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COOPERATIVE FIELD EVALUATION OF MIL-L-2104C LUBRICANT IN ENGINE--ETC(U)
SEP 78 P J KENNEDY, T C BOWEN

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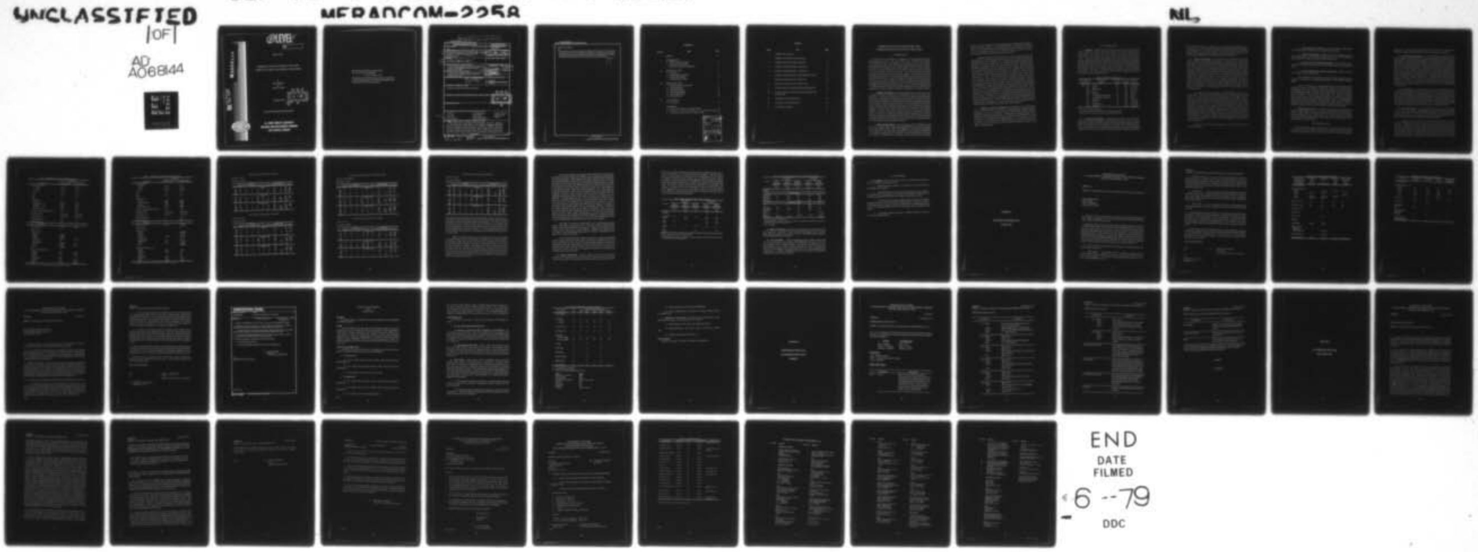

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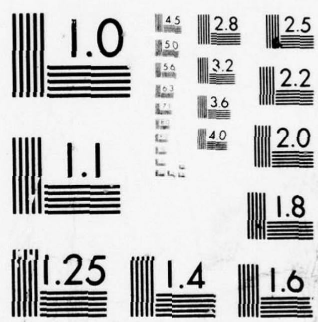

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Report 2258

COOPERATIVE FIELD EVALUATION OF MIL-L-2104C LUBRICANT IN ENGINE AND HYDRAULIC APPLICATIONS

by
Paul J. Kennedy
and
Thomas C. Bowen

September 1978

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U.S. ARMY MOBILITY EQUIPMENT
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers a cooperative, lubricants program conducted in conjunction with the developmental testing (DTII) of a new Family of Lightweight Engineering Construction Equipment, known collectively by the acronym, FAMECE. This equipment was of interest because MIL-L-2104C engine oil served as a universal lubricant for engine, transmission, and hydraulic systems. The use of the Grade 10 oil as an Army hydraulic fluid was of particular interest. The overall objective of the program was to

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obtain base-line data on field application of MIL-L-2104C engine oil for use in future modification of the MIL-L-2104 engine oil specification. This report covers the laboratory evaluation of used oils collected during DTII and the investigation of fuel-related problems encountered during tests. Data indicate satisfactory oil performance.

CONTENTS

TABLES

COOPERATIVE FIELD EVALUATION OF MIL-L-2104C LUBRICANT IN ENGINE AND HYDRAULIC APPLICATIONS

I. INTRODUCTION

Developmental testing (DTII) of a new Family of Lightweight Engineering Construction Equipment, known collectively by the acronym, FAMECE, was conducted at Fort Belvoir, Virginia. This equipment was designed to meet the high mobility and airlift/airdrop requirements of the Army Airborne and Airmobile units. In cooperation with the Project Managers Office (PMO), FAMECE/UET, the Energy and Water Resources Laboratory participated in a cooperative program involving field testing of a reference lubricant in selected vehicles. This reference lubricant is presently in the Army supply system and is typical of the quality of lubricant that will be used in FAMECE after fielding. The Energy and Water Resources Laboratory provided this MIL-L-2104C reference oil for use in the engines, transmissions, and hydraulic systems of selected vehicles and, in addition, conducted an engine inspection and lubricant analysis related to lubricant performance. The overall objective of this participation in FAMECE DTII was to obtain base-line data on the use of MIL-L-2104C engine oil as a hydraulic fluid with the intention of possible modification of a future MIL-L-2104 specification to include hydraulic performance requirements not currently included.

1. **FAMECE DTII Evaluation.** The original intent of this evaluation was to subject thirteen vehicles to 1000 hours of field evaluation under service typical of their intended use. Operation of this prototype construction equipment and field maintenance tasks were performed by military personnel stationed at Fort Belvoir with the overall test being monitored by the Mechanical and Construction Equipment Laboratory. Equipment evaluated included two graders, two water distributors, two dumpers, a dozer, a loader, a scraper, a tamping-foot compactor, and a smooth-wheel compactor. Testing was conducted after vehicle arrival from the contractor, Clark Equipment Company. The first unit, dumper I, arrived in July 1977, and the other vehicles arrived at later dates. In April 1978, before the arrival of the last two vehicles of the test set, a decision was made to terminate testing at Fort Belvoir and to complete the DTII evaluation at other installations. This revision of the test plan affected the data base of this report in that only five units had accumulated a significant number of operational hours during this limited time frame.

2. **Lubrication Requirements.** The lubrication orders for FAMECE require the use of a Grade 30 MIL-L-2104C engine oil (OE/HDO-30) for crankcase lubrication and a Grade 10 MIL-L-2104C engine oil (OE/HDO-10) for transmission and hydraulic system lubrication. The effectiveness of OE/HDO-30 as an engine oil and OE/HDO-10 as a transmission fluid is fairly well established. Of particular interest to this laboratory is the use of OE/HDO-10 as a hydraulic fluid since this represents a significant

departure from the standard lubrication requirements for combat-support equipment. Normally, hydraulic fluids, such as MIL-H-6083 (OHT) and MIL-H-46170 (FRH), which were specifically designed to satisfy military hydraulic requirements are required for use in combat-support equipment. No significant studies on the use of an engine oil as a hydraulic fluid in Army equipment have been reported.

Hydraulic fluids differ from engine oil in several important physical and chemical aspects. Certain parameters involved in the use of an engine oil in hydraulic applications need to be considered. Use of military hydraulic fluids provides low-temperature operability, minimal wear of critical hydraulic fluid components, and a high level of rust protection for valves and exposed ram shafts. The MIL-L-2104C (OE/HDO) specification does not address the above hydraulic-fluid requirements but is primarily concerned with the performance of a candidate oil in an operating diesel engine. Approximately 200 oil companies are qualified to produce MIL-L-2104C lubricants, and wide variations in the type of additive package used in the oil formulation are found. These variations do not significantly affect engine performance; however, wide variations in secondary, non-engine lubrication properties that are directly related to the use of this oil in hydraulic applications are known. For example, in the area of rust protection, a study of a randomly selected sample of OE/HDO indicated variations in rust protection levels from 36 hours to more than 360 hours. It is suspected that certain variations in hydraulic-system performance will be dependent on the types of OE/HDO-10 formulations in the supply system. On the other hand, the use of OE/HDO as a universal lubricant for military construction equipment is of particular value to this equipment since operation with minimal support is needed. In addition, there is the recognized fire hazard associated with off-highway equipment; and the use of OE/HDO-10 as compared to MIL-H-6083 significantly reduces this threat. A letter to PMO, FAMECE, relative to this fire threat is included as part of Appendix A. At present, the extent of the tradeoffs made in the implementation of this lubrication concept needs further validation.

