AD A

Service Life Extension of MIL-PRF-21260 Preservative Engine Oil

INTERIM REPORT
TFLRF No. 343

by

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Under Contract to

U.S. Army TARDEC
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An investigation determined an appropriate drain interval for preservative engine oil (PEO) using a variety of bench scale tests and engine dynamometer tests. Analytical methods were investigated to determine the presence of preservative oil additive and its remaining life. A field evaluation confirmed the laboratory-derived oil drain interval for PEO.

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EXECUTIVE SUMMARY

Problems and Objectives: The current oil drain criteria for preservative engine oil (PEO) is five hours. This results in excessive waste oil for disposal. The objective of the project was to investigate and validate methods to enhance and extend the service life of MIL-PRF-21260 oil when used for the preservation of U.S. Army vehicles and equipment.

Importance of Project: This project addresses important environmental issues regarding the reduction of the amount of waste oil that must be disposed of in a safe and environmentally sound method.

Technical Approach: An appropriate oil drain interval will be determined experimentally based on the remaining preservation properties in used oil. Analytically, methods will be investigated to find a method of defining the remaining preservative life of a used oil. The revised oil drain criteria and analytical methods will be verified in a field test.

Accomplishments: A revised oil drain interval of 50 hours was defined, validated and recommended.

Military Impact: Revision of two technical manuals is recommended to reflect the new oil drain criteria. Adoption of the new PEO oil drain interval will reduce waste oil for disposal and could reduce costs by as much as $525,000 per year.

FOREWORD/ACKNOWLEDGMENTS

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, during the period March 1997 through August 1999 under Contract No. DAAK70-92-C-0059. The work was funded by the Army Acquisition Pollution Prevention Program and administered by Mr. Thomas Landy, Team Leader, U.S. Army Tank-Automotive RD&E Center, Materials, Environmental, Packaging, and Special Processes Team (AMSTA-TR-E/MEPS/270), Warren, Michigan. Mr. Luis Villahermosa (AMSTA-TR-D/210) served as the TARDEC project technical monitor.

Special thanks is given to Ms. Wendy Mills of TFLRF for her help in the preparation and editing of this report.

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ACRONYMS & ABBREVIATIONS

TARDEC = U.S. Army Tank Automotive Research, Development and Engineering Center

TFLRF = U.S. Army TARDEC Fuels and Lubricants Research Facility

PEO = Preservative Engine Oil

TM = Technical Manual

AOAP = Army Oil Analysis Program

GNG = Go-No-Go

HC = Humidity Cabinet Test

SW = Sea Water Immersion Test

AN = Acid Neutralization Test

GM = General Motors

DDC = Detroit Diesel Corporation

AWR = Army War Reserve

DF2 = diesel fuel No. 2

SAE = Society of Automotive Engineers

DC = Daily Driving Cycle

HMMWV = High Mobility Multipurpose Wheeled Vehicle

RPM = Revolutions per minute

TGA = Thermal Gravimetric Analysis

SwRI = Southwest Research Institute

°F = degrees Fahrenheit

lb-ft = pound-foot

lb/hr = pound per hour

FT-IR = Fourier Transform Infrared Analysis

TBN = Total Base Number

R^2 = squared correlation coefficient

cm^{-1} = reciprocal centimeters

wt% = weight percent

°C = degrees Centigrade

SEP (CV) = Standard error of prediction, cross validated

F = Fail

P = Pass

USMC = United States Marine Corps

PS = powershift

THM = Turbohydromatic

ECS = Equipment Concentration Site

IMD = Intermediate Maintenance Division

I. INTRODUCTION AND BACKGROUND

The military uses Preservative Engine Oil (PEO) (MIL-PRF-21260) (1) to protect equipment in storage from corrosion. PEO is the preservative/operational oil that remains in the equipment when removed from storage and is used until the next oil drain is designated by the Army Oil Analysis Program (AOAP). PEO consists of heavy-duty diesel engine oil with a supplement anticorrosion additive. PEO preservation properties are determined by three corrosion bench tests: Humidity Cabinet Test, Acid Neutralization Test, and Sea Water Immersion Test. The details of these bench tests are presented in Section III.

This project addressed the extremely short oil drain interval specified for PEO by Army doctrine. The Technical Manual (TM-38-450) states that PEO should be changed after five hours of operation. (2)* This can occur during equipment exercises and off ship maintenance. AOAP tests do not measure the remaining corrosion protection in a used PEO. This can only be determined by running the three corrosion bench tests. The short oil drain requirements for PEO contribute to a waste stream of used engine oil that is costly to dispose and potentially damaging to the environment. It has been estimated that one quart of used oil can contaminate 1,000,000 gallons of drinking water. The potential benefits of extending the PEO drain interval include the following:

- Reduced cost of used PEO disposal
- Reduced cost of used oil filter disposal
- Reduced cost of new PEO procurement
- Reduced cost of new oil filters
- Reduced cost of maintenance labor

A quantitative cost savings analysis based on the results of this project is presented in Section X.

II. OBJECTIVE AND APPROACH

The objective of this project was to reduce the quantity of a waste stream (used oil). Project effort was to investigate and validate methods to enhance and extend the service life of MIL-PRF-21260 engine oil when used for preservation of Army vehicles and equipment. The approach included the following three project objectives:

***Numbers in parentheses represent references at the end of the document**

- Define appropriate PEO drain interval with controlled engine tests.
- Develop a quick Go-No-Go (GNG) methodology to determine the remaining preservation life of used PEO.
- Validate the new PEO drain interval and GNG test with a field demonstration.

The documents that will be modified upon successful completion of this project are:

- TM 38-450 "Storage and Maintenance of Prepositioned Material configured to Unit Sets"
- TM 38-470 "Storage of Army War Reserve (AWR) 3 Material Prepositioned Afloat"

III. PRESERVATIVE OIL BENCH TESTS

MIL-PRF-21260 (PEO) preservation properties are defined by three laboratory corrosion tests.

A. Humidity Cabinet Test (HC)

This test is defined in Federal Test Method 791, Method 5329 (4). In this test, triplicate steel panels (FS1009) are immersed in PEO at 25°C, and then suspended in a humidity cabinet at 49°C for 30 days. At the end of the test, the panels are rated for rust and corrosion spots. A fail is defined as 4 or more spots on the panel or any one spot greater than 1 mm in diameter. Both sides of the panel are rated with these pass/fail criteria for all 3 bench tests. Figure 1 shows a new steel panel, and Figure 2 shows a severe failing panel.

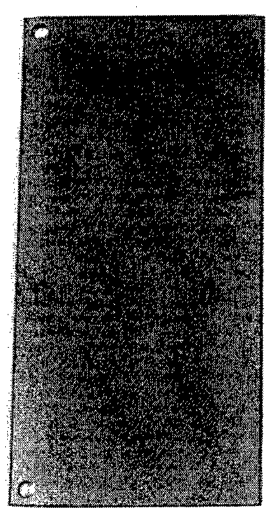

Figure 1. New/Passing Panel

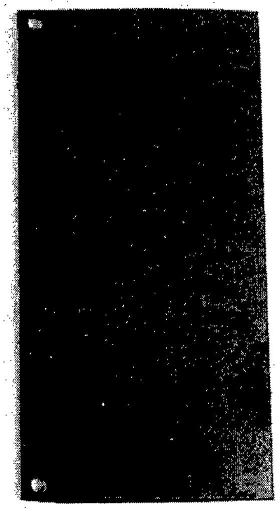

Figure 2. Severe Failing Panel

B. Sea Water Immersion Test (SW)

This test is defined in specification MIL-PRF-21260. In this test, triplicate steel panels (FS1009) are immersed in PEO at 25°C then placed in synthetic sea water at 25°C for 20 hours. At the end of the test, the panels are rated for rust and corrosion spots as described previously.

C. Acid Neutralization Test (AN)

This test is defined in specification MIL-PRF-21260. In this test, triplicate steel panels (FS1009) are dipped in dilute hydrobromic acid (HBr) and then placed in the PEO for five hours. At the end of the test, the panels are rated for rust and corrosion as described previously. This test was placed in the specification to protect steel components from the halide acids that are produced by the lead scavenger additives in leaded gasoline. With the elimination of leaded gasoline from virtually all military ground systems and equipment, the importance of this test is substantially reduced.

D. Improved Panel Rating Method

A quantitative panel-rating procedure was developed to better differentiate between pass, fail and severe-fail panels. The surface of each panel is rated, averaged by panel, then averaged for the three panels for an overall average panel rating for a given oil sample. The rating guideline is shown in Table 1.

Table 1. Rating Guideline for Corrosion Panels

PASS		Description
1		Clean
2	Border pass OR	no more than 3 spots less than 1mm no corrosion in significant area
FAIL		
3	Border fail OR	4 spots one spot larger than 1 mm
4		5-25 spots
5		26-100 spots
6		More than 100 spots, dots, flecks
7		Combination of spot sizes (1 mm, 2 mm, etc)
8		Estimated corrosion less than 50%
9		Estimated corrosion greater than 50%

The quantitative, numerical ratings were useful in attempting to correlate various property tests with level of corrosion.

IV. DETERMINATION OF HARD-TIME (FIXED INTERVAL) OIL DRAIN INTERVALS FOR PEO

A. Introduction

Two diesel engines (GM 6.2L and DDC 6V53T) that are representative of high-density Army engine families were operated on engine dynamometer test stands under conditions that simulate equipment usage and maintenance patterns found within the Army War Reserve (AWR). In addition, a 1996 Chevrolet diesel powered pickup truck was used to age PEO. Used PEO samples were obtained periodically during the tests and evaluated for their preservation characteristics using the test procedures specified in MIL-PRF-21260. The fuel used for all engine dynamometer testing was reference DF2. Commercial low-sulfur diesel fuel was used in the pickup truck. A single batch of MIL-PRF-21260 PEO was used for the engine tests. The properties of the PEO are presented in Table 2. A sample of an Army SAE15W40 engine oil (MIL-PRF-2104E) (Ref.) was evaluated in the three corrosion bench tests to determine the extent of preservation offered by current engine oils. This oil failed the HC test in 3 to 7 days, and also severely failed the SW and AN tests.

TABLE 2: PEO Properties	
Property	**AL-24841**
KVIS 40°C cST, D445	109.85
KVIS 100°C cST, D445	14.43
VI, D2270	134
HTHS VIS CP, D4624 150°C	3.87
FLASH PT°C, D	221
POUR PT°C, D	-33
SULFD ASH %, D	1.037
TAN, D664	3.17
TBN, D4739	7.84
API GRAVITY,°, D287	27.9
TFOUT MINUTES, D4742	157
S,%, by xRF	0.65
ICP PPM D5185, PPM	
CA	1526
MG	546
P	1199
ZN	1889
AG	<1
AL	1
B	<1
BA	<1
CR	<1
CU	>1
FE	3
NA	6
NI	<1
PB	<1
SI	8
SN	2
MIL-PRF-21260 PRESERVATIVE ENGINE OIL TESTS	
HUMIDITY CABINET FTM791	
METHOD 5329 30 DAYS	PASS
SALT WATER IMMERSION TEST	PASS
ACID NEUTRALIZATION TEST	PASS

B. PEO Aged in 1996 Chevrolet 6.5L Diesel Pickup Truck

This vehicle was selected to age PEO because the 6.5L diesel engine is representative of the engine used in the HMMWV. It should be noted that the new panel rating procedure was not yet developed when the initial tests in the pickup truck were conducted.

1. Initial Tests in Pickup Truck

Initially, PEO was aged using the 6.5L Chevrolet diesel pickup truck. The truck was operated at conditions intended to simulate the maintenance cycle of a preserved vehicle. Used PEO samples (500 ml) were taken at 15-minute intervals for up to 6.5 hours. The daily driving cycle (DC) and sampling schedule are defined in Tables 3 and 4.

Table 3. Daily Driving Cycle (DC)

1	2	3	4	5	6	7	8	9
Idle	Collect Sample	Drive	Collect Sample	Cool Down	Drive	Collect Sample	Idle	Collect Sample
15 min.	If required	15-20 mn	If required	3 hours	15-20 mn	If required	15 min.	If required

See map, figure 3

Table 4. Sampling Schedule

Test Cycle	Day	Tasks
A	1	DC (S1*, S2, S3, S4); drain oil
B	2	DC; no sampling
	3	DC (S5, S6, S7, S8); drain oil
C	4	DC; no sampling
	5	DC; no sampling
	6	DC (S9, S10, S11, S12); drain oil
D	7	DC; no sampling
	8	DC; no sampling
	9	DC; no sampling
Test Cycle	Day	Tasks
	10	DC (S13, S14, S15, S16); drain oil
E	11	DC; no sampling
	12	DC; no sampling
	13	DC; no sampling
	14	DC; no sampling
	15	DC (S17, S18, S19, S20); drain oil

* S1-S20 refers to used oil samples 1 through 20.

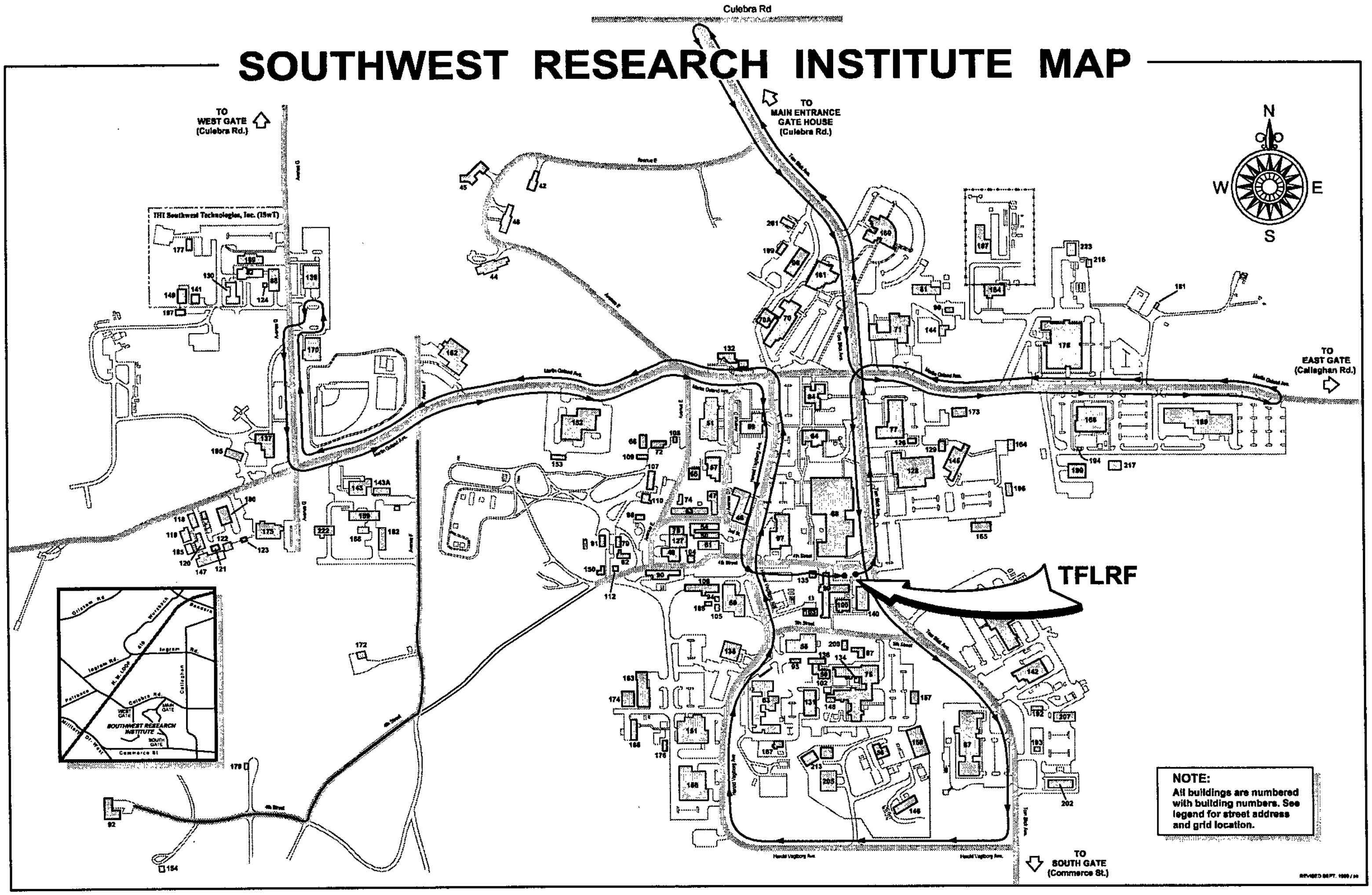

Figure 3. Test Course

Five hundred ml. of used PEO was removed from the engine at each sample point (S1, S2, S3, etc.). The remaining oil was drained and replaced at the end of each test cycle as indicated in Table 3. Total time on used PEO was approximately five hours.

