	2420-00-567-0135	214 375		56 Proposed	200 Proposed		
D007	Semitrailer, Low Bed, 40-ton	CMI Corp. Load King	403LF (XM870)		750					
R033	Roller, Vibratory, Self-Propelled	Tampo Mfg. Rexnord	RS-28 SP848	3895-01-012-8875 3895-01-075-2823	204 64					
R034	Roller, Pneumatic, Variable Pressure	Hyster Co.	C530A	3895-01-013-3630	193					
M089	Tamper, Backfill, Hand-Operated	Stone Cont. Eq. Co.	VP-11	3895-01-013-4328	130					
R032	Compactor, High-Speed, Self-Propelled	Koehring Road. Div.	K300	3895-01-024-4064	250					
R071	Tester, Density and Moisture	Campbell Pacific Nuclear	MC-1	6635-01-030-6896	140					
R041	Compressor, Air, 750-CFM, 100-PSI, Trailer Mounted	Sullair Corp.	750 DPQ	4310-01-053-3891	166					
R037	Truck, Concrete, Mobile, 8 CU YD	Am General Corp. National Concrete Machinery Co.	Crane Carrier Co. 3824-4	3895-00-028-4391	176					
M021	Trailer, FB 15-Ton, Engineer Equipment Transporter	Hyster Co.	HP15T	2330-01-060-8141	38					
M031	Distributor, Water, 2500-3000 Gal.					17 Proposed				
M051	Tractor, Ft, D-3					12 Proposed				
M060	Tractor, Tf, D-5					48 Proposed				

APPENDIX B. ARMY PRESENT AND PLANNED CCE/SMHE (CONT'D)

SSN	DESCRIPTION	MANUFACTURER	MODEL	NSN	TOTAL TO DATE	82	83	84	85	86
M064	Loader-Scoop, 2 1/2 CU YD					36 Proposed				
R038	Grader, Road, Motorized, HVY.					43 Proposed				
R142	Scraper, Elevating, SP 9 CU YD, Sec					9 Proposed				
R143	Scraper, Elevating, SP, 9 CU YD, Non-Sec					18 Proposed				
M013	Crane, 20-Ton, Rough	Harnischfeger Corp.	320-RT	3810-00-275-1167	83			Planned	Planned	Planned
M014	Crane, Self-Propelled (Scamp)					40 Proposed	40 Proposed	40 Proposed	40 Proposed	
M412	Container Handler, 50,000-LB, RT	Caterpillar	C9888	3930-01-082-3758	159	82 Proposed	87 Proposed		86 Proposed	
M413	Truck, Forklift, 4000-LB, RT	J. I. Case	MK4	3930-01-076-4237	999	764 Proposed	Planned	Planned	Planned	
M474	Truck, Forklift, 4000-LB, PT	Allis-Chalmers	AC40	3930-01-040-4594	182					
	Truck, Forklift, 4000-LB, PT	Clark	C45Y500	3930-01-085-3767	193					
M475	Truck, Forklift, 6000-LB, PT	Allis-Chalmers	AC60	3930-01-052-5050	492					
M488	Truck, Forklift, 10,000-LB, R & T	IHC	M10A	3930-01-054-3833	646					
M488	Truck, Forklift, 10,000-LB, R & T					*358 Proposed*	*189 Proposed*	*268 Proposed*		
M489	Truck, Forklift, 10,000 LB, R&T						343 Proposed	419 Proposed	470 Proposed	Planned
M471	Truck, Forklift, 3000 LB	Schrech Ind.		3930-01-049-8700	80					
M472	Truck, Forklift, 10,000 LB, Electric	Allis-Chalmers	ACE 100	3930-01-031-9379	11					
M492	Truck, Forklift, R & T, 144-180 Lift, GED, SRT, 4000 Lb	Allis-Chalmers	ACE 40	3930-00-327-1603	333					
M499	Ramp, Mobile, 16,000 LB	Magline		3990-01-026-1575	82					
	Ramp, Mobile, 16,000 LB	Brooks & Perkins		3990-01-059-0104	692					
	Ramp, Mobile, 16,000 LB	Magline			138	139 Proposed		Planned		
R308	Crane, 250-300 Ton	Harnischfeger (P&H)		3950-01-027-9253	4					
R309	Crane, 140 Ton	FMC		3950-01-110-9224	6	24 Proposed	12 Proposed	Planned		
R036	Distributor, Water 6000 Gal.	McCloud		3825-01-065-6221	101					
R004	Ditching Machine						Planned	Planned	Planned	
R077	Drilling Machine, Well, 6 IN. at 1500 Ft.	Failing Co.		3802-01-075-4924	8		6 Proposed			