3. **Objectives of Lubricant Evaluation.** This laboratory has custodial responsibility for the MIL-L-2104C specification and lubricant RDTE programs within the Department of the Army. Presently, the use of OE/HDO-10 in satisfying hydraulic-application requirements is under study. Consideration is presently being given to the optimization of hydraulic-fluid performance requirements of OE/HDO-10 in a future modification of the MIL-L-2104 specification; however, such requirements must first be defined. This participation in FAMECE DTII was to provide information that would serve in part as base-line data in determining the requirements needed in a future MIL-L-2104 specification.

II. DETAILS OF TEST

4. **Equipment.** FAMECE represents a class of wheeled, construction and earth-moving equipment. Units are modular in design with a work unit consisting of a power-module section coupled to a work section. Each section weighs less than 15,000 pounds. The various types of work sections used in this test are shown in Table 1. In testing, a separate power module was used for each work section. Since all power modules are identical in construction, these units are listed by serial number. Total hours accumulated for each work unit at arrival and at test completion are also included in this table. The power train for these units consists of a Cummins VT555 Turbo Charged 218 HP Diesel Engine with a Clark Model LT-7853 transmission. The hydraulic controls and a 70-gallon hydraulic reservoir are also located on the power module. The work section consists of the working component (e.g., blade, roller) and a secondary hydraulic system.

Table 1. FAMECE Test Equipment

Power Modules (Serial No.)	Work-Unit Section	Hr @ Start of Test	Hr @ End of Test	Lubricant Type
446 X 104	Grader I	273	1061	Comm oil (2)
105	Loader	153	1103	Comm oil
106	Distributor I	97	901	Comm oil
107(1)	Dozer	78	824	Ref oil (3)
108(1)	Dumper I	20	1266	Ref oil
110	Tamping-Foot Compactor	110	406	Ref oil
112	Smooth-Wheel Compactor	63	355	Ref oil
113	Dumper II	26	400	Comm oil
114	Scraper	29	251	Comm oil
115	Distributor II	10	247	Comm oil
116	Grader II	–	540	Comm oil

(1) These units used a silicone brake fluid.

(2) Commercial oil used for hydraulic fluid, crankcase, and transmission lubrication.

(3) Reference oil used for hydraulic fluid, crankcase, and transmission lubrication.

5. **Lubrication Requirements.** Lubrication orders require the use of MIL-L-2104C oils for engine, transmission, and hydraulic applications. SAE 10 Viscosity Grade oil is required for crankcase lubrication when expected temperatures are above +40°F and 10 grade oil when temperatures are less than +40°F. SAE 30 Viscosity Grade oil is required for use in transmissions and hydraulic systems if temperatures are above -10°F. For arctic conditions or when the ambient temperature is less than

0°F, MIL-L-46167(OEA) is required for use as a power-train lubrication and as a hydraulic fluid. Lubrication orders originally required drain and refill of the crankcase and transmission oils at 400-hour intervals and the hydraulic fluid at 1000 hours; however, these orders were later modified to 250 hours for the crankcase oil, 500 hours for the transmission oil, and 1000 hours for the hydraulic fluid.

6. **Reference Oil Program.** On 14 February 1977, personnel from the Energy and Water Resources Laboratory participated in a meeting with the FAMECE/UET staff relative to the use of reference-grade lubricants, referee grade fuels, and silicone brake fluid in certain vehicles that were scheduled for DTII evaluation. At this meeting, it was indicated that a referee-grade fuel could not be utilized in DTII because of logistic considerations but that possible program coordination could be achieved relative to the use of the reference-grade lubricant and silicone brake fluid. Following this meeting, a letter dated 23 February 1977 (Appendix A) was forwarded to PMO, FAMECE/UET, outlining a proposed lubricant test plan that involved the use of a reference-grade MIL-L-2104C oil for use in crankcase, transmission, and hydraulic systems and silicone brake fluid in the brake systems of five vehicles. Concurrence with the test program was obtained from PMO, FAMECE/UET, in a DF dated 18 March 1977 (Appendix A) except that six rather than five vehicles (dumper, scraper, grader, distributor, dozer, and compactor) would utilize reference-grade oils and silicone brake fluid.

The finalized, reference-oil program for FAMECE DTII is included as part of Appendix A. This program required the forwarding of six 55-gallon drums of Grade 10 and six 55-gallon drums of Grade 30 MIL-L-2104C reference engine oils and 1 gallon of a candidate MIL-B-46176 silicone brake fluid to the FAMECE facility at Clark Equipment Company, Benton Harbor, Michigan, and the factory use of this fluid for factory fill of six vehicles. The vehicles were later identified as those vehicles having power sections with serial numbers 446X107 to 446X112. Following this, the major part of the reference-oil program was to involve the monitoring of this set of vehicles during testing by periodic oil sampling/analysis to determine overall MIL-L-2104C/FAMECE system compatibility as reflected by wear-metal analysis and potential degradation of lubricants as indicated by selected tests designed to measure lubricant quality. Other vehicles not included in the test plan were to have used a commercial oil of MIL-L-2104C quality for factory fill and OE/HDO from the supply system for refill requirements.

Several factors had considerable impact on the data base provided by this cooperative program:

a. **Early Termination of DTII.** Only five vehicles had accumulated sufficient operational hours to be of value in satisfying the test objectives.

b. **Invalid Commercial Oil.** Analysis of the physical properties and elemental composition of the factory-fill oil indicates that it is not a MIL-L-2104C oil and cannot serve as a basis for comparison with the reference oil.

c. **Factory Errors in Fill of Reference Vehicles.** The factory-fill, commercial oil was used in place of the reference oil in the hydraulic system of the dumper and dozer.

d. **Test Plan Modification on Silicone Brake Fluid.** Silicone brake fluid use was limited to the dumper and dozer.

The combination of these factors prevents drawing any conclusion concerning the effectiveness of OE/HDO-10 lubricants in the FAMECE hydraulic system.

Because of changes in the original lubrication order, the sampling schedule outlined in the reference-oil program was modified. Samples of engine, transmission, and hydraulic fluids were obtained on vehicle arrival at the test site and at vehicle-accumulated-hour readings of 250, 500, 750, and 1000 hours. Two types of oil samples were obtained. Thirty-two-ounce drain samples were collected at scheduled drain and refills, and 12-ounce intermediate samples were collected by the standard vehicle sample procedure using a syringe and plastic tubing. Several laboratories including the Materials Technology Laboratory, the Energy and Water Resources Laboratory, and the Army Fuels and Lubricants Research Laboratory located at Southwest Research Institute were involved in the analysis of these oil samples.

7. **Fuel-Monitoring Activity.** In addition to involvement in the reference-oil program, this laboratory became actively involved in fuel-related problems that developed in FAMECE DTII. The primary activity in this area was a fuel cloud point monitoring program during the winter months. The activity was initiated by reported cold-start-up problems possibly related to fuel quality. Other problems such as fuel-filter clogging were also investigated.

III. RESULTS OF TEST

Lubricant performance was evaluated primarily by physical and chemical testing of used oil samples from FAMECE equipment and by physical inspection of engine and transmission components from one of these vehicles. This latter inspection, conducted on a vehicle during teardown, showed certain typical wear patterns which significantly facilitated the interpretation of data on wear-metal concentrations.

8. Engine/Transmission Inspection. A DTII test program requirement included physical teardown and replacement of the engine and transmission components on one of the vehicles. Teardown was performed on the 10-ton dumper unit (power module #446X108 and dumper I work section) that had accumulated 1250 hours of long- and short-haul service under fully loaded conditions. Inspection data on the component parts of the Cummins Model VT555 – C240 engine and Clark Model LT-7853 transmission are included in Appendix B. Inspection of the pistons, rings, crankshaft, camshaft, and valve train indicated normal wear patterns. The primary problem area was severe wearing of the No. 4 (rear) bearing. It was observed that a large quantity of copper was dislodged from the bearing surface. A peripheral problem involved scoring of thrust washers by dislodged copper debris. Transmission parts did not show any abnormal wear patterns. Mr. A. Barnabae, Field Technician for Cummins Diesel Engines, Inc., was present at teardown. He indicated that No. 4 (rear) bearing failures normally indicate lubricant starvation due to cold start-ups or insufficient engine idling before shutdown.