The data acquisition system that was installed on the vehicle logged the average operating conditions every 10 seconds. The coolant temperature, oil sump temperature, intake air temperature, oil pressure, and RPMs are shown in Figures 4-6 for a representative daily driving cycle (DC). Each stage of the DC is labeled in Figure 4. The engine was idled for 15 minutes, an oil sample was taken, and the truck was driven for 6.5 miles (approximately 25 minutes). Another oil sample was taken before the three-hour cooldown period. The process was then repeated for the second half of the DC. The same stages can easily be seen in Figures 5 and 6 for the oil pressure and engine RPM. Twenty used oil samples were taken during the oil aging. The used oils were evaluated for preservation quality using the corrosion tests specified in MIL-PRF-21260: HC, SW and AN. Because of limited HC space during this test sequence, the HC samples were tested in duplicate, not triplicate. The results are presented in Table. 5. All 20 samples passed the AN, SW and HC tests. These samples were used in the development of a GNG test as discussed in a following section. In conclusion, the PEO that aged up to 5.8 hours in the pickup truck did not degrade the preservation properties of the oil.

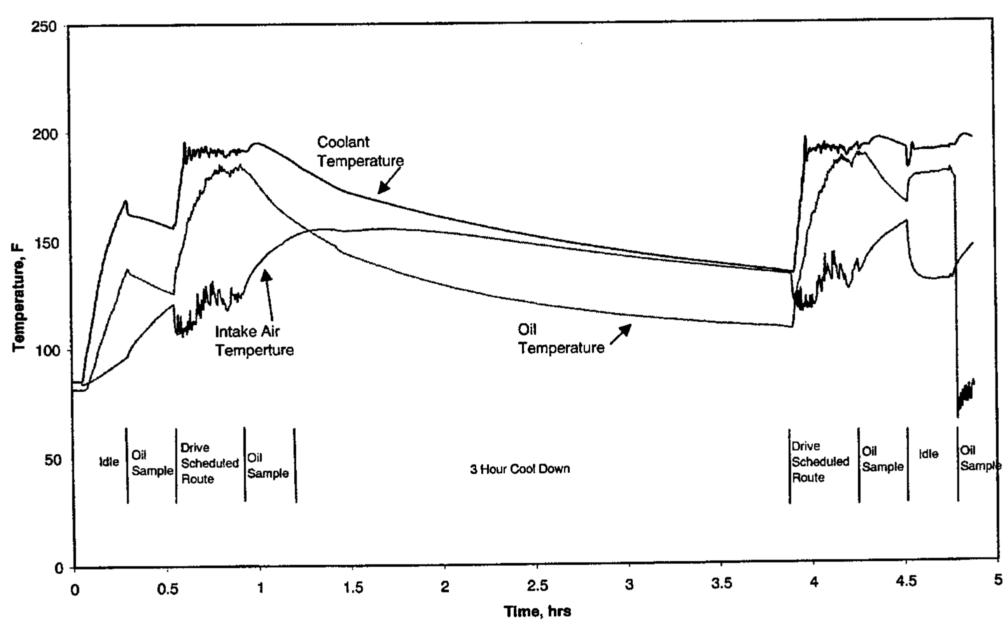

Figure 4. Engine Temperatures, Representative Daily Driving Cycle

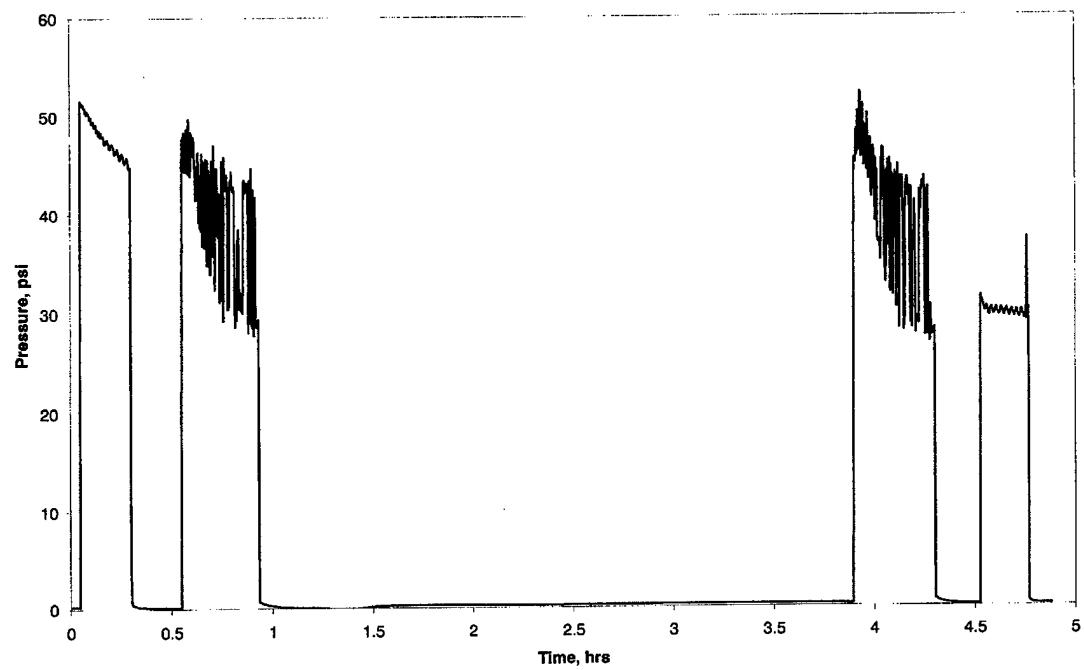

Figure 5. Oil Pressure, Representative Daily Driving Cycle

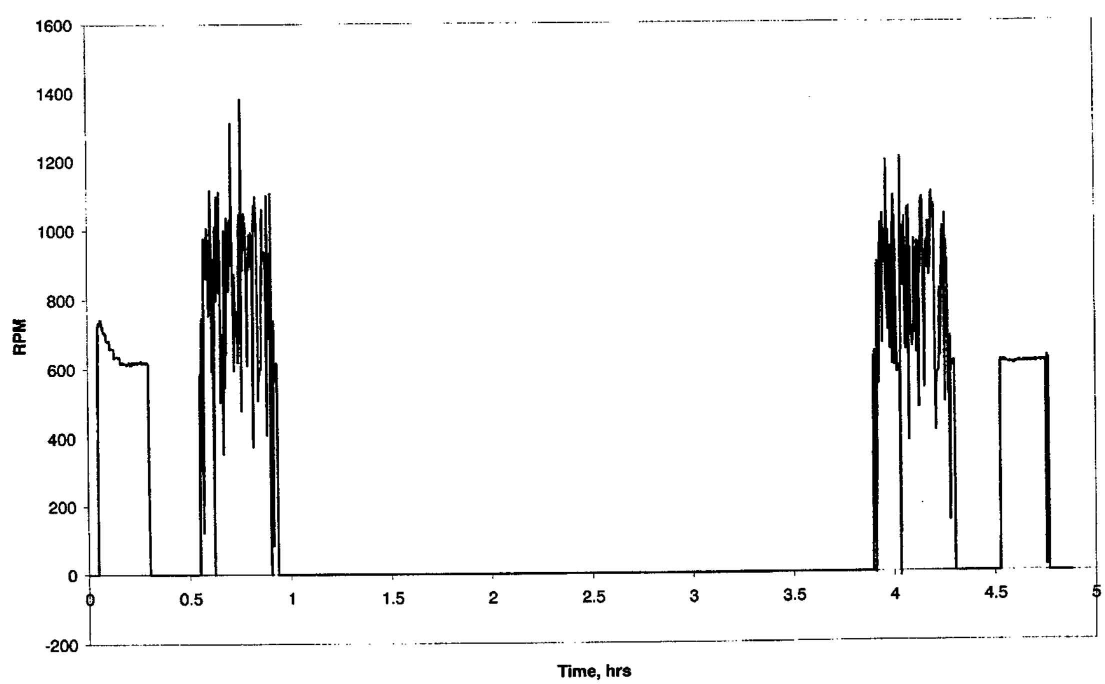

Figure 6. RPM, Representative Daily Driving Cycle

TABLE 5: Results of PEO Aging in Pickup Truck						
	Total Time on Oil, hrs	**Humidity Cabinet**	**Sea Water Test**	**Acid Corr Test**	**TBN D-479**	**TGA Soot %**
Sample #1	0.25	2 pass	3 pass	3 pass	7.18	0.00
Sample #2	0.58	2 pass	3 pass	3 pass	7.04	0.2
Sample #3	0.91	2 pass	3 pass	3 pass	7.02	0.1
Sample #4	1.16	2 pass	3 pass	2 pass 1 fail	7.23	0.2
Sample #5	1.41	NT*	3 pass	3 pass	7.41	0.00
Sample #6	1.74	NT	3 pass	3 pass	7.53	0.1
Sample #7	2.07	NT	3 pass	3 pass	7.81	0.00
Sample #8	2.32	NT	3 pass	3 pass	7.63	0.00
Sample #9	2.57	2 pass	3 pass	3 pass	6.77	0.1
Sample #10	2.9	2 pass	3 pass	3 pass	7.26	0.1
Sample #11	3.23	2 pass	3 pass	3 pass	7.48	0.1
Sample #12	3.48	1 pass 1 fail	3 pass	3 pass	7.54	0.1
Sample #13	3.73	2 pass	3 pass	3 pass	7.53	0.1
Sample #14	4.06	2 pass	3 pass	3 pass	7.51	0.1
Sample #15	4.39	2 pass	3 pass	3 pass	6.91	0.2
Sample #16	4.64	2 pass	3 pass	3 pass	6.62	0.3
Sample #17	4.89	2 pass	3 pass	3 pass	7.31	0.1
Sample #18	5.22	2 pass	3 pass	3 pass	7.74	0.00
Sample #19	5.55	2 pass		3 pass	7.44	0.00
Sample #20	5.8	2 pass	3 pass	3 pass	7.54	0.1

*NT = Not Tested, no space available in humidity cabinet

2. Accelerated Tests in Pickup Truck

Another series of PEO aging tests were conducted using the 6.5L Chevrolet diesel pickup truck. The procedure was modified to accelerate the accumulation of time on the oil. In this procedure, the truck was idled for 15 minutes, then driven over the SwRI course of Lap 1, then idled 15 minutes and driven lap2. This cycle was repeated for five laps, and then the truck had a two-hour cooldown. Three additional laps, with 15-minute idles interspaced in the afternoon, were made for a total of approximately 5.3 hours of operation per day (3.3 hours driving and two hours idling), as shown in Figure 7. The average oil sump temperature during a lap was 186°F; engine speed averaged 802 rpm during a lap, and vehicle speed averaged 17.7 mph. Used PEO samples were taken at 5.3, 10.6, 15.9, 21.2, 26.5, 42.4, 53 and 79.5 test hours. Results for the SW, AN and HC tests are shown in Table 6. The only fail result was for the 79.5 hour sample in the AN test.

3. Extended Tests at Idle in Pickup Truck

The effect of extended engine operation at idle conditions on PEO performance was determined in the 1996 Chevrolet 6.5L Turbo Diesel Pickup Truck. Used PEO samples were analyzed after 50, 100, 125 and 150 hours of idle. Results are presented in Table 7. No oil was added during the test. After 150 hours of idle, the SW and HC tests were still a pass. The AN test failed at less than 50 hours.

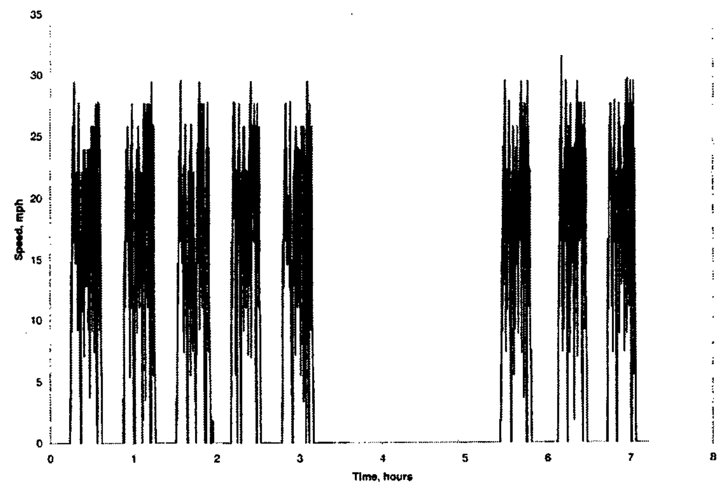

Figure 7. Vehicle speed during a day of accelerated operation

TABLE 6: Results of PEO Aging in Pickup Truck, Accelerated Cycle						
	Total Time on Oil, hrs	**Humidity Cabinet**	**Sea Water Test**	**Acid Corr Test**	**TBN D-479**	**TGA Soot %**
Sample #21	5.3	3 pass	3 pass	3 pass	6.93	0.1
Sample #22	10.6	3 pass	3 pass	3 pass	7.10	0.0
Sample #23	15.9	3 pass	3 pass	3 pass	7.76	0.0
Sample #24	21.2	3 pass	3 pass	3 pass	7.6	0.0
Sample #25	26.5	3 pass	3 pass	3 pass	7.4	0.0
Sample #26	42.4	3 pass	3 pass	3 pass	7.6	IP*
Sample #27	53	3 pass	3 pass	3 pass	7.4	IP
Sample #28	79.5	2 pass 1 fail	3 pass	3 fail	4.8	IP
*IP=Test in Progress						

TABLE 7. Idle in P/U Oil, AL-24841								
Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C	TBN D4739
	Panels	Rating	Panels	Rating	Panels	Rating	cst	
50	3 fail	4.0	3 pass	1.0	3 fail	3.3	14.6	7.7
100	3 fail	4.7	3 pass	1.0	3 pass	1.3	14.6	7.6
125	3 fail	5.0	3 pass	1.0	3 pass	1.7	14.6	7.7
150	3 fail	5.0	2 pass 1 fail	2.3	2 pass 1 fail	2.3	14.8	7.5

4. Results from Oil Aged in Pickup Truck

The following results are drawn based on the investigations of PEO aged in the 1996 Chevrolet 6.5L diesel pickup truck:

- Used PEO retained full corrosion protection during the initial 5.8 hours of mixed stop and go light-duty driving.
- Used PEO retained full corrosion protection in the HC and SW tests for over 80 hours of mixed stop-and-go, light-duty operation. The AN test was passed at 53 hours, but failed at 80 hours.
- Used PEO retained full corrosion protection in the HC and SW tests for over 150 hours at engine idle conditions. The AN test failed at <50 hours.
- Excellent corrosion protection was retained in the SW and HC test for a minimum of 80 hours.