APPENDIX C. MANUFACTURER OF HYDRAULIC/POWER TRANSMISSION COMPONENTS AND DRIVES OF CCE/SMHE IN ARMY INVENTORY

SSN	DESCRIPTION	MANUFACTURER	MODEL	NSN	ENGINE	TRANSMISSION	TORQUE CONVERTER	FINAL DRIVE	OIL PUMP	STEERING GEAR	FRONT DRIVE
R021	Distributor, Bituminous, 1500 Gal.	E. D. Etnyre AM General	[illegible]	[illegible]	Cummins	CAT	CAT	Rockwell	---	Ross	---
R030	Truck, Dump, 20 Ton	IHC AM General	F-5070 F-5070	3805-01-028-4389	IH DDA	IH DDA	IH DDA	IH DDA	[illegible]	IH DDA	---
R020	Crane, Truck Mounted, HYD, 25-Ton	Harnischfeger Corp. Grove Mfg.	MT-250 TMS-300	3806-00-018-2021 3810-01-054-9779	DDA Cummins	Dana Spicer Eaton (Fuller)	--- ---	Dana Spicer Rockwell	[illegible]	Garrison Ross Garrison	Dana Spicer Rockwell
R035	Roller, Steel Wheel, 10-14 Ton	Hyster Co.	C350A0	3895-00-578-0372	DDA	Sundstrand	Sundstrand	---	[illegible]	DDA	---
R039	Loader, Scoop, 4 1/2-5 CU YD	Clark Eq. Co. IH	175B H100	3805-00-602-5006 3805-01-052-9043	CAT IH	Clark IH	Clark Rockford	Clark IH	Commercial [illegible] Vickers	Commercial Shearing Vickers	Clark IH IH
R044	Tractor, Crawler, T-H	CAT CAT	D-8F D-8F	2410-00-574-7597 2410-00-574-7597	CAT CAT	CAT CAT	CAT CAT	CAT CAT	CAT CAT	CAT CAT	CAT CAT
040	Tractor, Wheeler, w/front Loader and Backhoe	John Deere & Co. John Deere & Co.	JD-410 JD-410	2420-00-567-9135	John Deere John Deere	John Deere John Deere	--- ---	John Deere John Deere	John Deere John Deere	Char-Lynn Char-Lynn	--- ---
D007	Semitrailer, Low Bed, 40-Ton	GMI Corp. Load King	40DLE (XM870)		---	---	---	---	---	---	---
R033	Roller, Vibratory, Self-Propelled	Tampo Mfg. Rexnord	RS-28 SP848	3895-01-012-8875 3895-01-025-2823	Detroit Diesel GM Diesel	Funk Mfg. Hydrostatic Sundstrand	--- ---	Rockwell Rockwell	Sundstrand Sundstrand	Vickers Vickers	--- ---
R034	Roller, [illegible]matic, Variable Pressure	Hyster Co.	C530A	3895-01-013-4630	DDA	DDA	DDA				---
M089	Tamper, Backfill, Hand-Operated	Stone Cont. Eq. Co.	VR-11	3895-01-013-4328	2-cycle [illegible]	Chrysler	---	---	---	---	---
R032	Compactor, High-Speed, Self-Propelled	Koehring Road, Div.	K300	3895-01-024-4064	CAT	Clark	Clark	Clark	Char-Lynn	Char-Lynn	---
R071	Tester, Density and Moisture	Campbell Pacific Nuclear	MC-1	6635-01-030-6896	---	---	---	---	---	---	---
R041	Compressor, Air, 750-CFM, 100-PSI, Trailer Mounted	Sullair Corp.	750 DPQ	4310-01-051-4891	DDA	Part of Sullscrew compressor	--	---	-	---	---
R037	Truck, Concrete, Mobile, 8 CU YD	Am General Corp. National Concrete Machinery Co.	Crane Carrier Co. [illegible]	3895-00-025-4141	Dalbin Mobile Products Corp. 8 Barber-Green [illegible] Mounted on M-917						
M021	Trailer, FB 15-Ton, Engineer Equipment Transporter	Hyster Co.	HP15T	[illegible]	---	---	---	---	---	---	---
M041	Distributor, Water, 2500-3000 Gal.		Proposed								
M051	Tractor, TF, D-5		Proposed								
M060	Tractor, TF, D-7		Proposed								