9. New Oil Analysis. The physical properties and elemental compositions that characterize the commercial and reference oils used in this test are listed in Tables 2 and 3. Significant differences in chemical properties such as total acid number (TAN), total base number (TBN), and elemental composition are evident. It should be noted that the SAE 10 Viscosity Grade commercial oil (Table 2) has a pour point of -11°F. This indicates that the commercial oil is not of MIL-L-2104C quality because Specification MIL-L-2104C requires a pour point of -25°F. The relatively high pour point of this commercial product could result in low-temperature lubricity problems.

10. Wear-Metal Analysis. The concentrations of wear metals, silicone, and additive metals that were found in used oil samples from the grader, loader, water distributor, dozer, and dumper are presented in Tables 4 through 8. From this set of vehicles, the dozer and dumper were to be factory filled with the reference lubricant, and the other vehicles were to be factory filled with a commercial lubricant.

Additive metal concentrations were included in these tables so as to allow calculation of dilutional effects and to verify the type of oil used for factory fill and field refill. Examination of Table 3 reveals that the primary difference between the SAE 30 Viscosity Grade commercial and reference oils is that the reference oil contains 4400 parts per million (p/m) calcium whereas the commercial oil contains approximately 2500 p/m calcium. Inspection of the calcium concentration in initial, engine-oil samples taken from these vehicles (Tables 4 through 8) indicates that the factory-fill procedure was correct. Examination of Table 2 indicates that the SAE 10 Viscosity

Table 2. FAMECE Factory Fill 10 Grade Lubricants

Properties	Oil Type: Commercial Oil	Oil Type: Reference Oil
Viscosities (cSt)		
@ 100°F	38.72	47.0
@ 210°F	5.97	6.7
Index	107.72	10.3
TAN	1.74	2.5
TBN	9.26	12.7
Insolubles (%)		
Pentane	0.012	0.02
Pentane W/ Coag.	0.004	0.01
Benzene	0.00	0.02
Benzene W/Coag.	0.017	0.01
Gravity (° API @ 60°F(15.5°C))	29.5	28.3
Flash Point (°F)	435(224°C)	417(214°C)
Pour Point (°F)	-11(-24°C)	-24(-31°C)
Carbon Residue (%)	1.45	1.7
Sulfated Ash (%)	1.47	1.7
Elements		
Nitrogen (% wt)	0.330	0.06
Boron (p/m)	13	–
X-Ray Flor. (%)		
Barium	0.2060	–
Calcium	0.3080	–
Chlorine	0.0120	<0.01
Copper (p/m)	<25	–
Phosphorus	0.1000	0.12
Sulfur	0.2900	0.42
Zinc	0.0800	–
Atomic Absorption (p/m)		
Barium	1910	<50
Calcium	2932	4400
Copper	<1	–
Magnesium	88.0	22.0
Sodium	11.0	20.0
Zinc	692.0	800.0

Note: The less-than symbol (<) is used to indicate lowest detection level of method.

Table 3. FAMECE Factory Fill 30 Grade Lubricants

Properties	Oil Type: Reference Oil	Oil Type: Commercial Oil
Viscosities (cSt)		
@ 100°F	121.0	119.4
@ 210°F	12.0	12.15
Index	101.0	99.54
TAN	2.3	1.70
TBN	13.9	6.75
Insolubles (%)		
Pentane	0.04	0.018
Pentane W/Coag.	0.04	0.004
Benzene	0.03	0.00
Benzene W/Coag.	0.01	0.008
Gravity (° API @ 60°F(15.5°C))	25.5	27.3
Flash Point (°F)	433(223°C)	450(232°C)
Pour Point (°F)	2(-17°C)	-7(-22°C)
Carbon Residue (%)	2.1	1.13
Sulfated Ash (%)	1.6	0.94
Elements		
Nitrogen (% wt)	0.07	0.0660
Boron (p/m)	–	<1
X-Ray Flor. (%)		
Barium	–	<0.0200
Calcium	–	0.2350
Chlorine	<.001	0.0130
Copper (p/m)	–	<25
Phosphorus	0.13	0.1200
Sulfur	0.48	0.4400
Zinc	–	0.0900
Atomic Absorption (p/m)		
Barium	<50	<50
Calcium	4400	2531
Copper	–	<1
Magnesium	26.0	8.0
Sodium	10.0	22.0
Zinc	700.0	748.0

Note: The less-than symbol (<) is used to indicate lowest detection level of method.

Table 4. Summary of Oil Analysis Data: Grader (P/M)

Vehicle Type: Grader

Power Section: 446X104

	Wear Metals					Additive Metals				
Hours	Aluminum	Iron	Chromium	Copper	Lead	Silicone	Phosphorus	Barium	Zinc	Calcium
					Engine Oil					
273	20	5	3	23	10	3	720	–	820	1350
500	8	20	2	30	3	6	750	90	860	1800
750	20	40	0	18	6	10	720	10	1100	4500
1000	–	–	–	–	–	–	–	–	–	–
					Transmission Oil					
273	37	86	2	280	70	6	650	–	500	3600
500	22	47	0	300	40	6	700	1000	860	4500
750	35	45	3	92	16	10	780	300	530	–
1000	25	37	2	88	7	7	640	270	600	–
					Hydraulic Fluid					
273	40	8	2	6	1	8	680	–	860	3200
500	18	4	0	5	0	3	750	1100	1100	5000
750	33	9	1	22	1	13	600	860	540	–
1000	32	10	1	19	1	11	590	810	590	–

Table 5. Summary of Oil Analysis Data: Loader (P/M)

Vehicle Type: Loader

Power Section: 446X105

	Wear Metals					Additive Metals				
Hours	Aluminum	Iron	Chromium	Copper	Lead	Silicone	Phosphorus	Barium	Zinc	Calcium
					Engine Oil					
154	26	10	2	5	9	7	680	–	800	1800
250	–	–	–	–	–	–	–	–	–	–
500	18	26	0	200	17	3	650	50	700	7000
750	–	–	–	–	–	–	–	–	–	–
1000	54	73	28	6	1	12	530	0	30	–
					Transmission Oil					
154	40	55	3	500	75	8	580	–	800	3000
250	38	80	2	400	50	8	550	–	500	3200
500	21	57	0	350	25	5	750	1080	1100	6500
750	–	–	–	–	–	–	–	–	–	–
1000	28	68	2	160	64	10	640	500	650	–
					Hydraulic Fluid					
154	38	7	1	5	1	8	660	–	860	3700
250	34	16	3	8	8	6	700	–	650	3500
500	18	11	0	8	0	4	755	1300	1000	6000
750	–	–	–	–	–	–	–	–	–	–
1000	26	18	3	7	1	11	650	1050	690	–

Table 6. Summary of Oil Analysis Data: Water Distributor I (P/M)

Vehicle Type: Water Distributor I

Power Section: 446X106

	Wear Metals					Additive Metals				
Hours	Aluminum	Iron	Chromium	Copper	Lead	Silicone	Phosphorus	Barium	Zinc	Calcium
					Engine Oil					
96	25	8	4	8	10	12	750	–	680	1650
250	–	–	–	–	–	–	–	–	–	–
500	21	27	0	5	6	0	640	10	860	5500
750	26	28	5	5	1	6	530	0	570	–
1000	–	–	–	–	–	–	–	–	–	–
					Transmission Oil					
96	36	50	2	215	55	8	550	–	500	3100
250	21	35	0	135	17	0	700	600	1000	7500
500	22	50	0	240	130	0	500	330	1100	6500
750	29	35	3	88	4	10	990	0	–	–
1000	–	–	–	–	–	–	–	–	–	–
					Hydraulic Fluid					
96	36	9	2	17	6	12	700	–	600	4300
250	21	2	0	12	0	0	750	1200	1100	6000
500	17	5	0	12	12	6	700	1100	1000	5000
750	29	8	1	14	4	11	640	1200	570	–
1000	–	–	–	–	–	–	–	–	–	–

Table 7. Summary of Oil Analysis Data: Dozer (P/M)

Vehicle Type: Dozer

Power Section: 446X107

	Wear Metals					Additive Metals				
Hours	Aluminum	Iron	Chromium	Copper	Lead	Silicone	Phosphorus	Barium	Zinc	Calcium
					Engine Oil					
78	32	14	1	65	10	20	550	–	450	4000
250	30	7	6	94	25	16	750	40	1200	6000
500	23	38	0	52	13	3	660	0	1100	7500
750	–	–	–	–	–	–	–	–	–	–
1000	–	–	–	–	–	–	–	–	–	–
					Transmission Oil					
78	47	74	4	1100	200	12	750	–	480	3700
250	31	76	0	550	250	5	800	380	780	5000
500	33	60	9	700	130	3	820	220	1100	5000
833	32	29	0	130	34	11	580	0	500	–
					Hydraulic Fluid					
78	36	7	2	7	8	8	700	–	600	5200
250	17	1	0	6	2	3	750	920	1000	6000
500	–	–	–	–	–	–	–	–	–	–
833	32	13	1	12	1	9	750	820	720	–
1000	–	–	–	–	–	–	–	–	–	–