C. PEO Aged in GM 6.2L Diesel Engine

PEO was aged in a GM 6.2L diesel engine mounted on a dynamometer test stand. The GM 6.2L, 4-cycle, indirect injection diesel engine is used to power the HMMWV. A description of the engine is presented in Table 8. A photo of the engine mounted in a test cell is presented in Figure 8.

The GM 6.2L engine completed a two-day break-in procedure prior to start of PEO aging. The following conditions were used to age PEO in the 6.2L engine:

Series 1 conditions

Speed:	1800 rpm
Oil Sump Temperature:	220°F
Full Load:	273 lb-ft
Fuel Flow:	40 lb/hr

Table 8. GM 6.2L Engine Specifications	
Engine Type:	Naturally Aspirated, Ricardo Swirl Precombustion Chamber, Four-Stroke, Compression Ignition
Cylinders:	8, V-Configuration
Displacement, L (in.^{3}):	6.2 (379)
Bore x Stroke, mm (in.):	101 x 97 (3.98 x 3.82)
Compression Ratio:	21.3:1
Rated Power, kW (BHP):	96.9 (130) CUCV, 107.7 (145) HMMWV
Rated Torque, Nm (ft-lb):	325 (240)
Oil Capacity, L (gal.):	6.62 (1.75)
Engine Structure:	Cast Iron Head and Block (No Cylinder Liners), Aluminum Pistons
Injection System:	Stanadyne DB-2 F/I Pump with Bosch Pintle Injectors

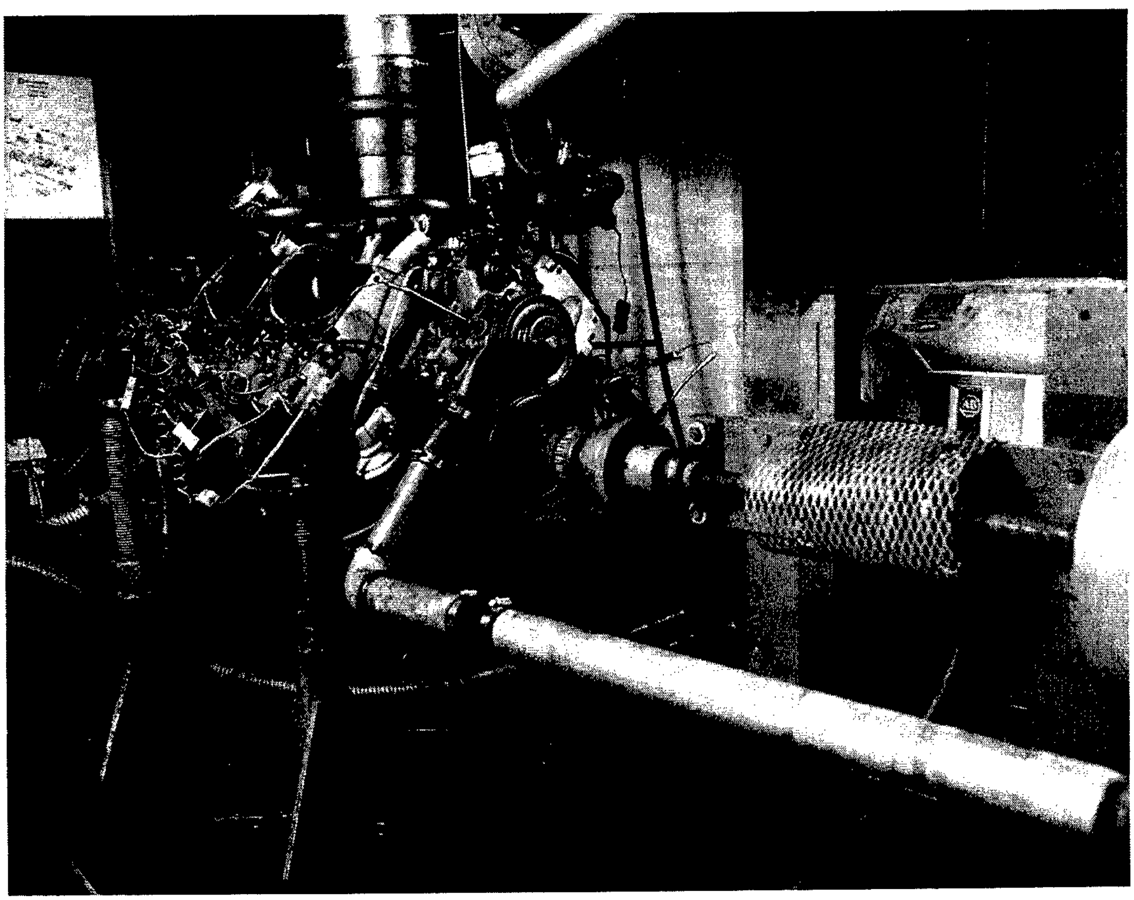

Figure 8. Installation of GM 6.2L Engine

Used oil samples were taken at 5, 10, 15, 20, 35, 49, 70 and 119 hours. The used oils were analyzed, and the results are shown in Table 9.

TABLE 9. 6.2L Engine Series 1 Conditions									
Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C cst	TBN D4739	Soot W%, TGA
	Panels	Rating	Panels	Rating	Panels	Rating			
5	3 pass	1.0	1 pass 2 fail	3.0	2 pass 1 fail	2.0	14.87	6.9	0.2
10	2 pass 1 fail	2.3	2 pass 1 fail	2.0	3 pass	1.3	14.95	6.8	0.2
15	3 fail	4.7	2 pass 1 fail	2.3	3 pass	1.0	15.09	6.8	0.4
20	3 fail	4.3	2 pass 1 fail	2.7	3 pass	1.0	15.24	6.7	0.7
35	3 fail	6.0	2 pass	2.7	3 pass	1.0	15.48	6.4	1.1
49	3 fail	6.0	2 pass 1 fail	3.0	3 pass	1.0	15.82	6.4	1.4
70	3 fail	6.0	3 fail	3.3	3 pass	1.3	17.68	5.5	2.1
119	3 fail	6.0	3 fail	9.0	3 pass	1.0	19.88	6.1	3.2

FT-IR traces were obtained for each sample and compared with FT-IR calibration standards of the supplemental anti-rust additive as discussed in a following section. Under these conditions, the sample lost acid-neutralization preservation properties between ten and 15 hours. Protection in the SW test was lost between 49 and 70 hours. The used oils still passed the HC test at 119 hours.

In series 2, the oil sump temperature was lowered to 200°F, while the other operating conditions remained as in Series 1.

Series 2 conditions

Speed:	1800 rpm
Oil Sump Temperature:	200°F
Full Load:	273 lb-ft
Fuel Flow:	40 lb/hr

Used oil samples were taken at 10, 15, 20, 35, 50, 70, 100 and 120 hours. The results are shown in Table 10.

TABLE 10. 6.2L Engine Series 2 Conditions									
Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C cst	TBN D4739	Soot W%, TGA
	Panels	Rating	Panels	Rating	Panels	Rating			
10	3 fail	5.0	3 pass	1.7	3 pass	1.0	15.17	7.6	0.7
15	3 fail	5.0	3 pass	1.0	3 pass	1.0	15.26	7.6	0.9
20	3 fail	6.0	3 pass	1.3	3 pass	1.3	15.38	7.5	1.0
35	3 fail	6.0	3 pass	1.0	2 pass 1 fail	2.0	16.28	7.0	1.3
50	3 fail	6.0	3 pass	1.0	3 pass	1.7	17.36	6.3	1.4
70	3 fail	6.0	3 pass	2.0	3 pass	2.0	19.47	6.0	2.0
100	3 fail	6.0	1 pass	3.3	3 pass	2.0	25.04	4.5	3.1
120	3 fail	6.0	2 pass	2.7	1 pass	3.0	28.48	4.3	3.8

The AN test failed at ten hours, while the other two corrosion tests continued to pass until 100 hours.

Series 3 conditions repeated Series 2 (1800 rpm, 200°F OST) to confirm the AN test failures at low hours. The results did indeed confirm that the AN test failed early, as shown in Table 11.

TABLE 11. 6.2L Engine Series 3 Conditions									
Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C cst	TBN D4739	Soot W%, TGA
	Panels	Rating	Panels	Rating	Panels	Rating			
5	3 fail	4.7	3 pass	1.0	3 pass	1.7	15.29	7.6	0.7
10	3 fail	5.0	3 pass	1.0	1 pass 2 fail	3.0	15.50	7.0	0.8
15	3 fail	5.0	3 pass	2.0	3 pass	2.0	15.90	7.1	1.0
20	3 fail	6.0	2 pass 1 fail	2.7	3 pass	2.0	16.43	6.9	1.2
28	3 fail	6.0	NT		3 pass	1.3	17.44	6.4	1.5
40	3 fail	6.0	1 pass 2 fail	3.0	3 pass	2.0	18.24	6.2	1.6

Series 4 was conducted to better define the point at which the SW test began to fail, while operating at 1800 rpm and 220°F oil sump temperature (Series 1 conditions). The results are shown in Table 12 and indicate that the SW test begins to fail between 50 and 55 hours under these conditions.

TABLE 12. 6.2L Engine Series 4 Conditions						
Test Hours	Acid Neutralization	Sea Water Immersion		Humidity Cabinet	KVIS, 100°C cst	TBN D4739
		Panels	Rating			
50	NT	2 pass 1 BL fail	2.3	NT	17.11	6.5
55	NT	1 pass 2 fail	3.0	NT	17.91	6.6
60	NT	1 pass 2 fail	3.7	NT	18.93	6.4
65	NT	3 fail	3.0	NT	19.54	5.8
70	NT	1 pass 2 fail	3.3	NT	20.36	6.2
NT=Not tested						

Series 5 was conducted to better define the point at which the AN test begins to fail, while operating at 1800 rpm and 220°F oil sump temperature. Used PEO samples were taken at 1, 3, 5, and 10 hours of operation and analyzed in the AN test. The results are shown in Table 13 an indicate that under these operating conditions, the loss of protection in the AN test occurs within one hour.

TABLE 13. 6.2L Engine Series 5 Conditions							
Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet	KVIS, 100°C cst	TBN D4739
	Panels	Rating	Panels	Rating			
1	3 fail	4.0	3 pass	1.0	NT	15.02	7.1
3	3 fail	4.0	3 pass	1.3	NT	15.02	7.1
5	3 fail	4.0	3 pass	1.3	NT	14.83	7.2
10	3 fail	5.0	3 pass	1.3	NT	14.90	7.4
NT=Not tested							

Results of PEO aging in the 6.2L diesel engine on a dynamometer test stand are summarized below:

1. 6.2L, 1800 rpm (Series 1,4,5), 220°F OST
   AN Test – Fails at <1 hour operation
   SW Test – Passes at 50 hours
   HC Test – Passes at 119 hours

2. 6.2L, 1800 rpm (Series 2,3), 200°F OST
   AN Test – Fails at <10 hours operation
   SW Test – Passes at 120 hours
   HC Test – Passes at 100 hours

D. PEO Aged in DDC 6V53T Diesel Engine

PEO was aged in a DDC two-cycle diesel engine mounted on a dynamometer test stand. The 6V53T engine is used in the M-113 Armored Personnel carrier and is representative of the two-cycle diesel engine family that is used in many Army vehicles as shown in Table 14. A description of the 6V53T engine is presented in Table 15, while the engine dynamometer test cell is presented in Figure 9.

Table 14. Army Combat/Tactical Vehicles Powered by DDC Two-Cycle Engines

Designation	Description	Engine Model
M106A1, A2	Mortar, Self-Propelled (SP), 107 mm	6V-53
M107	Gun, Self-Propelled, 175 mm	8V-71T
M108	Howitzer, Self-Propelled, 105 mm	8V-71T
M109A1, A2, A3	Howitzer, Medium, 155 mm	8V-71T
M110A1, A2	Howitzer, Self-Propelled, 8 inch	8V-71T
M42A1	Gun, Anti-Aircraft, SP	6V-53
M163A1	Gun, Air Defense, SP	6V-53
M113A1, A2	Carrier, Guided Missile, TOW; Personnel, Full-Tracked (FT)	6V-53
M113A1 (Stretch)	Carrier, Personnel, Stretched, FT, Armored	6V-53T
M113A2E1	Carrier, Personnel, FT, Armored	6V-53T
M125A1, A2	Mortar, Self-Propelled, FT	6V-53
M132A1	Flame Thrower, Self-Propelled	6V-53
M116	Carrier, Cargo, Amphibious	6V-53
M548	Carrier, Cargo, Tracked	6V-53
M548 (Stretch)	Carrier, Cargo, Tracked, Stretched	6V-53T
M551	Armored Reconnaissance/Airborne Assault Vehicle (Sheridan)	6V-53T
M561	Truck, Cargo, 1¼ T (Gamma Goat)	3-53
M792	Truck, Ambulance, 1¼ T	3-53
M577A1, A2	Carrier, Command Post, Light-Tracked	6V-53T
M578	Recovery Vehicle, FT, SP	8V-71T
M992, XM1050	Field Artillery Ammunition Support Vehicle (FAASV), FT, SP	8V-71T
M752, M688E1	Carrier, Loader/Launcher/Transporter (Lance)	6V-53
M667	Carrier, Guided Missile (Lance), Equipment, SP, FT	6V-53
XM727	Carrier, Guided Missile, Equipment, SP, FT	6V-53
M730, A1	Carrier, Guided Missile (Chaparral), SP, FT	6V-53
M730, A2	Carrier, Guided Missile (Chaparral), SP, FT	6V-53T
M741, A1	Chassis, Gun, AA (VULCAN), 20 mm, SP, FT	6V-53
M806E1	Recovery Vehicle, FT, Armored	6V-53
M901, A1	Improved TOW Vehicle Carrier, FT	6V-53
M981	Fire-Support Team Vehicle, FT, SP	6V-53
M1015, A1	Carrier, Electronic Shelter, FT, SP	6V-53
M1059	Carrier, Smoke Generator, FT, SP	6V-53
M113A1, A2	Fitters Vehicle, FT, SP	6V-53
M878, A1	Truck, Tractor, 5 T, Yard Type	6V-53T
M911	Truck, Tractor, Heavy Equipment Transporter	8V-92TA
M746	Truck, Tractor, Heavy Equipment Transporter	12V-71T
M977, 978, 985	Truck, Cargo, Tactical, 8x8 HEMTT	8V-92TA
M978	Truck, Tank, FT, 2500 gal.	8V-92TA
M983	Truck, Tractor, Tactical, 10T, HEMTT	8V-92TA
M984,A1	Truck, Wrecker, Tactical	8V-92TA
M1070	Truck, Tractor, HET	8V-92TA
M1074,M1075	Truck Cargo, Hy PIS	8V-92TA
M915A2	Truck Tractor, Line Haul	8V-92TA

Table 15. DD 6V-53T Engine Specifications	
Model:	5063-5395
Engine Type:	Two Cycle, Compression Ignition, Direct Injection, Turbo-Supercharged
Cylinders:	6, V-Configuration
Displacement, L ($in.^3$):	5.21 (318)
Bore x Stroke, mm (in.):	9.8 x 11.4 (3.875 x 4.5)
Compression Ratio:	18.7:1
Rated Power, kW (BHP):	224 (300) at 2800 RPM
Rated Torque, Nm (ft-lb):	858 (633) at 2200 RPM
Injection System:	DD Unit Injectors, N-70