APPENDIX C. MANUFACTURER OF HYDRAULIC/POWER TRANSMISSION COMPONENTS AND DRIVES OF CCE/SMHE IN ARMY INVENTORY (CONT'D)

SSN	DESCRIPTION	MANUFACTURER	MODEL	NSN	ENGINE	TRANSMISSION	TORQUE CONVERTER	FINAL DRIVE	HYDRAULIC PUMP	STEERING UNIT	FRONT DRIVE
M064	Loader-Scoop, 2 1/2 CU YD		Proposed								
R038	Grader, Road, Motorized, HVY.		Proposed								
R142	Scraper, Elevating, SP 9 CU YD, Sec		Proposed								
R143	Scraper, Elevating, SP, 9 CU YD, Non-Sec		Proposed								
M013	Crane, 20-Ton, Rough	Harnischfeger Corp.	320-RT	3810-00-275-1167	Cummins	DDA	DDA	Dana			
M014	Crane, Self-Propelled (Scamp)		Proposed								
M412	Container Handler, 50,000-LB, RT	Caterpillar	C988B	3930-01-082-3758	CAT	CAT	CAT	CAT	CAT	CAT	CAT
M413	Truck, Forklift, 4000-LB, RT	J. I. Case	MK4	3930-01-076-4237	Case	Clark	Clark	Rockwell	Gessna	TRW	Rockwell
M474	Truck, Forklift, 4000-LB, PT	Allis-Chalmers	AC40	3930-01-040-4594	AC	DDA	DDA	AC	AC	AC	---
	Truck, Forklift, 4000-LB, PT	Clark	C45Y500	3930-01-085-3767	Ford	Clark	Clark	Clark	Husco	Gen Sig Corp	---
M475	Truck, Forklift, 6000-LB, PT	Allis-Chalmers	AC60	3930-01-052-5050	AC	DDA	DDA	AC	AC	AC	---
M488	Truck, Forklift, 10,000-LB, R & T	IHC	M10A	3930-01-054-3833	IH	IH	IH	IH	IH	Same as Hydr Pump	IH
	Truck, Forklift, 10,000-LB, R & T	IHC	M10A	3930-01-054-3833	IH	IH	IH	IH	IH	Same as Hydr Pump	IH
M489	Truck, Forklift, 10,000 LB, R&T			Proposed							
M471	Truck, Forklift, 3000 LB	Schrech Ind.		3930-01-049-8700	Electric						
M472	Truck, Forklift, 10,000 LB, Electric	Allis-Chalmers	ACE 100	3930-01-031-9379	Electric	AC	---	AC	Gessna	Barnes Corp	---
M492	Truck, Forklift, R & T, 144-180 Lift, GED, SRT, 4000 Lb	Allis-Chalmers	ACE 40	3930-00-327-1603	Electric	AC	---	AC	Gessna	Barnes Corp	---
M499	Ramp, Mobile, 16,000 LB	Magline		3990-01-026-1575	---	---	---	---	---	---	---
	Ramp, Mobile, 16,000 LB	Brooks & Perkins		3990-01-059-0104	---	---	---	---	---	---	---
	Ramp, Mobile, 16,000 LB	Magline							---	---	---
R308	Crane, 250-300 Ton	Harnischfeger (P&H)		3950-01-027-9253	DDA	Dana	---	Dana	Vickers	Garrison	Dana
R309	Crane, 140 Ton	FMC		3950-01-110-9225							
R036	Distributor, Water 6000 Gal.	McCloud		3825-01-065-6221							
R004	Ditching Machine			Proposed							
R077	Drilling Machine, Well, 6 IN. at 1500 Ft.	Failing Co.		3820-01-075-4974							

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