Table 8. Summary of Oil Analysis Data: Dumper (P/M)

Vehicle Type: Dumper

Power Section: 446X108

	Wear Metals					Additive Metals				
Hours	Aluminum	Iron	Chromium	Copper	Lead	Silicone	Phosphorus	Barium	Zinc	Calcium
					Engine Oil					
20	44	5	2	8	10	10	680	–	740	4100
250	45	42	3	18	55	16	580	–	720	4400
500	20	20	3	10	6	0	600	0	1100	7500
750	34	38	17	27	90	20	650	0	950	6000
1000	33	60	11	17	68	9	530	0	580	–
					Transmission Oil					
20	48	10	2	95	45	8	760	–	880	1200
250	45	25	2	200	60	7	680	–	860	5700
500	20	9	0	86	18	5	740	0	1000	6000
750	–	–	–	–	–	–	–	–	–	–
1000	31	49	2	450	178	6	780	0	630	–
					Hydraulic Fluid					
20	48	5	3	3	1	7	760	–	900	5300
250	45	0	1	5	1	8	760	–	900	5300
500	22	0	0	6	0	4	800	540	1100	6000
750	22	1	0	7	0	5	770	560	800	6000
1000	31	7	2	12	1	9	780	560	650	–

Grade commercial oil contains barium but SAE 10 Grade reference oil does not contain barium. Inspection of Tables 4 through 8 indicates that the commercial product was mistakenly used for factory fill of the dozer transmission. This error is not considered serious because the reference oil was used as a refill oil at the 500-hour drain interval. Examination of these tables also indicated that the commercial oil was used as the hydraulic fluid in all of these vehicles. None of the vehicles' hydraulic systems was factory filled with reference oil. This factory error invalidated the primary objective of this study.

Silicone is normally considered as a contaminant metal. The concentration of elemental silicone in the used-oil samples is a measure of dirt (silica) ingestion. It is included in these tables because extremely dusty conditions were noted at the test site during summer months creating the ever-present possibility of accidental dirt ingestion during oil addition. Dirt ingestion can cause an accelerated wear of all engine components. Oil-analysis data indicate fairly constant and low level of silica in the engine oil. The effect of silica on engine wear appears to be minimal in that the aluminum concentration (from piston skirts), iron concentration (from cylinder walls, crankshaft, and camshaft), and chromium (from piston rings) did not show any direct variation with silicone concentration.

The inspection of engine parts during teardown indicated a potential, bearing-wear problem. Bearings utilized in the FAMECE are of a steel-backing, copper-flashing, and lead-overlay design. Normal bearing wear would be indicated by the initial presence of lead followed by copper after a wearing away of the lead overlay. In Tables 4 through 8, wear-metal data are presented for engine oil samples collected on vehicle arrival at the test site and at each 250-hour drain interval. The reference oil was used as the refill oil for all of these vehicles. With the exception of the water distributor, all units showed elevated copper and lead concentrations. These results suggest an accelerated bearing wear. The absence of bearing-wear signs in the water distributor is difficult to explain because a variety of factors such as the inability to use the distributor during winter months, the operator, the speed, and the load need to be considered. Findings suggest that there is no clear indication of differences in the ability of the commercial and reference oils to prevent rapid bearing wear. Another factor that needs to be considered is that bearing failure is characterized by coarse copper metal particles which would not be detected in oil analysis. For example, in the dumper where bearing failure has been documented, high-lead concentrations are found considerably in excess of the copper concentrations. This is not true in the case of the grader, loader, distributor, and dozer. Wear-metal data for the grader, loader, and dozer indicate copper concentrations in excess of lead concentrations which may indicate a more normal but accelerated bearing wear. Although the copper/lead concentration shows a general decrease, these units do show significant increases in iron concentrations that tend to indicate some type of a wear problem.

Inspection of wear-metal concentrations in the transmission-oil samples indicates high copper, lead, and iron levels. These levels reflect the initial break-in process. After the initial, 500-hour oil change, the wear-metal concentrations significantly decrease in all vehicles except the dumper. Although copper and lead levels were high in the dumper, physical inspection of the dumper's transmission did not indicate any unusual wear problems.

Used oil samples from the hydraulic systems of the vehicles indicate slightly elevated copper levels in the grader, dozer, and dumper and slightly elevated iron levels in the loader and dozer. These levels might result from abrasive wear caused by dirt ingestion. The iron concentration of these oils would be indicative of wear of the hydraulic control valves; however, because a physical inspection of the dumper hydraulic system could not be made, no correlation of wear-metal concentrations with hydraulic-system wear can be made.

11. **Lubricant Degradation.** Viscosity changes and the amount of pentane insolubles in used engine oils are presented in Table 9, and data on the viscosity changes and total solids content of transmission and hydraulic fluids are presented in Table 10.

Because of a shortage of laboratory personnel, pentane insolubles and solids content were determined on only a few randomly selected oil samples. Data from Table 9 indicate an average engine oil viscosity increase of approximately 9% for 250 hours of operation. Viscosity increases as high as 25% are considered acceptable. Data do not indicate excessive deterioration of OE/HDO-30. Data from Table 10 indicate minimal solids content and viscosity increases in used transmission oils and hydraulic fluids. The apparent viscosity increase in the commercial oil is questionable. The reference oil viscosity of 6.7 cSt is considerably in excess of the 6.0 cSt viscosity of the commercial oil, and the use of the reference grade oil as make-up would at least contribute to this observed viscosity increase. No significant viscosity increases were found in the used reference oil samples.

Table 9. Viscosity Changes and Insolubles Content of Engine Oils

Properties	Commercial Oil 30 Grade			Reference Oil 30 Grade	
	Grader (446X104)	Loader (446X105)	Distributor (446X106)	Dozer (446X107)	Dumper (446X108)
	Vis(cSt@210°F) Insol[1] (%)	Vis(cSt)@210°F) Insol (%)	Vis(cSt@210°F) Insol (%)	Vis(cSt@210°F) Insol (%)	Vis(cSt@210°F) Insol (%)
Viscosity of New Oil	–	12.1	–	12.2	–
Initial Oil[2] Sample	11.5	10.9 0.034	11.8	12.5 0.50	12.7 0.02
1st Oil Drain	11.6	–	–	13.0 0.19	13.0 0.26
2nd Oil Drain	13.3	12.7	13.4	13.3	13.7
3rd Oil Drain	–	–	13.4	–	14.2

(1) Pentane insolubles determined by ASTM Method D893.

(2) Initial samples taken on delivery of vehicles to Fort Belvoir. Operating hours were grader (273), loader (153), distributor (97), dozer (78), and dumper (20).

Table 10. Viscosity Changes and Solids Content of Transmission and Hydraulic Oils

Properties	Commercial Oil 10 Grade			Reference Oil 10 Grade	
	Grader (446X104)	Loader (446X105)	Distributor (446X106)	Dozer (446X107)	Dumper (446X108)
	Vis(cSt@210°F) Solids (%)	Vis(cSt)@210°F) Solids (%)	Vis(cSt@210°F) Solids (%)	Vis(cSt@210°F) Solids (%)	Vis(cSt@210°F) Solids (%)
Viscosity of New Oil	–	6.0	–	6.7	–
Transmission Oils					
On Arrival[2]	–	5.8	6.0	6.7	6.6
Intermediate	6.4	6.1	6.5	6.8	6.9
250-hr Sample	–	0.006	–	–	0.008
Oil Drain	6.5	6.4	6.9	6.7	6.8
500-hr Sample	–	–	0.005	0.015	ND[3]
Hydraulic System Oils					
Initial	–	6.2	6.3	6.5 0.004	6.4
Intermediate	6.3	6.0	6.5	6.5	6.7
250-hr Sample	0.005	0.006	ND	0.003	0.005
Intermediate 500-hr	6.3	6.4	6.3	–	6.4/0.013
Intermediate 750-hr	6.6	–	6.4/0.04	7.0/0.12	6.4/0.007
Final Sample	6.6/0.14	6.1/0.01	–	–	6.3/0.16

(1) Solids determined by ASTM Method F313.

(2) Initial sampling taken on delivery of vehicles to Fort Belvoir. Operating hours were grader (273), loader (153), distributor (97), dozer (78), and dumper (20).

(3) ND – not drained.