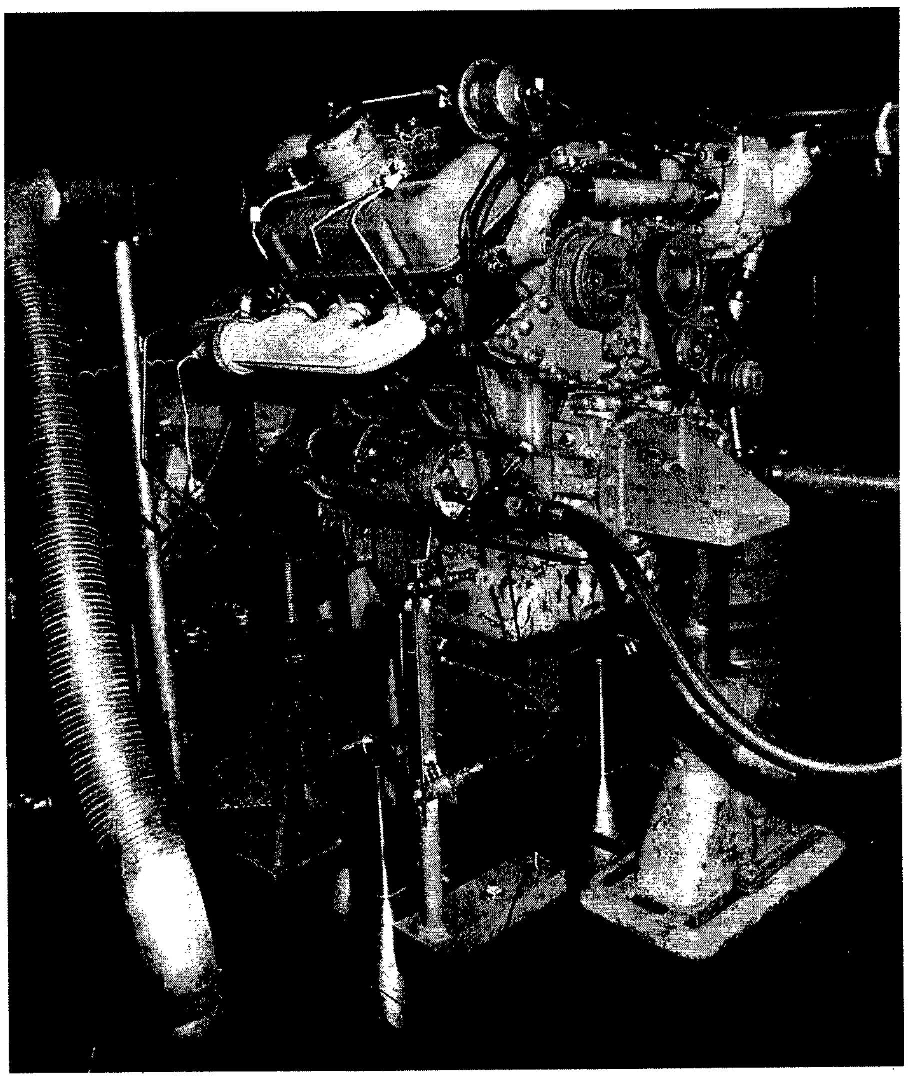

Figure 9. Installation of DD 6V-53T Engine

Routine engine break-in of 20 hours at a variety of load conditions was completed before starting oil aging tests. The data for Series' 1 through 7 are presented below. Several series of tests were conducted to determine the effect of used oil soot content on PEO bench-test performance. The used oil soot content was varied by varying the engine load at 1400 rpm. Series 1 oil aging tests were initiated at the following conditions:

Speed:	1400 rpm
Load:	430 lb-ft (75% of max)
Oil Sump Temperature:	200°F

Oil samples were taken at 5, 10, 15, and 20 hours, and analyzed. The results are presented in Table 16.

TABLE 16. 6V53T Engine Series 1 Conditions

Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C cst	TBN D4739	Soot W%, TGA
	Panels	Rating	Panels	Rating	Panels	Rating			
5	3 pass	1.0	3 pass	1.0	3 pass	1.0	14.53	7.7	0.7
10	3 pass	1.0	3 pass	1.3	3 pass	1.0	14.48	7.6	0.3
15	3 pass	1.3	3 pass	1.0	3 pass	1.0	14.36	7.7	0.5
20	2 pass 1fail	1.7	3 pass	1.0	3 pass	1.0	14.51	7.2	0.6

At these conditions, the 20-hour used oil sample passed all three corrosion bench tests.

Series 2 conditions were 1400 rpm, 100-percent load, and 200°F oil sump temperature. Used oil analyses are presented in Table 17.

TABLE 17. 6V53T Engine Series 2 Conditions

Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C cst	TBN D4739	Soot W%, TGA
	Panels	Rating	Panels	Rating	Panels	Rating			
1	3 pass	1.0	3 pass	1.0	3 pass	1.0	14.84	7.9	0.3
5	3 pass	1.0	3 pass	1.0	3 pass	2.3	15.80	7.2	0.6
10	3 pass	1.0	3 pass	1.0	2 pass 1 fail	1.3	17.28	7.5	0.8
15	3 pass	1.0	3 pass	1.0	3 pass	1.0	19.54	7.4	1.3
20	3 pass	2.0	3 pass	1.3	3 pass	1.3	20.84	7.3	1.5

Series 2 conditions produced increased used-oil soot and oil thickening: however, the AN, SW and HC tests were still passed by the 20-hour used oil sample.

Series 3 conditions were a repeat of Series 1 conditions, which were run as a quality check. The results essentially repeated Series 1 results, as shown in Table 18.

TABLE 18. 6V53T Engine Series 3 Conditions

Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C cst	TBN D4739	Soot W%, TGA
	Panels	Rating	Panels	Rating	Panels	Rating			
5	3 pass	1.0	3 pass	1.0	3 pass	1.0	14.82	7.7	0.4
10	3 pass	1.0	3 pass	1.0	3 pass	1.3	14.80	7.9	0.5
15	3 pass	1.7	3 pass	1.0	3 pass	1.3	14.80	7.9	0.6
20	2 pass 1 fail	2.0	3 pass	1.3	3 [ass	1.3	14.81	7.5	0.8

Series 4 conditions were 1400 rpm, 50-percent load, and 200°F oil sump temperature. The results are presented in Table 19.

TABLE 19. 6V53T Engine Series 4 Conditions

Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C cst	TBN D4739	Soot W%, TGA
	Panels	Rating	Panels	Rating	Panels	Rating			
5	3 pass	1.3	3 pass	1.0	2 pass 1 fail	2.0	14.54	7.6	0.3
10	3 pass	1.0	3 pass	1.3	3 pass	1.0	14.40	7.7	0.2
15	3 pass	1.0	3 pass	1.0	3 pass	1.7	14.27	7.8	0.3
20	3 pass	1.0	3 pass	1.0	3 pass	1.3	14.17	7.6	0.4

At the 50-percent load condition, oil degradation was very minimal in 20 hours and all used oil samples passed the AN, SW and HC tests.

The oil sump temperature was increased and Series 5 conditions were 1400 rpm, 75-percent load, and 220°F oil sump temperature. The results are presented in Table 20.

TABLE 20. 6V53T Engine Series 5 Conditions									
Test Hours	Acid Neutralization		Sea Water Immersion		Humidity		KVIS, 100°C cst	TBN D4739	Soot W%, TGA
	Panels	Rating	Panels	Rating	Panels	Rating			
5	3 pass	1.3	3 pass	1.7	2 pass 1 fail	2.3	14.70	7.6	0.3
10	3 pass	1.3	3 pass	1.3	1 pass 2 fail	2.3	14.54	7.7	0.4
15	3 pass	1.0	3 pass	1.0			14.46	7.7	0.4
20	3 pass	2.0	3 pass	2.0	1 pass 2 fail	2.3	14.38	7.0	0.4
25	3 pass	2.0	3 pass	2.0	3 pass	1.3	14.28	7.5	0.4
35	3 fail	4.0	3 pass	2.0	2 pass 1 fail	2.3	14.15	7.5	0.5
50	3 fail	4.7	3 pass	2.0	3 pass	1.0	13.83	7.6	0.4

The 50-hour used oil passed the SW test, while the AN test first failed with the 35-hour used oil sample. The 20°F increase in oil sump temperature did not impact the SW results up to 50 hours. The HC test still passed at 35 hours. The 10-20 hour HC results are considered anomalies. No makeup PEO was added during the test.

Series 6 conditions were 1400 RPM, 75-percent load, and 200°F OST. This was an extension of previous series (1 and 3) to 100 hours, with used PEO samples taken at 25, 35, 50, 60, 70, 80, 90 and 100 hours. The results are presented in Table 21. The AN was a pass through 50 hours, while the SWI test was still passed by the 100-hour used PEO sample. The HC results between 35 and 70 hours were borderline fails with extremely light corrosion; however, the HC test was a pass at 100 hours.

TABLE 21. 6V53T Engine Series 6 Conditions								
Test Hours	Acid Neutralization		Sea Water Immersion		Humidity		KVIS, 100°C cst	TBN D4739
	Panels	Rating	Panels	Rating	Panels	Rating		
25	3 pass	1.0	3 pass	1.7	2 pass 1 fail	2.7	15.39	8.0
35	3 pass	1.0	2 pass 1 fail	2.3	3 fail	4.0	16.75	7.3
50	2 pass 1 fail	2.7	2 pass 1 fail	2.3	3 fail	4.0	18.78	6.8
60	3 fail	4.3	3 pass	2.0	3 fail	4.0	21.34	7.2
70	3 fail	4.0	3 pass	2.0	1 pass 2 fail	3.7	23.16	7.3
80	3 fail	4.3	3 pass	2.0	3 pass	2.0	23.71	7.2
90	3 fail	5.0	3 pass	2.0	3 pass	1.7	28.02	7.5
100	3 fail	5.0	3 pass	2.0	3 pass	2.0	27.65	7.2
NT=Not Tested								

Series 7 was conducted at 1400 RPM, 75-percent load, and 220°F OST for 100 hours. This was an extension of Series 5. The results are presented in Table 22.

TABLE 22. 6V53T Engine Series 7 Conditions								
Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		KVIS, 100°C cst	TBN D4739
	Panels	Rating	Panels	Rating	Panels	Rating		
55	3 pass	1.0	3 pass	2.0	3 pass	1.0	16.11	6.6
60	1 pass 2 fail	3.3	3 pass	1.3	3 pass	2.0	16.65	7.1
70	3 fail	4.0	3 pass	1.3	2 pass 1 fail	2.3	17.92	6.8
80	3 fail	4.7	3 pass	1.0	3 pass	2.0	20.68	6.6
90	NT		3 pass	1.7	3 pass	2.0	25.02	6.7
95	NT		3 pass	1.0	2 pass 1 fail	2.3	25.42	6.5
100	NT		2 pass 1 fail	2.3	3 fail	3.3	27.16	6.5
NT=Not Tested								

The AN test was a pass at 55 hours, while the SW test was passed at 100 hours. HC tests passed at 95 hours. The increased OST (+20°F) had no effect on time to failure in either the AN or SW tests in the 6V53T engine. The increased OST caused the HC test to fail between 95 and 100 hours.

Results of PEO aging in the 6V53T diesel engine on a dynamometer test stand are summarized below:

1. At 1400 rpm, 200°F oil sump temperature
   - SW and HC passed at 100 hours
   - AN passes at 50 hours
2. At 1400 rpm, 220°F oil sump temperature
   - SW passed at 100 hours
   - HC passed at 95 hours
   - AN passed at 55 hours

E. Static Aging of Used PEO

An experiment was conducted to determine if used PEO continues to degrade under static conditions such as a stored engine.

The effect of static aging at ambient temperature (75°F) on a used PEO sample was determined. The 20-hour used oil sample from the 6V53T engine (Series 2 conditions) was stored in a metal can and retested monthly for 12 months in the PEO corrosion bench tests to determine if the PEO performances further degraded under static storage. The results are shown in Table 23.

Table 23. Static Aging -Used PEO

Test Hours	Acid Neutralization		Sea Water Immersion		Humidity Cabinet		TBN D4739
	Panels	Rating	Panels	Rating	Panels	Rating	
6V-2-20 hours	3 pass	2.0	3 pass	1.3	3 pass	1.0	7.3
At 1 mo	3 fail	4.0	3 pass	1.0	3 pass	1.0	7.1
At 2 mo	3 fail	4.0	3 fail	4.0	NT	NT	6.9
At 3 mo	3 fail	4.7	2 pass 1fail	2.3	3 pass	1.0	6.7
At 4 mo	3 fail	4.0	3 pass	1.0	3 pass	1.0	7.3
At 5 mo	3 fail	4.0	3 pass	1.3	3 pass	1.7	6.5
At 6 mo	3 fail	5.0	3 pass	1.0	3 pass	1.0	6.8
At 7 mo	3 fail	5.0	3 pass	1.3	3 pass	1.0	6.8
At 8 mo	3 fail	5.0	3 pass	2.0	3 pass	1.0	7.7
At 9 mo	3 fail	5.0	3 pass	1.7	3 pass	1.7	7.3
At 10 mo	3 fail	4.3	3 pass	1.0	3 pass	1.0	6.2
At 11 mo	3 fail	4.0	3 pass	1.3	3 pass	1.0	7.2
At 12 mo	3 fail	4.3	3 pass	1.0	3 pass	1.3	6.5

The corrosion-protection performance of the used PEO in the AN test degraded under static conditions. No corrosion protection loss was observed in the HC or SW tests through 12 months. TBN did not consistently decrease over time. Under static storage conditions, PEO corrosion protection was retained for 12 months (except in the AN test).

F. Extended Humidity Cabinet Tests

Extended duration tests were conducted in the HC to assist in understanding the corrosion inhibitor deterioration with time. Table 24 shows the results. Rust protection was provided for up to 75 days in the severe humidity cabinet environment for all three used oil samples evaluated.

Sample AL-25687, which had operated 43 hours in a Cummins 6CTA 8.3 engine prior to the HC tests, passed the HC test after 75 days of storage but failed at 140 days. The extended HC tests demonstrated that corrosion protection of a used oil lasts 2-3 times the minimum requirement for new, unused oil.

Table 24. Extended Humidity Cabinet Tests			
Sample No.	AL-25687	AL-25542	AL-25522
Vehicle Hrs (mi)	43	115	(304)
Equipment	M931A2	Grader	M1025
Engine	6CTA8.3	Cat 3304	6.2L
Duration, Days			
30	3P 1.3	3P 1.0	3P 1.0
45	3P 1.3	3P 1.3	3P 1.3
60	2P, 1F 2.3	3P 2.0	3P 1.7
75	3P 2.0	3P 2.0	1P,2F 2.7
90	3P 2.0	1P,2F 3.3	3F 4.0
140	1P,2F 3.3	NT NT	3F 4.0
NT=Not Tested			

V. GO-NO-GO TEST INVESTIGATIONS

The objective of this investigation was to develop and demonstrate a quick GO-NO-GO (GNG) test to determine the preservation properties of used diesel engine oil. At present, there is no quick way to determine if a used oil has retained its preservation qualities. Developing a quick GNG test method will reduce the number of oil changes, thus the quantity of used oil for disposal, by draining oil only when necessary.

The following techniques were investigated for use as a GNG test method for the remaining preservative properties of a used oil:

A. Total Base Number

The hypothesis was that loss in corrosion protection of the used oil would follow the loss in TBN. There are several proven techniques for rapid determination of TBN in a non-laboratory setting. Solid state microsensors (6), titra lube (7) and the ruler device made by Fluidtec (8) are possible methods.

Examination of the test results in Tables 9-13 for the used oil from the 6.2L tests and Tables 16-22 for the 6V53T tests shows that used oil TBN does not consistently predict corrosion test performance.

B. Soot Content or Insoluble Content

The hypothesis was that soot accumulation in the used oil would provide a large surface area that would compete for the anticorrosion additive. The hypothesis was as follows: as soot increased, the PEO remaining life would decrease. The soot meter (an infrared technique) is portable and quick (9). Examination of the TGA soot content of used PEO form the engine dynamometer tests (Tables 9-11 and 16-20) shows that used oil soot content does not predict corrosion test performance.