12. **Silicone Brake Fluid.** Of the two units utilizing silicone brake fluid, one unit is still under test. Admixing VV-V-680 brake fluid (glycol-based) with the silicone fluid invalidated testing on one of the two vehicles. No problems directly related to the use of this brake fluid were reported.

13. **Fuel Surveillance.** Certain starting/engine failure problems during DTII testing were suspected of being related to VV-F-800B diesel fuel quality. As part of this cooperative effort, technical assistance was provided in the resolution of fuel-related problems as they occurred. Primary problems were traced to housekeeping practices, fuel contamination of unknown origin, and use of a nonrecommended fuel de-icing agent. A complete chronological account of the problems with supportive laboratory data is presented in Appendix C.

IV. CONCLUSIONS

14. Conclusions. Based on the results of this test and observations made during the test, the following conclusions are made:

a. Wear-metal analysis indicates an accelerated wear of main bearings in the FAMECE power modules.

b. Contributing factors to bearing wear are believed to be nonconformity to lubrication-order requirements to use the SAE 10 Grade MIL-L-2104C engine oil for ambient temperatures less than 40°F and improper operational procedures.

c. The performance of the SAE 10 MIL-L-2104C engine oil in the FAMECE hydraulic system has not been identified in FAMECE DTII. A commercial, factory-fill oil that does not correspond to the SAE 10 Grade MIL-L-2104C specification was used as the factory-fill product for the five vehicles that served as the basis of this report.

d. Cold-starting problems reported in FAMECE DTII were caused by diesel fuel of marginal quality.

APPENDIX A

REFERENCE OIL PROGRAM FOR

FAMECE DTII

DEPARTMENT OF THE ARMY
U. S. ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

DRDME-GL

SUBJECT: Flammability Characteristics of Hydraulic Fluid vs Automotive Engine Oils

Project Managers Office
FAMECE/UET
ATTN: DRCPM-FM
Ft. Belvoir, VA 22060

1. Reference is made to your meeting on 5 January 1977 with Mr. M. LePera (this office) relative to potential use of Less Flammable Hydraulic Fluids (MIL-H-46170 Amd 1, FRH) in FAMECE/UET systems.

2. During the referenced meeting, the potential advantages resulting from substitution of FRH Hydraulic Fluids in place of MIL-L-2104C, OE/HDO-10 engine oil were discussed. To clarify some areas of concern, it was agreed that this office would forward laboratory flammability data comparing the fluids in question. Prior to discussing the flammability data, a tabulation of the pertinent specification requirements for the FRH and OE/HDO-10 products was prepared. In addition to these fluids, the requirements for the conventional MIL-H-6083D (OHT) hydraulic fluid and the Aberdeen Proving Ground Purchase Description (APG PD) No. 1 Arctic Engine Oil were also included. These pertinent specification requirements are shown on Table (A)1.

3. To clairfy questions arising during the discussions, the following identify the fluid/oil and its intended use:

a. MIL-H-6083D – This hydraulic fluid is essentially a polymer-thickened kerosene which prior to the Middle East conflict was the hydraulic fluid used in all Army armored equipment. It is still the corrosion-inhibited hydraulic fluid used in all except the M60/M48 series tanks.

b. MIL-H-46170 Amd 1 – This is a synthetic hydrocarbon base hydraulic fluid referred to as a poly-alpha-olefin. This is now being re-introduced for use in the M60 and M48 series tanks as the less-flammable hydraulic fluid. Its development and subsequent introduction were intended as a short-term solution. RDTE efforts currently underway are focusing on the long-term solution which involves a non-flammable hydraulic fluid.

c. APG PD No. 1 – This is an automotive engine oil formulated using either a synthetic diester fluid or an alkylated benzene which was introduced in 1969 for use in Army engine and transmission systems for operating in arctic environments. These fully formulated fluids have been extensively tested in hydraulic, transmission, and I-C engine systems.

d. MIL-L-2104C – This is a conventional automotive engine oil designed for Army tactical equipment. It is fully formulated to meet or exceed API CD/SC performance levels.

4. The flammability data generated thus far was reviewed to provide back-to-back comparisons. Table (A)2 provides comparisons of representative properties. Where no values are given, the particular test was not conducted. From this preliminary flammability data, it would appear that very little, if any, advantage may accrue from substitution of FRH in place of OE/HDO-10 oil. This is evidenced by somewhat equivalent Flash Points, Mist Flammability Flashback values, and Impact Dispersion ratings.

5. To further clarify this point, additional laboratory experimentation is in process to definitively establish the vulnerability hazards associated with OHT, FRH, OE/HDO-10, and commercial CCE hydraulic fluids. Germane to this, the water-abosorption phenomena is being concurrently evaluated. As soon as completed, this data will be forwarded to your attention.

FOR THE COMMANDER:

2 Incl
as

/t/s/ RICHARD P. SCHMITT
Acting Chief
Energy and Water Resources Laboratory

CF:
AFLRL (Mr. Lestz) w incl
DRDME-H w incl

Table (A)1. Comparison of Fluid/Oil Properties

Specification No:	MIL-H-6083D	MIL-H-46170	APG PD No. 1	MIL-L-2104C
Military Symbol:	OHT	FRH	OEA	OE/HDO-10
NATO Designation:	C-635		O-183	O-237
Fluid Type:	Petroleum	Syn Hydrocarbon	Diester	Petroleum
Inspection Reqms:				
Kinematic Viscosity, cSt:				
@ 210°F	–	3.5 min	5.75 min	5.7 to 7.5
@ 100°F	14.0 min	19.5 min	–	–
@ 0°F	–	–	–	(1200 cp)
@ -40°F	800 max	2600 max	8800 max	–
@ -65°F	3500 max	report	–	–
Pour Point, °F max	-75	-65	-65	-25
Flash Point, °F min	200	425	425	400
Fire Point, °F min	–	475	–	–
Auto Ignition				
Temp, °F min	–	650	–	–
Particulate				
Contamination	required	required	–	–
Flammability Test High Temp/ High Pressure spray	–	must pass	–	–
Flame Propagation	–	must pass	–	–
Limits of Operation	-65 to 275	-40 to 275	down to -65	down to -25

Table (A)2. Comparison of Fluid/Oil Properties

Specification No:	MIL-H-6083D OHT	MIL-H-46170 FRH	APG PD No. 1 OEA	MIL-L-2104C OE/HDO-10
Typical Properties				
Kinematic Viscosity, cSt:				
@ 210°F	4.3	3.9	6.2	6.7
@ 100°F	14.6	17.3	29.3	46.2
@ 0°F	132	356	784	3200
@ -40°F	731	2464	7420	–
@ -65°F	2435	–	47,640	–
Flash Point, °F	200	410	480	430
Fire Point, °F	210	435	–	–
Auto Ignition Temp, °F	460	770	–	–
Mist Flammability Mean inches Flashback	4.1	2.0	1.3	1.8
Impact Dispersing Flammability Rating	C	A	A	A

DEPARTMENT OF THE ARMY
U. S. ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

DRDME-GL 23 FEB 1977

SUBJECT: Participation in the FAMECE/UET Program

Project Manager FAMECE/UET System
ATTN: DRCPM-FM (COL Schneider)
Fort Belvoir, VA 22060

1. Reference is made to a meeting held 14 February with FAMECE/UET staff and personnel from this office relative to possible program coordination.

2. As was explained, this office has the responsibility in Fuels and Lubricants RDTE programs within DA, under Project No. 1F662611AH69, which addresses new fuel, lubricant, grease, etc., requirements being generated by implementation of a new design concept. This office also has custodial responsibility for Army ground-vehicle fuel and lubricant specifications.

3. During the discussions at the reference meeting, the potential utilization of reference/referee vs standard procurement products was recommended by this office. The need to utilize reference/referee products in RDTE development programs was previously addressed in our response to a TECOM query (Incl 1). In line with this, it was proposed that a request be prepared identifying those areas wherein cooperative participation was being solicited by the Fuels and Lubricants Division. The point of interest involves the forthcoming DT-1 testing of thirteen FAMECE units.

4. The extent of our participation would encompass the following areas of interest:

a. The FAMECE utilizes MIL-L-2104C OE/HDO-10 as a hydraulic fluid. Since this oil has been and is formulated to meet spark- and diesel-engine performance needs, its use in hydraulic systems may be optimized once the requirements have been defined. To accomplish this and to generate baseline data on performance of engine oils as hydraulic fluids, it is proposed to use a "reference grade" MIL-L-2104C oil in the hydraulic systems, crankcase, and transmission systems of five FAMECE units.

Incl 1

b. Once introduced, samples of the oil from the five units and others operating on a standard supply MIL-L-2104C product will be obtained before, during, and at the termination of the DT-1 test. The sampling schedule and methodology will be developed and forwarded upon approval of this request. It should be noted that our participation will be on a non-interference basis with the pending DT-1 test. Analysis of the used oils will be performed (at no cost to your office) to identify possible wear problems, oil system compatibility, and overall system performance.

c. The other area of interest involves the possible use of candidate silicone hydraulic brake fluids in the FAMECE systems. These new fluids possessing vastly superior properties over conventional VV-R-68Q fluids have been exposed to limited field fleet tests in M151 vehicles. In early spring, this office is planning to propose to TARADCOM a total retrofit to these silocone fluids for all Army vehicles. It is therefore proposed that the candidate silicone fluid be introduced in the five FAMECE systems.

5. This office believes that data derived from cooperative efforts as described above will provide valuable input for the Army's Fuels and Lubricants research and development program as well as essential information for evaluating performance of your equipment under test. The reference lubricant and fluid will be supplied at no cost.

6. Should you have any questions relative to this request, please contact Messrs LePera or Kennedy (354-3576/4594) at this office. Your comments relative to the above would be appreciated.

FOR THE COMMANDER:

1 Incl
as

/t/ JOHN A. CHRISTIANS
Chief,
Energy and Water Resources Laboratory

CF: AFLRL (Mr. Lestz) wo/Incl
DRDME-HK wo/Incl

DISPOSITION FORM

For use of this form, see AR 340-15, the proponent agency is TAGCEN.

REFERENCE OR OFFICE SYMBOL	SUBJECT
DRCPM-FM-TM	Reference Oil Program for FAMECE DTII

TO DRDME-GL FROM PMO, FAMECE/UET DATE 18 Mar 1977 CMT 1
Mayo/met/41635

1. Reference letter, DRDME-GL, 23 Feb 77, Subject: Participation in the FAMECE/UET Program.

3. This office concurs in your participation in a "reference grade" oil (including silicone brake fluid) testing program as described in referenced letter, with the following recommendations:

a. An organized system be developed and implemented to identify/segregate FAMECE vehicles with and without reference grade oil to preclude inadvertent mixing of different grades of oil.

b. That 6 rather than 5 FAMECE vehicles be included as "reference grade" candidates as follows: one each dumper, scraper, grader, distributor, dozer, and compactor.

3. Additional coordination on this program should be handled through:

a. LTC Joseph Martin of this office.

b. Art Follansbee, DRDME-HK (MERADCOM coordinator for FAMECE test).

/t/s/ MAX B. SCHEIDER
Colonel, CE
Project Manager for FAMECE/UET

CF:
MERADCOM, ATTN: Mr. Follansbee

Incl 1 to Incl 1

DA FORM 1 FEB 62 2496 REPLACES DD FORM 96, WHICH IS OBSOLETE.

REFERENCE OIL PROGRAM
FOR
FAMECE DTII

PURPOSE

To identify possible wear problems, oil/system compatibility, and oil degradation in FAMECE equipment.

SCOPE

A set of six vehicles (one each dumper, scraper, grader, distributor, dozer, and compactor) from the FAMECE DTII test group will utilize reference grade MIL-L-2104C fluids in engines, transmissions, and hydraulic systems and a silicone-based brake fluid in the power and work sections. This set of vehicles will be monitored during testing by periodic oil sampling/analysis to determine overall MIL-L-2104C/FAMECE system compatibility as reflected by wear metal analysis, or quality, and potential degradation of lubricants. Silicone brake fluid will be evaluated on a performance basis.

TEST FLUIDS/LUBRICANTS

The following test fluids/lubricants will be furnished by the Fuels and Lubricants Division, Energy and Water Resources Laboratory, MERADCOM:

a. **For Factory Fill:**

(1) Twelve 55-gallon drums of Grade 10, MIL-L-2104C, Reference Engine Oil (OE/HDO-10).

(2) Two 55-gallon drums of Grade 30, MIL-L-2104C, Reference Engine Oil (OE/HDO-30).

(3) Two one-gallon cans of silicone-based brake fluid.

b. **For Operations:**

(1) Six 55-gallon drums of Grade 10, MIL-L-2104C, Reference Engine Oil (OE/HDO-10).

(2) Six 55-gallon drums of Grade 30, MIL-L-2104C, Reference Engine Oil (OE/HDO-30).

(3) One 1-gallon can of silicone-based brake fluid.

Incl 2

The factory-fill engine lubricant will be forwarded directly from the manufacturer to Clark Equipment Company, FAMECE Facility (ATTN: CPT S. Miszkelvitz), Meadowbrook and Dewey Sts., Benton Harbor, MI 49022. It is estimated the lubricants will arrive at Clark Equipment by 30 Apr 77. The remaining materials will be supplied from MERADCOM to the equipment manufacturer or test site as applicable.

TEST PROCEDURE

The lubricant testing portion of DTII will be according to the following procedure:

a. **Factory Fill and Equipment Identification:**

(1) **Reference Grade MIL-L-2104C, OE/HDO-10 and OE/HDO-30:** The transmissions, scraper, hydraulic systems, and crankcases of the six referenced vehicles should be initially filled with the reference grade OE/HDO-10 and OE/HDO-30 fluids in accordance with the equipment lubrication orders. After fill, these vehicles should be identified by spraying the filling ports with a suitably colored heat resistant paint (e.g., bright red).

(2) **Silicone-Based Brake Fluid:** Silicone brake fluid should be used in place of the HBA VVB 680 brake fluid in these 6 vehicles. General hygiene should be practiced when handling this fluid. Employees should be instructed that silicone is a contact eye irritant and that hands should be washed well before rubbing eyes. Spills on metal surfaces that are to be spray painted can be cleaned with any organic type solvent.

b. **Field Testing:** During vehicle testing, compatibility will be monitored through used-oil analysis. Oil sampling will be conducted on a 200-hour interval basis either by extraction of a small sample (8 oz.) of fluid from the filling ports by use of a syringe and length of tubing or by collection of a large sample (32 oz.) during engine and transmission oil drain. Oil sampling will be performed by personnel from the Fuels and Lubricants Division, Energy and Water Resources, MERADCOM; however, drain sample collection by maintenance personnel may be required if drain intervals are irregular. If such assistance is required, labeled 32 oz. sample bottles will be supplied by this laboratory.

(1) Hydraulic fluid samples will be taken on a 200-hour interval basis and analyzed for water content, particulate contamination, viscosity changes, and other tests as appropriate.

(2) Transmission and crankcase oils will be analyzed in accordance with the following table. Additive depletion in transmission fluid will be monitored by infrared techniques and other tests as appropriate.

New and Used Oil Sampling and Analysis Schedule

Type Sample and Analysis***	New Oil	Hours of Engine Operation 200	400	600	800	1000
Type Sample*	1	2	2	2	2	2
Viscosity						
@ 210°F	X	X	X	X	X	X
@ 100°F	X	X	X	X	X	X
Total Acid No.	X	X	X	X	X	X
Total Base No.	X	X	X	X	X	X
Insolubles						
Pentane (A&B)	X	X	X	X	X	X
Benzene (A&B)	X	X	X	X	X	X
Gravity	X		X		X	
Flash Point	X		X		X	
Pour Point	X		X		X	
Carbon Residue	X		X		X	
Sulfated Ash	X		X		X	
Wear Metals**	X	X	X	X	X	X

* 1 = 32 oz. sample, 2 = 8 oz. sample

** Wear Metals (Mo, Pb, Fe, Al, and Cu)

*** Analyses to be conducted using the following methods:

Analysis	Method
Viscosity (210°F and 100°F)	D445
Total Acid Number	D664
Total Base Number	D2876
Insolubles (Pentane and Benzene)	D893 (Procedure A and B)
Flash Point	D92
Pour Point	D97
Carbon Residue	D524
Sulfated Ash	D872
Wear Metals	Atomic Absorption

(3) Sample analysis will be performed by MERADCOM.

(4) Reports of findings will be forwarded to the Product Manager's Office for FAMECE/UET.

c. **Information to be Recorded:** The following information should be maintained during the course of the test in the form of a test diary:

(1) Oil Consumption: Data, hours, miles, and quantity added.

(2) Engine Maintenance: Date, action, reason, i.e., scheduled or unscheduled.

(3) Changes in engine power/performance.

FUEL QUALITY

If desired, fuel quality evaluations can be made by this laboratory.