C. Dielectric Constant

The hypothesis was that changes in the used oil dielectric properties would predict loss in corrosion protection. The rationale was that used oil contaminants measured by dielectric constant would interfere with corrosion protection. A Northern Instruments LubriSensor Oil Analyzer (10) was used.

The LubriSensor, which measures the lubricant's dielectric constant, has been quite useful for evaluating the condition of used engine lubricants, especially when the baseline lubricant is known (Table 25). Therefore, 14 used PEO samples were selected that had pass, borderline fail, and fail performance in the PEO bench tests. Lubricants were field samples from Ft. Bliss, Tx. The No. 3 rating is the fail point for the AN, SW and HC tests. Figures 10-12 show that no real correlation exists between performance in the PEO bench tests and dielectric constant change from new PEO.

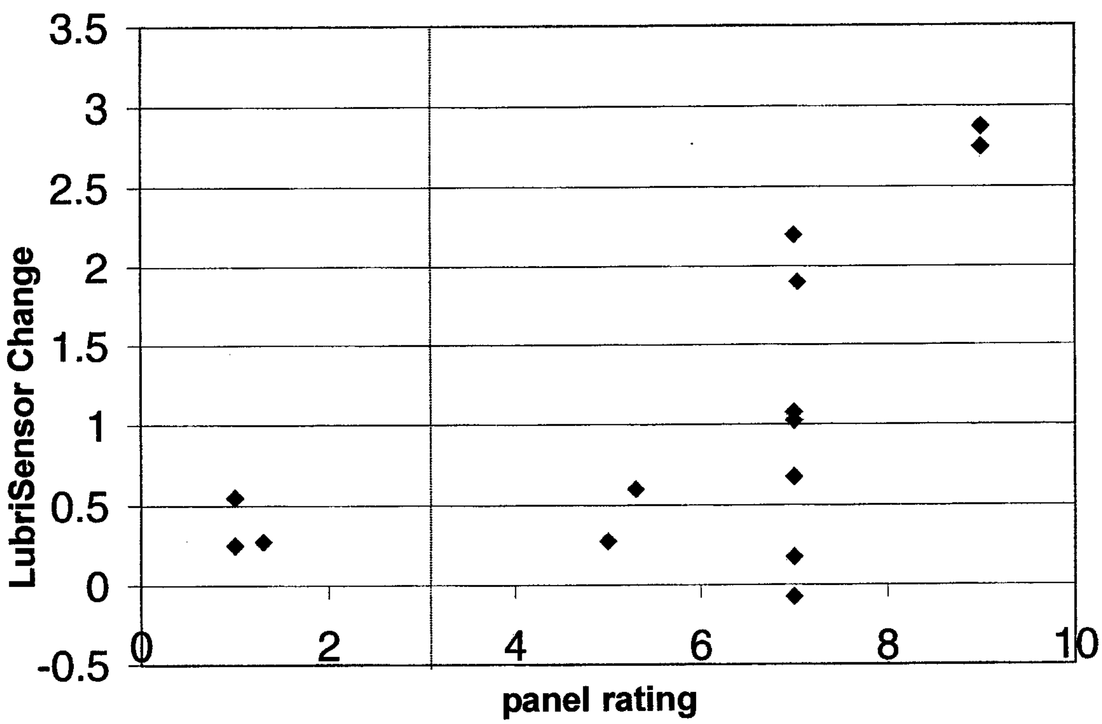

Figure 10. Lubri Sensor Change - Acid Neutralization Test

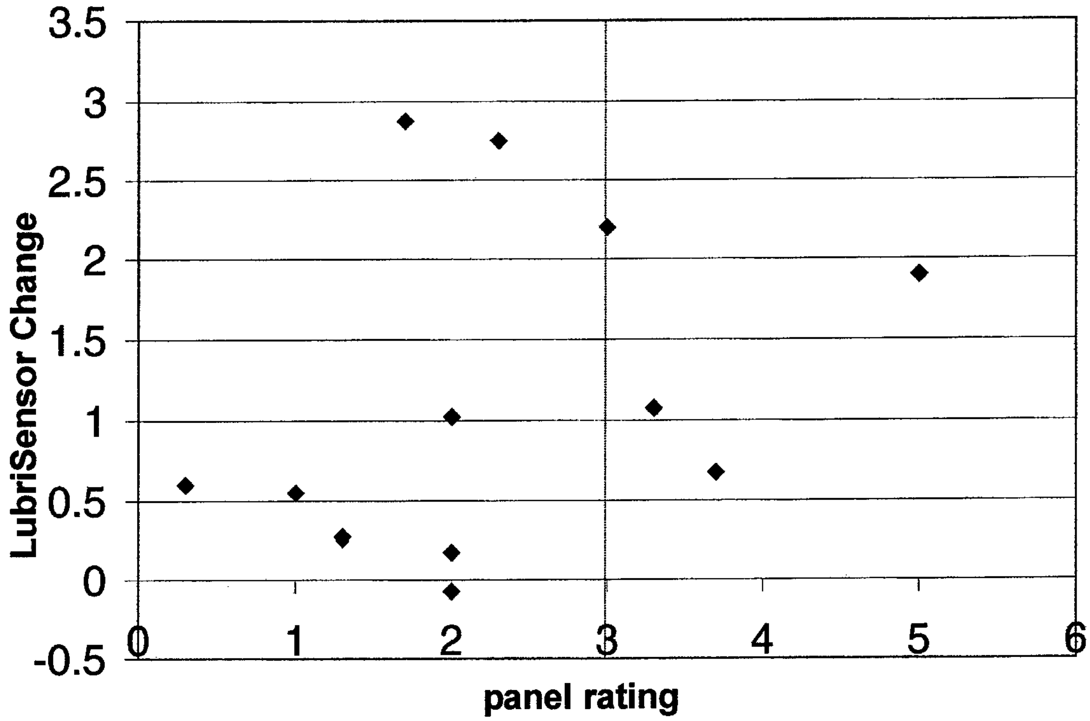

Figure 11. Lubri Sensor Change - Sea Water Immersion Test

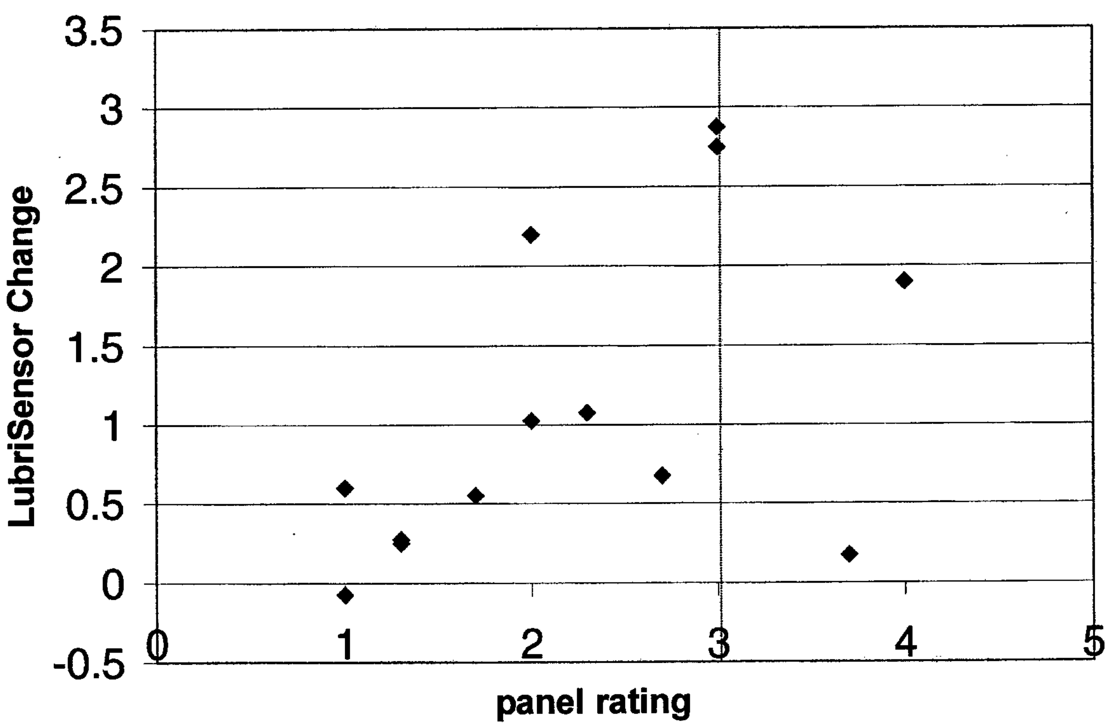

Figure 12. Lubri Sensor Change - Humidity Cabinet Test

Table 25. Lubri Sensor - Oil Quality Analyzer Model N1-2A

AL Code	Sample Date	1st Reading	2nd Reading*	Average Change from Baseline	Panel Rating			TBN D4739	KV@100°C D445
					Acid	Sea Water	Humidity Cabinet		
AL-24841	New (Baseline)	6.00	6.00	0					
AL-25535	Jul 98	6.15	6.40	0.275	5.0	1.3	1.3	7.4	13.31
AL-25540	Jul 98	6.55	6.70	0.675	7.0	3.7	2.7	6.0	15.23
AL-25541	Jul 98	7.05	7.10	1.075	7.0	3.3	2.3	6.5	11.79
AL-25333	Jul 98	7.80	8.00	1.90	7.0	5.0	4.0	6.2	12.11
AL-25543	Jul 98	8.25	8.50	2.75	9.0	2.3	3.0	3.0	10.66
AL-25544	Jul 98	8.70	9.05	2.875	9.0	1.7	3.0	1.4	13.94
AL-25530	Jul 98	6.95	7.10	1.025	7.0	2.0	2.0	7.4	14.02
AL-25454	Jul 98	8.15	8.25	2.20	7.0	3.0	2.0	4.8	16.72
AL-25520	Jul 98	6.05	6.30	0.175	7.0	2.0	3.7	6.1	13.53
AL-25522	Jul 98	6.60	6.60	0.60	5.3	1.3	1.0	5.8	14.50
AL-25539	Jul 98	5.80	6.05	-0.075	7.0	2.0	1.0	5.1	7.55
AL-25526	Jul 98	6.40	6.70	0.55	1.0	1.0	1.7	7.4	12.78
AL-25527	Jul 98	6.20	6.30	0.25	1.0	1.3	1.3	7.8	14.08
AL-25529	Jul 98	6.30	6.25	0.275	1.3	1.3	1.3	7.7	14.11

*Replaced Battery

D. RULER

The RULER device made by Fluidtec™ is a handheld unit that gives rapid indication of oil condition. It is based on electro-chemical properties (cyclic voltametry) of the used oil (8). The RULER has the ability to detect additive depletion in lube oil. A brief investigation of the RULER for use in this application was conducted for TFLRF by the manufacturer. New PEO and the 20-hour and 70-hour 6.2L samples (Table 9) were tested. The actual RULER traces are presented in Figures 13, 14 and 15. The results are summarized in Table 26.

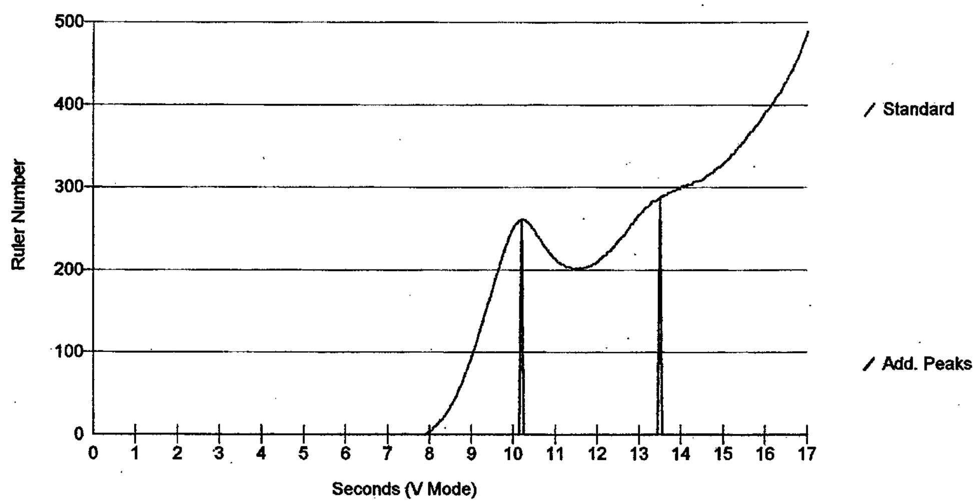

Figure 13. PEO Standard

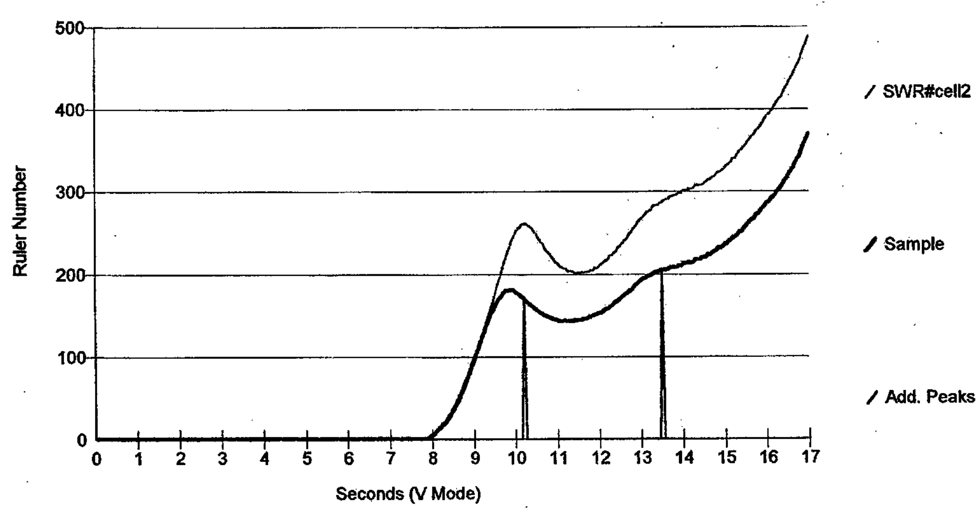

Figure 14. PEO, 20 hours

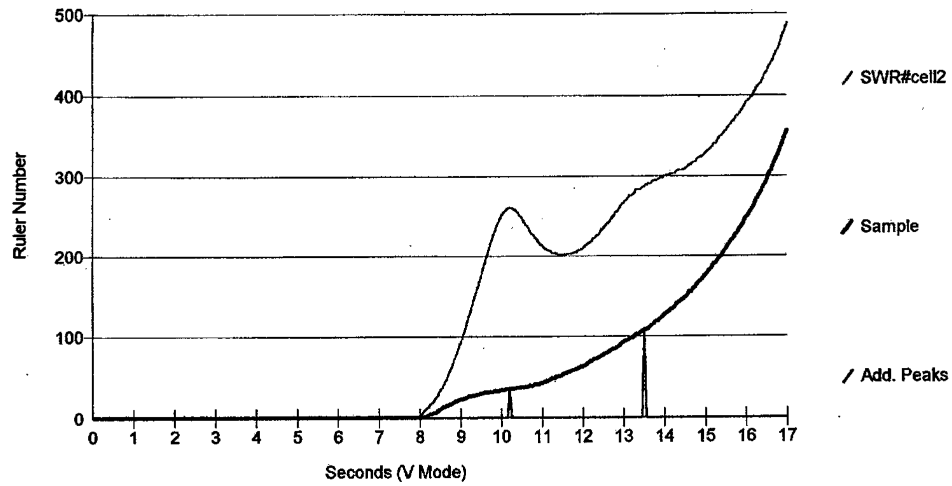

Figure 15. PEO, 70 hours

Table 26. RULER Results

	Corrosion Test Ratings	
	20 hours	**70 hours**
AN	4.3	6.0
SW	2.7	3.3
HC	1.0	1.3
RULER, Additive Remaining		
Area 1	65%	13%
Area 2	71%	38%

In this brief study, the RULER predicted reduced lubricant remaining life for each additive area with increasing test hours; however, it was not definitive for predicting corrosion protection. A concurrent investigation using FT-IR looked more promising and was emphasized. Additional investigation using the ruler might produce definitive results.