APPENDIX B

INSPECTION OF ENGINE AND

TRANSMISSION FROM FAMECE

DUMPER I

DEPARTMENT OF THE ARMY
US ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

jtw/43576

DRDME-GL

22 February 1978

MEMORANDUM FOR RECORD

SUBJECT: Inspection of Engine and Transmission From FAMECE/UET Unit No. 3

On 15 and 16 February 1978, Messrs. Bowen and Kennedy performed the subject inspection. The following provides data covering the items inspected and summarizes the inspection findings:

ENGINE	TRANSMISSION
Make: Cummins	Make: Clark
Model: VT555-C240	Model: LT-7853
Serial No: 20160902	Serial No: 63013T

OPERATION

Unit: FAMECE Dumper
Service: Long and short haul fully loaded
Time: 1250 hours

INSPECTION (Engine)

Component		Description
Pistons	General	Pistons were in satisfactory condition. Deposits were low. All rings were free and in good condition. All skirts showed moderate scratching resulting from dirt ingestion. Also, the thrust side of No. 7 and No. 8 pistons showed several small areas of light scuffing which could have resulted from the dirt ingestion or from cold starting.

INSPECTION (Engine) (Cont'd)

Component		Description
No. 1	Rings	Free and in good condition (wear ½ way across 2nd compression)
	Land 2	100% coverage with LC to MC deposits
	Land 3	100% coverage with lacquer deposits (BL-AL)
	Skirt	Lt – Med scratching
No. 2	Rings	Same as No. 1
	Land 2	Same as No. 1
	Land 3	100% coverage with AL-LAL deposits
	Skirt	Lt – Med Scratching
No. 3	Rings	Same as No. 1
	Land 2	Same as No. 1
	Land 3	40% coverage with LC-MC, 60% coverage with BL-AL deposits
	Skirt	Same as No. 1
No. 4	Rings	Same as No. 1
	Land 2	Same as No. 1
	Land 3	20% coverage with LC, 50% with AL-LAL and 30% clean
	Skirt	Same as No. 1
No. 5	Rings	Same as No. 1
	Land 2	Same as No. 1
	Land 3	50% coverage with AL-LAL, 50% clean
	Skirt	Same as No. 1
No. 6	Rings	Same as No. 1
	Land 2	80% coverage with LC-MC, 10% BL-DBRL and 10% clean
	Land 3	15% coverage with LC, 55%
	Skirt	Same as No. 1

INSPECTION (Engine) (Cont'd)

Component		Description
No. 7	Rings	Same as No. 1
	Land 2	90% coverage with LC-MC, 10% BL-DBRL
	Land 3	30% coverage with AL-LAL, 70% clean
	Skirt	Heavy scratch, several small areas of light scuffing
No. 8	Rings	Same as No. 1
	Land 2	Same as No. 1
	Land 3	85% coverage with LC-MC, 15% with BL-AL
	Skirt	Heavy scratching, one small area of light scuffing
Connecting Rod Bearings		All bearings showed scratching which was heaviest on the Nos. 3, 5, 6, and 8 bearings. In the case of the No. 6 bearing, the scratching was into copper underlay which showed heavy pitting. Pitting of the overlay was observed on all bearings.
Main Bearings		All bearings showed heavy scratching and wiping. The copper underlay was showing in varying degrees on all bearings, and the No. 4 (rear) bearing showed a large quantity of the copper removed. Also pitting of the copper underlay was observed on the No. 3 bearing.
Cam Shaft and Valve Train		Appeared normal with the exception that the inner bearing journals showed a significant amount of scratching. The drive gear appeared normal as did other valve-train components.
Crankshaft		All main and connecting-rod journals showed scratching.

DRDME-GL 22 February 1978

SUBJECT: Inspection of Engine and Transmission from FAMECE/UET Unit No. 3

INSPECTION (Engine) (Cont'd) and INSPECTION (Transmission)

Component	Description
Thrust Washer	Showed severe scoring with large quantities of copper from main bearings embedded in surface.
Combustion Chamber	Showed very low deposits (note valves were not removed).
Other	Oil pan, valve covers, valve deck, etc. were free of sludge and lacquer deposits.

The transmission appeared to be in satisfactory condition. Gears and bearings showed normal wear patterns. Although clutch packs showed some transfer of material between plates, their condition was considered acceptable.

T. BOWEN

P. KENNEDY

APPENDIX C

FUEL PROBLEMS ASSOCIATED WITH FAMECE DTII

DEPARTMENT OF THE ARMY
US ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

DRDME-GL 3 February 1978

MEMORANDUM FOR RECORD

SUBJECT: Fuel Problems Associated with FAMECE Units

1. This office was requested on numerous occasions to evaluate reported fuel-related problems that surfaced during DT-II testing of FAMECE equipment at Ft. Belvoir, North area. In view of the involvement of these on-site investigations, a chronological account of the problems, causative factors, and corrective actions/potential solutions is presented.

2. In late August 1977, fuel-filter plugging of one FAMECE power unit was noted. Subsequent analysis of the filter unit revealed the contaminant to be primarily iron oxide with trace amounts of silica and diesel fuel degradation products. This problem was subsequently traced to rusting of the interior bare-metal surface of the fuel-storage tank. These findings and recommendations were provided in a DF dated 28 September 1977 to DRCPM-FM-TM (Incl 1). The corrective action involved a change in the fuel-storage location.

3. In early December 1977, difficulties were reported in the starting of the FAMECE power modules. From the initial reports forwarded to this office, it was inferred that fuel "waxing" or "freezing" was considered to be suspect. On 14 December 1977, diesel fuel was sampled from the fuel tank and filter units of one of the affected FAMECE units (SCRAPER). Since "waxing" had been mentioned, our initial concern was to determine whether the proper diesel fuel was being used. To ascertain this, the fuel's Cloud Point was suspect. More specifically, the critical fuel factor affecting low-temperature operability is the Cloud Point. This is that temperature point wherein the first appearance of "wax" occurs as a precipitate. This separated wax can create a variety of problems such as fuel-filter plugging, fuel-line stoppage/restrictions, etc. The presence of trace water can also contribute to this problem when operating below the freezing point of water. Federal Specification VV-F-800b Fuel Oil Diesel, provides a temperature percentile guide for specifying the Cloud Point of diesel fuel to be procured. For December, the diesel fuel to be used/procured in Virginia should have a

Cloud Point not to exceed 26°F. The sample obtained from the fuel tank of the malfunctioning FAMECE had a Cloud Point of 46°F which is in excess of the specified limit indicating possible fuel waxing problems. This suspect fuel was traced to the fuel stored in No. 1 Storage Tank as this fuel had a Cloud Point of 48°F. It can be concluded that the relatively high Cloud Point of the diesel fuel being used was contributing to engine start-up failures as a result of the unusually cold temperatures being experienced in early December.

4. The No. 1 Storage Tank has a fill capacity of 10,000 gallons, and its construction is such that the fill-pipe end is fixed at 3 inches above the tank bottom. At the time of sampling mentioned above, 2000 gallons of diesel fuel remained in this tank. On 14 December, however, a delivery of 8000 gallons of diesel fuel was received and introduced into No. 1 Storage Tank. Subsequent analysis of the co-mingled fuel in No. 1 Storage Tank revealed the diesel fuel to have a Cloud Point of 64°F. This relatively high Cloud Point obviously was suspect relative to the limitation imposed under VV-F-800b for December (Cloud Point should not exceed 26°F). To ascertain whether fuel contamination, co-mingled product, etc. had occurred, the Ft. Belvoir Quality Assurance Program which provides for procurement product monitoring became involved. This program involves sampling of diesel fuel from delivery trucks prior to or during dispensing into holding tanks. The samples are subsequently forwarded to New Cumberland Army Depot, Petroleum Field Office (East), for analysis in conformance to specification requirements. Fuel samples (Nos. 3958-78 and 3959-78) obtained from the 14 November 1977 and 14 December 1977 deliveries to No. 1 Storage Tank which had been forwarded to New Cumberland Army Depot were reported to be in accordance with the limits required under VV-F-800b (Incl 2). Since their findings indicated that specification fuel was delivered in November and December, a possible explanation as to the wide discrepancies in Cloud Point may be related to water absorption or other heavier product contamination remaining in the fuel system. The water contamination could have been attributed to the ½ to 1 inch of water bottoms in No. 1 Storage Tank. In order to minimize and/or eliminate this problem, removal of water bottoms and adequate quality surveillance as specified in MIL-STD-HDBK-200 E were and are recommended.