E. FT-IR Investigations

Fourier Transform Infrared Analysis (FT-IR) was investigated as a potential method for determining remaining corrosion protection in used PEO. The envisioned method was based on the hypothesis that measuring preservative oil additive concentration in new and used lubricants will define the fraction of the expended preservative protection or the "remaining life" of these lubricants. It was expected that FT-IR spectroscopy would provide such data. Figure 16 shows FT-IR traces for the PEO additive, a base oil, and the PEO additive minus the base oil. Figure 17 shows a trace of the PEO additive with key absorption frequencies identified.

Noting that the recommended dosage of the engine preservative lubricant additive is 2.2 wt%, calibration training set samples were prepared within the 0.0 to 3.0 wt% range of the additive in Grades 1 and 2 of SAE 30 base stocks and in fully formulated MIL-L-2104-F lubricants, derived from these base stocks, to represent finished MIL-L-21260-D engine preservative oils. (Grade 1 base stock: <90% saturated hydrocarbons, >0.03% sulfur; Grade 2 base stock: >90% saturated hydrocarbns, <0.03%sulfur.) FT-IR spectra were obtained from each sample. Using the PLSplus™ computer program within the GRAMS/32™ spectroscopic package, calibration models were built from the individual and combinations of calibration training sets, using various spectral ranges. The applied spectral ranges included the full wavenumber range of 4,000 to 650 cm^{-1}, and restricted ranges of (a) 1,500 to 1420 cm^{-1}, (b) 1,320 to 980 cm^{-1}, and 1275 to 790 cm^{-1}. Evaluations of these models were accomplished using validation samples of lubricants that were not part of the training sets. The results of this work are summarized in the following section.

Calibration statistics on these models are given in Table 27. Two sets of data are given, corresponding to the maximum in squared correlation coefficient, R^2, and those corresponding to a compromise value, defined at lower number of factors, yielding lower R^2. It has been argued that under the compromise conditions, better FT-IR values may result on unknown samples because the mathematical overfitting of the model is minimized. The compromise values were used for validation purposes.

Table 27. Calibration Summary for PEO Additive in Base Stocks and Finished Lubricants

Filename	Spectral Range cm^{-1}	F @ PRESS (min)			F @ $p \leq 0.75$		
		F	SEP (CV)	R^2	F	SEP (CV)	R^2
TM-GR1BS	4000-650	6	0.063	0.9968	5	0.072	0.9959
TM-GR2BS	4000-650	8	0.084	0.9944	6	0.096	0.9928
TMGR12BS	4000-650	11	0.080	0.9940	8	0.083	0.9935
TM2104-1	4000-650	8	0.112	0.9922	6	0.125	0.9902
TM2104-2	4000-650	6	0.102	0.9924	5	0.119	0.9893
12TM2104	4000-650	9	0.037	0.9989	8	0.040	0.9986
Master	4000-650	10	0.090	0.9923	10	0.090	0.9923
TM2104A1	1500-1420	8	0.260	0.9428	4	0.282	0.9350
TM2004A2	1500-1420	4	0.210	0.9617	4	0.210	0.9617
12TM210A	1500-1420	11	0.259	0.9388	10	0.272	0.9335
Master-1	1500-1420	18	0.227	0.9517	15	0.240	0.9457
12-2104A	1320-980	11	0.027	0.9993	7	0.029	0.9993
Master-2	1320-980	13	0.046	0.9980	12	0.048	0.9978
12-2104B	1275-790	13	0.028	0.9993	10	0.029	0.9993
Master-3	1275-790	16	0.044	0.9982	14	0.074	0.9979

The data indicate that restricting the spectral range to 1,500-1,420 cm^{-1}, inferior calibration statistics result. Using any of the other frequency ranges, each of the calibration models provide very low calibration error, as expressed by low error, SEP(CV), and excellent scatter, R^2, values of the FT-IR data around the actual preservative additive concentrations. The maximum of the SEP(CV) error is below 0.12 wt% of the additive, while the minimum of indicated R^2 is greater than 0.98 (Figure 16).

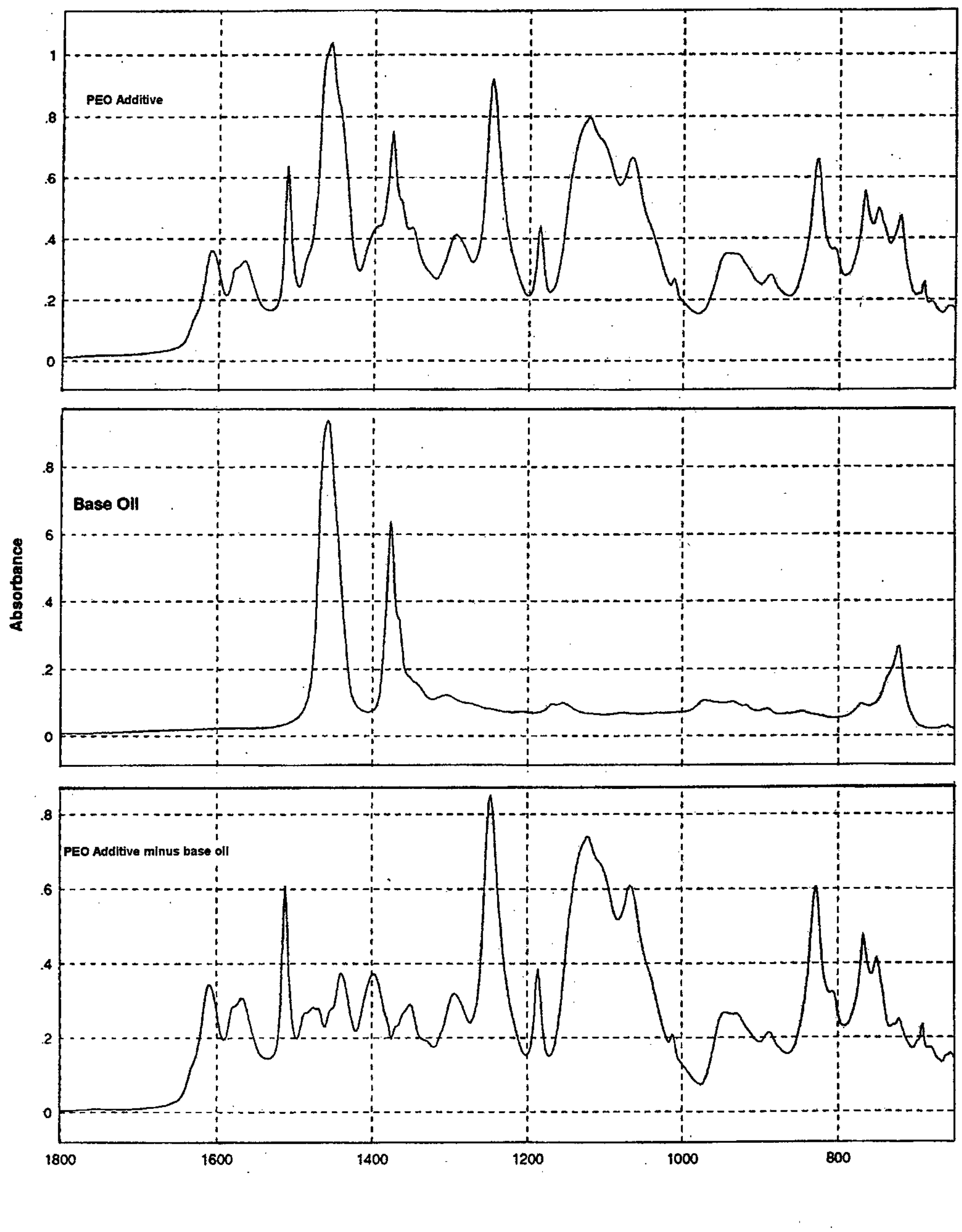

Figure 16. FT-IR Traces

Validation experiments were carried out for each of the calibration models using seven fully formulated MIL-L-21260 lubricants procured from various sources. Table 28 is a validation summary for the models. Throughout this table, the asterisks (*) indicate outlier data, as identified by the PLSplus program. The program considers a predicted value an outlier for samples that have probabilities greater than 99% (or 0.99) that are more than 3 standard deviations away from the rest of the population. The program applies the F-test to the spectral residuals to check that it is statistically similar to the training set data of the model. Samples that have F-test values greater than 0.99 are identified as outliers.

Table 28. FT-IR Predicted PEO Additive Concentrations in New MIL-L-21260 Preservative Engine Oils, Using Various Calibration Models

(A) Models Using SAE 30 Grades 1 & 2 Base Stocks Spectral range: 4000-650 cm^{-1}

Oil Samples	Spectral Range, cm^{-1}	Predicted Values, wt%, by Models		
		TMGR1BS	TMGR2BS	TMGR12BS
18955	4000-650	6.52*	6.23*	3.71*
19026	4000-650	7.00*	6.81*	4.50*
23882	4000-650	9.28*	9.37*	7.79*
23883	4000-650	5.87*	7.70*	7.24*
24841	4000-650	5.93*	5.50*	3.54*
25063	4000-650	7.44*	6.80*	5.04*
25067	4000-650	6.86*	5.97*	4.30*

(B) Models Using SAE 30 Grades 1 & 2 Base Stocks & MIL-L-2104-F Lubricants Spectral range: 4000-650 cm^{-1}

Oil Samples	Spectral Range, cm^{-1}	Predicted Values, wt%, by Models			
		TM2104-1	TM2104-2	12TM2104	Master
18955	4000-650	3.72*	5.30*	2.93*	2.17*
19026	4000-650	4.14*	5.64*	3.68*	2.93*
23882	4000-650	2.24	4.81*	2.43	2.56
23883	4000-650	0.84*	2.16	2.45	2.45
24841	4000-650	2.07	4.27*	1.96*	1.76*
25063	4000-650	3.05	5.50*	3.06*	2.94*
25067	4000-650	2.74*	5.13*	2.45*	2.49*

(C) Models Using SAE 30 Grades 1 & 2 Base Stocks & MIL-L-2104-F Lubricants Spectral range: 1500-1420 cm^{-1}

Oil Samples	Spectral Range, cm^{-1}	Predicted Values, wt%, by Models			
		TM2104A1	TM2104A2	12TM210A	Master-1
18955	1500-1420	-1.73*	14.66*	5.11*	7.81*
19026	1500-1420	-0.73*	14.93*	6.50*	7.03*
23882	1500-1420	-2.44	9.35*	2.43	2.70*
23883	1500-1420	-4.66*	1.49	1.85	2.86
24841	1500-1420	1.64*	18.39*	3.28*	6.06*
25063	1500-1420	0.33	17.71*	3.29	5.83*
25067	1500-1420	0.56*	16.66*	3.37*	7.22*

Table 28. FT-IR Predicted PEO Additive Concentrations in New MIL-L-21260 Preservative Engine Oils, Using Various Calibration Models (cont'd)

(D) Models Using SAE 30 Grades 1 & 2 Base Stocks & MIL-L-2104-F Lubricants Spectral range: 1320-980 cm^{-1}

Oil Samples	Spectral Range, cm^{-1}	Predicted Values, wt%, by Models 12-2104A	Master-2
18955	1320-980	2.87*	4.53*
19026	1320-980	2.93*	4.20*
23882	1320-980	2.26*	2.26*
23883	1320-980	2.22*	2.40*
24841	1320-980	2.83*	4.56*
25063	1320-980	2.39*	3.82*
25067	1320-980	6.34*	4.92*

(E) Models Using SAE 30 Grades 1 & 2 Base Stocks & MIL-L-2104-F Lubricants Spectral range: 1275-780 cm^{-1}

Oil Samples	Spectral Range, cm^{-1}	Predicted Values, wt%, by Models 12-2104B	Master-3
18955	1275-790	2.31*	4.16*
19026	1275-790	2.22*	4.12*
23882	1275-790	2.08*	2.26*
23883	1275-790	2.13*	2.39*
24841	1275-790	2.13*	3.81*
25063	1275-790	1.82*	3.12*
25067	1275-790	2.89*	4.18*

Notes:
TM-GR1BS: PEO Additive in OS-119596 SAE 30 base stock, grade 1 (4000-650 cm^{-1})
TM-GR2BS: PEO Additive in OS-119597 SAE 30 base stock, grade 2 (4000-650 cm^{-1})
TMGR12BS: Combination of TM-GR1BS & TM-GR2BS (4000-650 cm^{-1})
TM2104-1: PEO Additive in OS-119599 SAE 30 MIL-L-2104-F lubricant, grade 1 (4000-650 cm^{-1})
TM2104-2: PEO Additive in OS-119600 SAE 30 MIL-L-2104-F lubricant, grade 2 (4000-650 cm^{-1})
12TM2104: Combination of TM2104-1 & TM2102-2 (4000-650 cm^{-1})
Master: Combination of TMGR12BS & 12TM2104 (4000-650 cm^{-1})
TM2104A1: As TM2104-1 (1500-1420 cm^{-1})
TM2104A2 As TM2104-2 (1500-1420 cm^{-1})
Master-1: As Master (1500-1420 cm^{-1})
12-2104A: As 12TM2104, (1320-980 cm^{-1})
Master-2: As Master (1320-980 cm^{-1})
12-2104B: As 12TM2104, (1275-790 cm^{-1})
Master-3: As Master (1275-790 cm^{-1})
Grade 1 base stock: <90% saturated hydrocarbons; >0.03% sulfur
Grade 2 base stock: >90% saturated hydrocarbons; <0.03% sulfur
• data outliers as determined by PLSplus program
Recommended (expected) PEO additive concentration = 2.2wt%

The following paragraphs briefly discuss results of the validation data in order of presentation .

1. Models based on the full FT-IR spectra (4,000-650 cm^{-1}) of samples on PEO additive in SAE 30 Grades 1 & 2 base stocks (TMGR1BS and TMGR2BS) and their combinations (TMGR12BS) yielded uniformly bad data as the predicted values were substantially above the expected 2.2 wt% of additive content. The program identified each of the validation samples as outliers.

2. Models based on the full FT-IR spectra (4,000-650 cm^{-1}) of samples on PEO additive in SAE 30 Grades 1 & 2 MIL-L-2104-F lubricants (derived from the base stocks above) yielded improved values for the additive contents of the fully formulated MIL-PRF-21260 oils. Note, model TM2104-1 predicted 2.24 wt% of additive in sample 23882, and the sample was not identified as an outlier. Similarly, model TM2104-2 predicted 2.16 wt% of additive content in sample 23883; this sample was not identified as an outlier either. These two validation samples were derived from components in the training sets: TM2104-1 used SAE 30 Grade 1 MIL-L-2104-F components, while TM2104-2 used the corresponding Grade 2 oil. It was concluded that sample 23882 is a Grade 1 preservative engine oil, while 23883 is a Grade 2 product. These conclusions were confirmed by information from the manufacturer.

The model designated as 12TM2104 is a combination of TM2104-1 and TM2104-2, while the "Master" model is a combination of 12TM2104 and TMGR12BS. While these various models gave similar but not identical results on these samples, both of these combination models yielded "non-outlier" additive concentration data on samples 23882 and 23883. The FT-IR predicted concentration data on the other validation samples were close to the expected range of values. However, the composition of the other validation samples was sufficiently different that the program identified those as outliers.

3. Models using the restricted wavenumber range of 1,500-1,420 cm^{-1}, identified as C-H deformation frequencies, gave confusing and inferior predicted values. Such results may be due to interference(s) by the base stocks or by other components of these lubricants.