5. In late December and early January 1978, field personnel attempted to remove water in the fuel system by the non-authorized procedure of adding alcohol to scavenge (eliminate) separated water in fuel tanks. Samples of suspect diesel fuel forwarded to this office were characterized as having two discrete phases; namely, alcohol and diesel fuel, which is typical of alcohol-petroleum fuel mixtures where moisture

is present. Upon receipt of these samples, FAMECE/UET personnel were subsequently advised as to the proper "diesel fuel anti-icer" specified in TM 9-207/TO 36-1-40 "OPERATION AND MAINTENANCE OF ORDNANCE MATERIEL IN COLD WEATHER" which states under paragraph 1-31d(2)a the following:

> "Add Inhibitor, Icing, Fuel System (MIL-I-27686) to diesel fuel at the ratio of one pint of additive to 40 gallons of fuel at the time of refueling. Fuel filters must be drained immediately after operation to remove additive-water mixtures from the bottom of the filters."

This inhibitor, referred to as FSII which is essentially ehtylene glycol monomethyl ether, is presently under requisition for use in the remainder of the FAMECE DT-II testing program.

6. On 13 January 1978, the DUMPER Power Section experienced a noticeable power loss which was traced to the main (primary) fuel filter plugging. Subsequent analysis of the contaminant indicated it to be principally iron oxide. The most probable cause of this contamination would be a result of rust formation occurring in the vehicular fuel tank or the fuel trucker assigned to the North Area.

7. A sample of diesel fuel was obtained from the truck delivery to No. 1 Storage Tank on 23 January 1978. Subsequent analysis revealed this delivery lot of product has a Cloud Point of 24°F which met the specification requirement of VV-F-800b (a 24°F maximum Cloud Point limit is required for the month of January. This inferred the previous problems to have been caused by contamination existing in No. 1 Storage Tank. In view of our RDTE responsibility in fuel decontamination, this office suggested a fuel separator be used and subsequently offered an available unit for property transfer to the North Area.

8. A series of diesel fuel samples were delivered to this office on 27 January 1978. These represented the first vehicular fuel samples after the January delivery. Subsequent analysis of these samples revealed a gradual improvement in fuel quality; however, it was noted that fuel-alcohol contamination, water contamination, and rust continue to remain as an impairment to satisfactory fuel system performance. A summary listing of all fuel sample analysis, sampling dates, observations, etc. completed thus far is provided for your review on Table (C)1 (Incl 3). If further oper-

ational difficulties with FAMECE fuel system occur or if these units are to undergo future testing at other locations, draining and flushing of fuel tanks are strongly recommended.

3 Incl
as

/t/s/ PAUL J. KENNEDY
Chemist
Fuels & Lubricants Division

DRDME-GL | Fuel Filter Sludge in FAMECE Power Unit

FAMECE/UET | C, Fuels & Lubricants | 28 Sep 77
DRCPM-FM-TM (Mr. H. Mayo) | | Kennedy/cc/44594

1. Reference is made to the fuel filter sludge sample collected on 22 Aug 77 as part of the oil analysis program.

2. This sludge consisted of 59% Iron Oxide, 1.5% Silica and contained only minimal amounts of fuel deterioration products. Further information on the chemical composition of this material can be found in the attached report of chemical analysis (Incl 1).

3. Discussion with field personnel indicated that this problem surfaced after addition of new fuel to an underground storage tank. The chemical analysis indicates that the source of the sludge was the result of the mixing of tank corrosion products with the fuel oil.

4. Remedial action at the north area in response to this problem involved use of a fuel vehicle for distribution of fuel and conversion of the underground storage tank to gasoline. This corrective action has eliminated the fuel sludge problem.

5. If reuse of the original underground storage tank is planned, then installation of a fuel filter on the pump should be considered. Alternately, a significant reduction of sludge levels could be achieved by allowing approximately two days for particulate matter to settle out of the fuel after agitation.

/t/s/ MAURICE E. LEPERA
Chief, Fuels and Lubricants Division

Incl 1

U.S. ARMY FUELS AND LUBRICANTS RESEARCH LABORATORY
8500 CULEBRA ROAD–P.O. DRAWER 28510
SAN ANTONIO, TEXAS 78284

File: B-3
9 September 1977

USAFLRL

Commander
U.S. Army Mobility Equipment
Research & Development Command
Attn: DRDME-GL, Messrs. M.E. LePera
and Paul Kennedy
Ft. Belvoir, VA 22060

Re: Laboratory Report of Analyses for Sludge From FAMECE Vehicle Fuel Filter

Dear Sir:

1. The fuel filter sludge sample, coded AL-7075-X (received 6 September 1977 from your facility), was pentane washed, air, and 210°F oven dryed. Only 0.4% of the dry sample was soluble in BAM. IR #1286 for the dry sample and IR #1284 for the BAM soluble portion of the sample are attached. Very little organic fuel deterioration products were present in the dry sample. No evidence of microbiological debris was apparent. The XRF data for the dry AL-7075-X sample gave 0.4% Si, 0.2% S, and 41% Fe.

2. The data in item (1) suggest that the filter sludge (a representative sample of dry AL-7075-X is enclosed) is primarily rust due to fuel-tank corrosion.

3. It is suggested that additional filters be obtained and placed in individual one-gallon cans for shipment to AFLRL. Inspection of the fuel tank(s) for evidence of corrosion is also requested (to include photographic documentation).

4. Further details or assistance will be provided as requested.

Very truly yours,

R.D. Quillian, Jr.
Director

/t/s/ Leo L. Stavinoha
Sr. Research Chemist

Incl 1 to Incl 1

DEPARTMENT OF THE ARMY
US ARMY GENERAL MATERIEL AND PETROLEUM ACTIVITY
PETROLEUM FIELD OFFICE (EAST)
NEW CUMBERLAND ARMY DEPOT, NEW CUMBERLAND, PA 17070

STSGP-PE 10 January 1978

SUBJECT: Quality Surveillance Test Results

Ft. Belvoir
USA Mobility Equip Research
and Devel Center
Whse 335
Alexandria, VA 22314

MF: Meradcom Testing Area
Ft. Belvoir

1. Laboratory analysis of petroleum sample forwarded by your installation indicates:

a. X Product meets specification requirements for tests performed.

b. __ Product deviates slightly from specification requirements but is considered suitable for use.

c. __ Product does not meet specification requirements. See remarks.

2. Sample information:

a. Product: F.O. Diesel, DF2
b. Item Number: 1035-34
c. Lab Number: 1969 1970
d. Sample Number: 3958-78 3959-78
e. Lead Content (grams per gallon):
f. % Sulfur:
g. % Sulfur permitted by contract specification:

3. Remarks:

*3958-78 – Diesel Fuel Sampled: 14 Nov 1977
*3959-78 – Diesel Fuel Sampled: 14 Dec 1977

CF: HQDA (DAEN-FEU)
Post Engineer

/t/s/ GEORGE R. MARTELLO
Chief, Petroleum Field Office (East)

Incl 2

Table (C)1. Fuel Quality Monitoring

Sample Origin	Date Sampled	Cloud Point, °F	Specification RQMT	Remarks
Fuel Delivery Truck	14 Nov 77	24	36 Max	NCAD Sample 3958-78[1]
No. 1 Storage Tank	14 Dec 77	48	26 Max	–
SCRAPER Fuel Tank	14 Dec 77	46	26 Max	Unit experiencing starting problems
SCRAPER Fuel Filter Unit	14 Dec 77	46	26 Max	–
Fuel Delivery Truck	14 Dec 77	16	26 Max	NCAD Sample 3959-78[1]
No. 1 Storage Tank	14 Dec 77	64	26 Max	–
No. 1 Storage Tank	11 Jan 78	46	24 Max	–
Fuel Truck	14 Jan 78	46	24 Max	–
Loader Fuel Tank	12 Jan 78	40	24 Max	Alcohol phase noted
Loader Fuel Filter Unit	12 Jan 78	42	24 Max	Alcohol phase noted
Dumper Fuel Filter Unit	13 Jan 78	48	24 Max	Alcohol phase noted
Fuel Delivery Truck	23 Jan 78	24	24 Max	–
No. 1 Storage Tank	25 Jan 78	38	24 Max	–
No. 1 Storage Tank	26 Jan 78	36	24 Max	–
Dozer Fuel Tank (Bottoms)	25 Jan 78	34	24 Max	Separated water layer noted
Loader Fuel Tank	25 Jan 78	28	24 Max	Alcohol phase noted
Dumper Fuel Tank	27 Jan 78	24	24 Max	–
Dumper Fuel Filter Unit	27 Jan 78	24	24 Max	Dirt contamination evidenced

[1] Samples analyzed by New Cumberland Army Depot (NCAD).

Incl 3

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