4. Models using the combined components of Grades 1 & 2 of the SAE 30 MIL-L-2104-F products, within the restricted wavenumber range of 1,320-980 cm^{-1}, gave encouraging results in six out of seven validation samples, although all of these data were identified as outliers. In comparison, the combined model, which included not only the components of the two finished lubricants but also those of the two base stocks, gave higher than expected, *i.e.*, inferior results.

5. The most encouraging results were obtained on the PEO additive contents of the validation samples, when the model was based on components of Grades 1 & 2 of the SAE 30 MIL-L-2104-F products within the wavenumber range of 1,275-790 cm^{-1}, thus including those frequencies where the

base stocks have little or no contribution to the spectra. Interestingly, while all results under calibration model 12-2104B were identified as outliers, all these data were in the expected range of values. The reason(s) for this apparent anomaly are unknown.

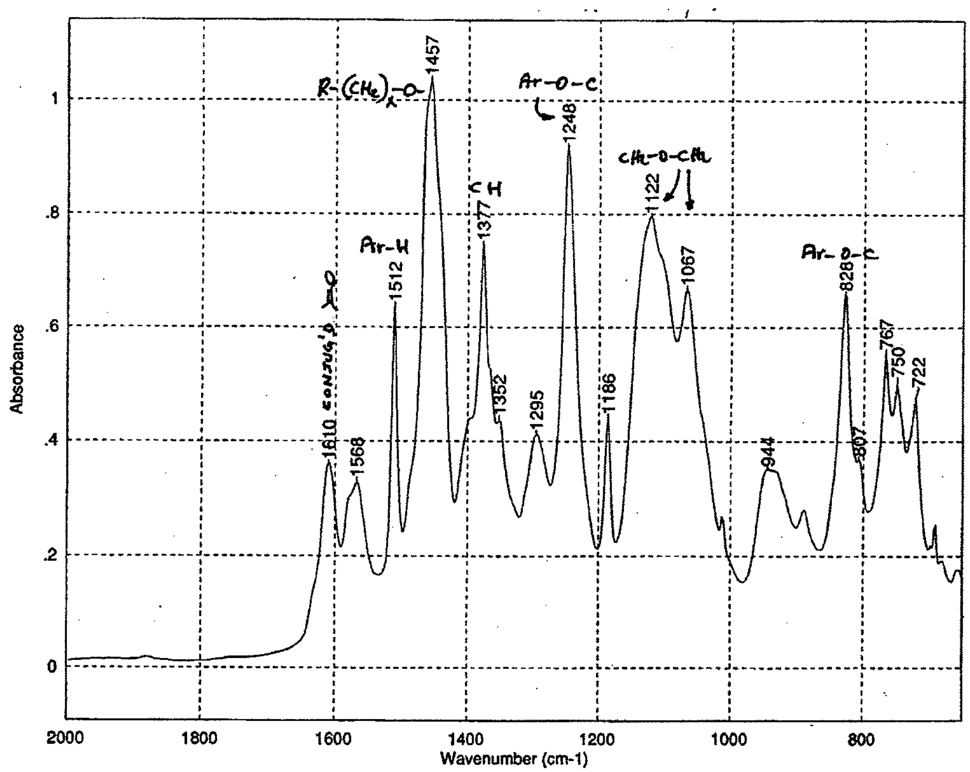

Figure 17. PEO Additive Absorptions

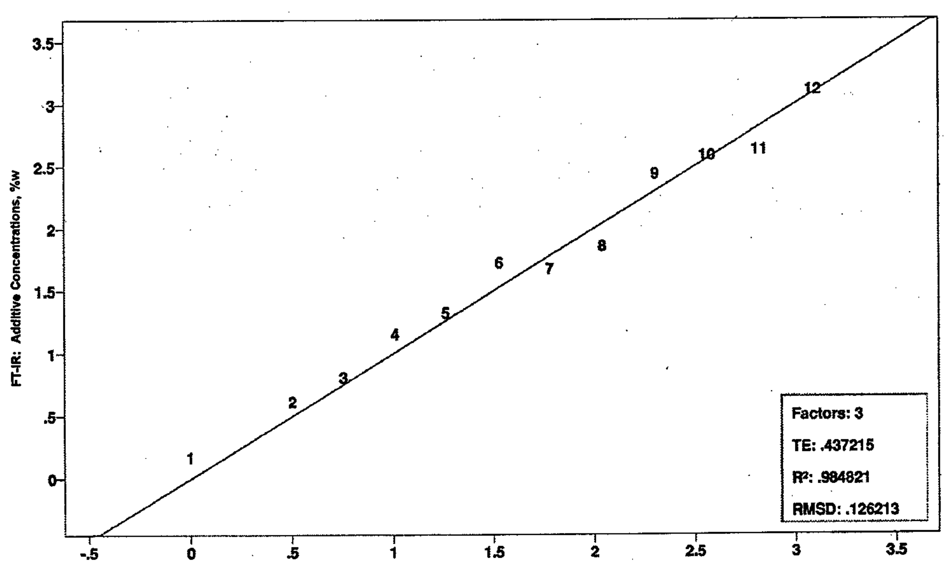

Figure 18. Calibration for PEO Additive in SAE 30 Group 1 Base Stock

VI. FT-IR ANALYSIS OF USED PEO SAMPLES

FT-IR traces were obtained for the used PEO samples from the following sources:

- PEO aged in the 1996 Pickup Truck
- PEO aged in the 6.2L diesel engine
- PEO aged in the 6V53T engine
- PEO aged in service by USMC, Blount Island, Fl
- PEO aged in Field Demonstration at Ft. Bliss, Tx
- PEO aged in the laboratory under accelerated conditions

FT-IR provides excellent prediction of the PEO additive concentration in new, unused PEO. PEO additive concentration in used PEO was confounded by interfering absorptions. No correlation was found between FT-IR of used PEO and performance of used PEO in the three bench tests.

A. Accelerated Aging of PEO

To accelerate evaluations of PEO lubricants, accelerated laboratory tests were performed on two MIL-PRF-21260D preservative engine oils (23882 and 23883) that were prepared from Grades 1 and 2 base stocks, respectively. Components of these lubricants were used earlier to develop the various calibration models to measure the PEO additive in these products. Accelerated tests were conducted to relate the results of the rapid laboratory tests to the operating engines. The preservative oil samples were stressed at 150°C for over 20 hours in the laboratory under oxygen atmosphere. The stressed samples were quenched, the oxygen consumed during the stress periods and the lubricants' TBNs were measured, and the samples' resistance to corrosion was evaluated and their FT-IR spectra were collected.

The accelerated test results indicate good correlations between actual and FT-IR predicted stress duration (minutes or hours) and oxygen consumption (micromoles) by the lubricant samples. Correlation between the measured and predicted TBN results were poor, as indicated by the relatively high error, SEP(CV), and low correlation, R^2, values (Table 29). During the approximately 20 hours of oxidative stress, the samples' TBN decreased from about 7 to about 3 mg KOH/g. Table 30 summarizes these samples, their stress periods and analytical data. Note, during these oxidation experiments lubricant No. 23882 used more oxygen and had lower TBN values than lubricant No. 23883. This may result from the compositional differences between the two base stocks; the more aromatic, higher sulfur containing No. 23882 is more susceptible to oxidation than the more paraffinic, lower sulfur content No. 23883. Figure 19 compares the raw oxygen consumption data.

Table 29. Calibration Summary for Stress Samples of Preservative Engine Oil Nos. 23882 and 23883

	F @ PRESS (min)			Calibration (F @ $p \leq 0.75$)		
Property	**F**	**SEP (CV)**	**R^2**	**F**	**SEP (CV)**	**R^2**
stress time, minutes	5	55.85	0.9811	4	64.56	0.9749
oxygen pickup, µmole	5	10.56	0.9767	4	12.36	0.9675
total base number	3	0.78	0.8112	2	0.81	0.7924

Notes:
MIL-PRF-21260D, SAE 30 preservative engine oils:
No. 23882 from Grade 1 base stock
No. 23883 from Grade 2 base stocks
PRESS predicted residual sum of squares
SEP(CV) standard error of prediction, cross validated
F factors = terms in equation to model property
p F-statistic probability
R^2 squared correlation coefficient

Table 30. Preservative Oils Stressed at 150°C Under Oxygen

Lubricant ID	Sample ID	Stress time minutes	O^2 µmole	TBN[a] mg KOH/g	S.W.	Humidity Cabinet
23880	23880	na	na	7.87	2P	2F
23882	DN33	0	0.00	7.30	2P	2P
	DN34	122	15.03	7.70	2P	2P
	DN35	240	52.80	7.28	2P	2P
	DN36	371	71.79	6.33	2P	2P
	DN37	484	95.84	6.32	2P	2P
	DN38	602	116.34	4.28	2P	2P
	DN39	724	131.09	4.50	2P	2P
	DN40	856	156.48	4.01	2P	2P
	DN41	981	175.57	3.60	2P	2P
	DN42	1095	189.55	3.25	1P/1F	2P
	DN43	1225	202.92	3.00	1P/1F	2P
23881	23881	na	na	7.37	2P	2F
23883	DN44	0	0.00	7.26	2P	2P
	DN45	123	21.27	6.85	2P	2P
	DN46	254	40.73	6.99	2P	2P
	DN47	366	58.39	6.61	2P	2P
	DN48	480	68.05	6.37	2P	2P
	DN49	596	81.64	6.43	2P	2P
	DN50	712	95.19	4.23	2P	2P
	DN51	848	110.94	3.83	2P	2P
	DN52	972	125.51	3.77	2P	2P
	DN53	1085	134.45	3.41	2P	2P
	DN54	1205	143.93	3.28	2P	2P

Notes:
23880 MIL-L-2104-F precursor of MIL-PRF-21260-D lubricant No. 23882
23881 MIL-L-2104-F precursor of MIL-PRF-21260-D lubricant No. 23883
a total base number
b corrosion protection test by salt-water immersion method
result code: XY, where X=number of sides of specimen; Y=Pass or Fail
c corrosion protection test by humidity cabinet method

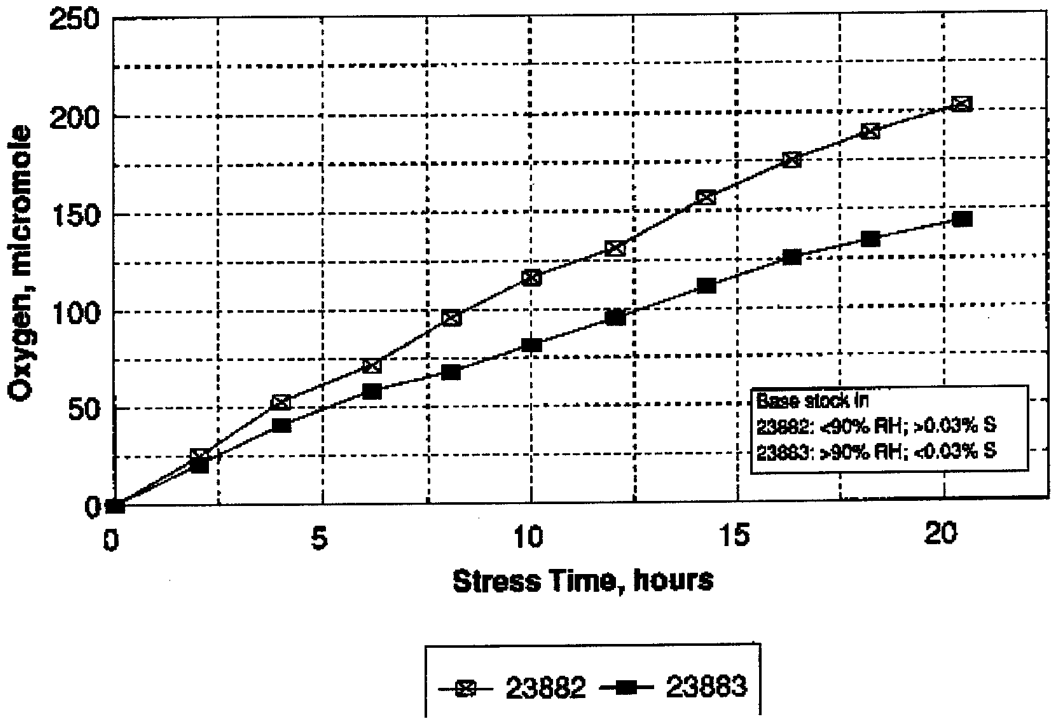

Figure 19. Oxygen Consumption of MIL-PRF-21260-D Preservative Oils at 150°C

It was expected that during the laboratory stressing of the preservative engine oil at 150°C under oxygen, as the samples' TBN values decreased, the PEO additive concentration would also decrease. As noted earlier, FT-IR calibration models for PEO additive in Grades 1 and 2 SAE 30 base stocks and in the corresponding MIL-L-2104-F lubricants (procured from the manufacturer of this additive) have already been developed. When the artificially aged samples were used as validation samples for the various FT-IR models for the determination of PEO additive concentrations, the results were inconclusive. While the calibration model using the 1,275-790 cm^{-1} spectral region gave additive concentration values in the expected range, all these predicted values were identified as "outliers," *i.e.*, suspect to be unreliable values by the computer program. Additionally, most predicted values increased with increasing stress duration, an absurd conclusion. Apparently, these lubricants produce oxidation products that interfere with measurements of PEO additive as measured by FT-IR models.

The SW and HC tests were used to evaluate teh performance of these new and stressed lubricants. Four unoxidized lubricants were used to provide a baseline for the corrosion protection tests: two fully formulated MIL-PRF-21260-D lubricants (Nos. 23882 and 23883), and the corresponding MIL-L-

2104-F products that were identical to these samples, except that they did not contain the preservative additive (Nos. 23880 and 23881).

All four unoxidized products passed the SW test. In the HC test, the MIL-L-2104-F lubricants failed after six hours of exposure, in contrast to MIL-L-21260-D lubricants that passed this test even after 30 days of exposure in the cabinet.

All oxidized samples of lubricant No. 23882 passed the SW if oxidized up to 16 hours, failing on one side only after 18 hours of oxidation. All samples of No. 23883 passed this test. According to the HC results, the severe oxidation applied to these samples did not reduce their corrosion protection capabilities. This finding indicates that, under the applied experimental condition and duration, corrosion protection does not seem to be substantially affected by the oxidation of these samples. Longer oxidative stress periods may further reduce the TBN values, which might result in loss of corrosion protection.

Results of this investigation indicate the following:

- Excellent calibration models may be obtained to quantitatively determine the concentration of preservative engine oil additive in various base stocks and finished products.
- Using the FT-IR spectral range of 1,275-790 cm^{-1} provided the best calibration models.
- The calibration models gave more precise data if the models were derived from the same components as those of the unknown lubricant, *i.e.*, these models should be used under trend-analysis conditions instead of using them for the analysis of random field samples.
- Oxidation of these products at 150°C under oxygen for up to about 20 hours reduces the TBN values from about 7 to about 3 mg KOH/g of sample, but does not seem to affect the corrosion protection provided by these lubricants, as determined by SW or HC tests. However, extended oxidation with resultant further reduction in TBN values may cause reduction in corrosion protection that these lubricants provide, thus providing correlatable data.
- Available engine test data do not correlate with FT-IR data.

Previous thermal aging of preservative oils AL-23882-L and AL-23883-L in pure oxygen at 150°C for up to 50 hours had little or no effect on the oil's corrosion protection capability. As a result, a longer oxidative stress period was proposed for evaluating the stability of the corrosion inhibiting additive. Samples of the preservative oil AL-24841-L were stressed at 150°C in pure oxygen for 162 hours. Samples were withdrawn from the reactor at regular time intervals over the 162 hour stress period. Ten 5 mL oil samples were sealed in 14.5 mL glass ampules with head space consisting of pure oxygen. The glass ampules were purged with oxygen, cocked. They were flame sealed immediately upon removal of the cork. The ampules were stressed in an isothermal reactor at 150°C . Ampules were removed from the reactor every 16 hours (average time interval) for the duration of the test. Oxygen consumption in each sample was determined by measuring the pressure inside the ampule. The pressure change was assumed to be proportional to the amount of oxygen consumed. Table 31 shows oxygen consumed, change in TBN, and the HC and SW tests with stress duration.

Table 31. Preservative Oil AL-24841-L Stressed at 150oC Under an Oxygen Atmosphere

Time (Hours)	TBN, D4739 mg KOH/gr.	Oxygen Consumed Micromoles	Humidity Cabinet	Humidity Cabinet Rating	Sea Water Immersion Test Rating	Sea Water Immersion Test Rating
0	8.08	0	1P/1F	2.0	2-P	1.0
19.5	1.99	206.6	2F	7.5	2-P	2.0
30.0	1.48	232.7	2F	9.0	2-P	2.0
43.0	1.27	243.7	2F	9.0	2-F	3.5
54.0	1.40	249.2	2F	9.0	2-F	7.0
67.5	0.99	240.4	2F	9.0	2-F	4.0
82.0	1.20	239.9	2F	9.0	2-F	8.0
95.0	1.27	237.2	2F	9.0	1-P/1-F	5.0
108.7	0.97	231.1	2F	9.0	2-F	5.0
132.2	1.25	232.8	2F	9.0	1-P/1-F	4.5
162.9	0.98	225.1	2F	8.5	2-F	7.5
P=Passed Test, F=Failed Test, Tests were performed in duplicate						

Previous stressing experiments on preservative oil have shown that oxygen consumption is relatively linear in the first 15 to 20 hours at 150°C. Beyond 20 hours, oxygen uptake slows down and essentially stops. The total available oxygen in an ampule was about 370 micromoles, so the oxidation essentially ceased after about 64 percent of the oxygen was consumed. It is believed that oxidation inhibitors produced during the oxidative stress are responsible for slowing the rate of oxidation.

Table 31 also shows TBN decreasing from 8 to 2 in the first 20 hours of oxidative stress. It appears that the alkali additives in the oil are neutralized by carboxylic acids formed from oxidative stressing. While the alkali additives were essentially depleted in 20 hours, the oil still passed the SW test after 30 hours of oxidative stress. The HC test failed after 20 hours of oxidative stress, suggesting that the zinc corrosion inhibitor could not prevent corrosion after the TBN dropped below 2. On the other hand, according to the SW test, the corrosion inhibitor continues to prevent corrosion well after the TBN falls below 2.

The conclusion of this experiment is that the corrosion inhibitor has a limited life of about 30 hours when the oil is stressed at 150°C. It is still unknown whether failure is caused by decomposition of the corrosion inhibitor or an overwhelming acid buildup in the oil.

VII. FIELD VALIDATION INVESTIGATIONS

The corrosion protection performance of MIL-PRF-21260 oil was determined from two field locations. Two series of used PEO samples were provided by the USMC from equipment stored on-board ships. Additionally, a controlled field validation test of PEO was conducted at Ft. Bliss, Tx.

A. USMC Samples

1. Batch 1 – Thirty used engine oil samples were received from the U.S. Marine Corps Pre-positioned ship refurbishing facility at Blount Island, FL (Batch #1, AL-24960 through AL-24989). Blount Island personnel obtained the samples form a variety of tactical and combat equipment (as shown in Table 32). The samples were analyzed at the TFLRF laboratory to determine their remaining preservation qualities. Table 33 contains the analyses, while Table 34 contains the panel ratings for the corrosion tests. Sample 16 (AL-24975) had only 1308 ppm Zn, somewhat low for PEO.

2. Batch 2 – A second batch of 30 used oil samples were received from Blount Island. The samples were obtained from 30 engines, 9 powershift (PS) transmissions, and 1 turbohydramatic (THM) transmission (Table 35) Elemental analyses were conducted on the samples to determine if preservative engine oil (PEO) appeared to be used (Table 36). PEO can be identified by its zinc content (usually > 1500 ppm). The 30 used oil samples were split into three groups based on their zinc content. Group 1 had zinc content that was typical of PEO (14 samples). Group 2 had a zinc content that was questionable (6 samples), and Group 3 had too low a zinc content to be PEO (10 samples). Results of the PEO corrosion bench tests are presented in Table 37. Of the Group 1 samples, 12 passed 2 or 3 of the 3 PEO bench tests, while 2 samples failed. Of the Group 2 (questionable PEO) samples, 1 passed and 5 failed the PEO bench tests. Of the Group 3 (low zinc) samples, all 10 failed 2 or 3 of the 3 PEO bench tests. Four of the Group 1 samples were from PS transmissions, and all passed the PEO bench tests. From Group 3 (low zinc), 4 PS transmission samples and the lone THM sample failed the PEO bench tests. Overall, equipment lubricated with PEO retained its preservation properties, while samples with low zinc content failed the PEO bench tests.

Table 32. Sample Identity

Chemistry Lab Report Sheet
Blount Island, Fla. Batch #1

WO #18346
Project #02-5137-582

Statistics On Blount Used Oil Samples

Oil Number	Equipment Model	Equipment Serial Number	End Item Model	End Item Serial Number	Date Taken	Type Oil	Miles/Hours
1 AL 24960 L	VT 400 903 cu in	522347	E0796		June 25, 1997	Engine	
2 AL 24961 L	VT 400 903 cu in	11175310	522597	522597	June 25, 1997	Engine	
3 AL 24962 L	VT 400 903 cu in	522677		11229613		Engine	
4 AL 24963 L	VT 400 903 cu in	11107047	522691	522691	June 25, 1997	Engine	
5 AL 24964 L	VT 400 903 cu in	11113743	522723		June 25, 1997	Engine	
6 AL 24965 L	VT 400 903 cu in	11296421		523323	June 25, 1997	Engine	
7 AL 24966 L	MLULL 10K	ENG 308825	GOM10FZ-179	USMC 571432	June 25, 1997		176 hr
8 AL 24967 L	MLULL 10K	ENG 329656	LOM10F7-404	USMC 571657	June 25, 1997		124 hr
9 AL 24968 L	MLULL 10K	ENG 333869	LOM10F7-428	USMC 571081	June 25, 1997		36 hr
10 AL 24969 L	MLULL 10K	ENG 335005	AIM10F7-455	USMC	June 25, 1997		118 hr
11 AL 24970 L	MLULL 10K	ENG 334895	AIM10F7-467	USMC 571720	June 25, 1997		44 hr
12 AL 24971 L	MLULL 10K	ENG 336952	AIM10F7-507	USMC 571760	June 25, 1997		220 hr
13 AL 24972 L	MLULL 10K	ENG 336620	AIM10F7-508	USMC 571761	June 25, 1997		37 hr
14 AL 24973 L	MLULL 10K	ENG 336953	BIM10F7-512	USMC 571765			113 hr
15 AL 24974 L	Detroit Silver	08VF114725	MK-48	561160	June 25, 1997	15W40	50 mi
16 AL 24975 L	Detroit Silver	08VF120025	MK-48	563055	June 25, 1997	15W40	3914 mi
17 AL 24976 L	Detroit Silver	551073E	MK-48	551073	June 25, 1997	15W40	7911 mi
18 AL 24977 L	Detroit Silver	08VF116861	MK-48	525099	June 25, 1997	15W40	14646 mi
19 AL 24978 L	Detroit Silver	08VF113563	MK-48	551188	June 25, 1997	15W40	5290 mi
20 AL 24979 L	Cummin NHC 250	11121248	M923	530464	June 25, 1997	15W40	6882 mi
21 AL 24980 L	Cummin NHC 250	11059586	M923	516468	June 25, 1997	15W40	8314 mi
22 AL 24981 L	Cummin NHC 250	11060473	M923	530354	June 25, 1997	15W40	32314 mi
23 AL 24982 L	Cummin NHC 250	11203572	M929 WO/W	532795	June 25, 1997	15W40	3366 mi
24 AL 24983 L	Cummin NHC 250	11233158	M930 W/W	530963	June 25, 1997	15W40	7328 mi
25 AL 24984 L	6.2 Detroit	5HUM701	M998 WO/W	535023	June 25, 1997	15W40	18686 mi
26 AL 24985 L	6.2 Detroit	JJA1014	M998 WO/W	539189	June 25, 1997	15W40	18219 mi
27 AL 24986 L	6.2 Detroit	H029277	M998 WO/W	556153	June 25, 1997	15W40	1547 mi
28 AL 24987 L	6.2 Detroit	6HUMM911	M1044	546917	June 25, 1997	15W40	7190 mi
29 AL 24988 L	6.2 Detroit	H009316	M1046 W/W	544308	June 25, 1997	15W40	14845 mi
30 AL 24989 L	6.2 Detroit	H009278	M1046 W/W	544319	June 25, 1997	15W40	8007 mi

Table 33. Analysis of Batch #1 Samples
Chemistry Lab Report Sheet
Blount Island, Fla. Batch #1

WO #18346
Project #02-5137-582

	Sample	1 AL 24960 L	2 AL 24961 L	3 AL 24962 L	4 AL 24963 L	5 AL 24964 L	6 AL 24965 L	7 AL-24966 L	8 AL-24967 L	9 AL 24968 L	10 AL 24969 L
Humidity Cabinet Test	(30 days)	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass
Salt Water Corrosion		3 fail	1 pass/2 fail	2 pass/1 fail	3 pass	3 pass	3 passs	1 pass/2 fail	3 pass	3 pass	3 pass
Acid Neutralization Test		3 fail	3 fail	3 pass	3 fail	3 fail	3 fail	3 pass	3 pass	3 pass	3 pass
FTIR*	128 scan	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.
Viscosity @ 100°F	D-445	11.91	11.64	9.39	11.14	11.38	12.07	13.58	13.57	12.5	12.86
Total Acid Number	D-664	2.09	2.44	2.66	2.65	2.17	2.32	2.43	2.38	2.49	2.54
Total Base Number	D-4739	6.78	6.5	6.8	6.66	7.14	7.28	6.68	6.88	6.27	7.3
TGA Soot, wt%		0.2	0.2	0.1	0.2	0.1	0.1	0.2	0	0.1	0.2
Wear Metal Analysis	D-5185										
ICP 16 – Ca & Na	Ca	1386	1351	1445	1544	1420	1530	1558	1557	1522	1523
ppm	Mg	473	446	502	497	483	453	537	540	492	526
	P	1255	1266	1245	1295	1276	1327	1396	1411	1331	1366
	Zn	1633	1662	1769	1666	1727	1655	1797	1805	1660	1773
	Al	3	7	1	4	7	7	1	1	1	1
	B	6	49	3	42	9	36	11	12	11	13
	Ba	<1	1	<1	<1	<1	2	2	2	<1	2
	Cr	24	11	2	6	12	15	1	1	1	1
	Cu	538	131	158	82	456	425	5	6	6	7
	Fe	45	60	10	26	45	64	10	7	5	5
	Ni	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Pb	15	15	5	8	6	18	2	<1	<1	4
	Si	17	14	6	12	37	38	6	6	6	7
	Sn	2	<1	1	1	2	2	<1	<1	1	<1
	Na	22	14	16	16	22	41	23	21	23	17
	Mo	x	x	x	x	x	x	x	x	x	x
	Mn	x	x	x	x	x	x	x	x	x	x
	Sb	x	x	x	x	x	x	x	x	x	x
	Ag	x	x	x	x	x	x	x	x	x	x
	S, %wt.	0.683	0.573	0.728	0.6	0.719	0.642	1.135	1.094	0.078	1.044

Table 33. Analysis of Batch #1 Samples
Chemistry Lab Report Sheet
Blount Island, Fla. Batch #1

WO #18346
Project #02-5137-582

	Sample	11 **AL 24970 L**	12 **AL 24971 L**	13 **AL 24972 L**	14 **AL 24973 L**	15 **AL 24974 L**	16 **AL 24975 L**	17 **AL-24976 L**	18 **AL-24977 L**	19 **AL 24978 L**	20 **AL 24979 L**
Humidity Cabinet Test	(30 days)	3 pass	3 pass	3 pass	3 pass	3 pass	3 fail	2 pass/1 fail	3 pass	3 fail	3 pass
Salt Water Corrosion		3 pass	3 pass	3 pass	3 pass	2 pass/1 fail	3 fail	3 pass	1 pass/2 fail	3 fail	3 pass
Acid Neutralization Test		3 pass	1 pass/2 fail	3 pass	3 pass	3 fail	3 fail	3 fail	3 fail	3 fail	3 pass
FTIR*	128 scan	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.
Viscosity @ 100°F	D-445	12.88	12.97	13.08	13.12	9.72	12.38	11.9	12.06	11.19	11.63
Total Acid Number	D-664	2.67	2.64	2.47	2.53	2.66	2.11	2.42	2.76	2.81	2.74
Total Base Number	D-4739	6.37	6.63	6.26	6.11	6.11	4.98	6.02	5.53	6.81	6.62
TGA Soot, wt%		0.1	0.2	0.1	0.2	0.2	0.4	0.1	0.2	0.1	0.2
Wear Metal Analysis	D-5185										
ICP 16 – Ca & Na	Ca	1480	1532	1466	1495	1454	1117	1466	1550	1624	1504
ppm	Mg	485	529	470	536	521	458	492	489	546	517
	P	1304	1348	1255	1329	1290	12.76	12.99	12.4	1377	1329
	Zn	1680	1779	1666	1770	1747	1308	1706	1745	1520	1831
	Al	1	1	1	1	2	3	2	3	1	1
	B	12	12	12	10	4	5	4	<1	1	3
	Ba	<1	2	<1	2	16	2	2	<1	<1	1
	Cr	<1	<1	1	1	4	2	4	3	2	<1
	Cu	5	4	5	6	157	187	140	27	11	7
	Fe	6	9	6	6	66	71	56	82	54	6
	Ni	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Pb	<1	2	1	<1	28	10	30	10	8	7
	Si	7	5	6	6	17	23	57	16	20	8
	Sn	<1	<1	<1	2	3	4	22	4	3	1
	Na	21	19	21	18	18	15	28	13	11	18
	Mo	x	x	x	x	x	x	x	x	x	x
	Mn	x	x	x	x	x	x	x	x	x	x
	Sb	x	x	x	x	x	x	x	x	x	x
	Ag	x	x	x	x	x	x	x	x	x	x
	S, %wt.	0.708	1.037	0.712	1.022	0.512	0.759	0.742	0.78	0.799	1.133

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Table 33. Analysis of Batch #1 Samples
Chemistry Lab Report Sheet
Blount Island, Fla. Batch #1

	Sample	21 AL 24980 L	22 AL 24981 L	23 AL 24982 L	24 AL 24983 L	25 AL 24984 L	26 AL 24985 L	27 AL-24986 L	28 AL-24987 L	29 AL 24988 L	30 AL 24989 L
Humidity Cabinet Test	(30 days)	3 pass	3 fail	3 fail	3 fail	3 pass	3 fail	3 fail	3 fail	3 fail	3 fail
Salt Water Corrosion		3 pass	3 fail	3 fail	3 fail	3 pass	3 pass	3 pass	2 pass/1 fail	3 pass	3 pass
Acid Neutralization Test		3 pass	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail
FTIR*	128 scan	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.	9-30-97 B.G.
Viscosity @ 100°F	D-445	12.00	11.42	11.55	11.71	14.17	12.79	11.82	11.88	12.94	11.64
Total Acid Number	D-664	2.67	2.87	2.79	2.82	2.82	2.77	2.64	2.64	2.38	2.64
Total Base Number	D-4739	7.08	6.33	6.45	6.55	5.96	6.44	6.57	6.69	6.28	5.35
TGA Soot, wt%		0	0.2	0	0.2	0.1	0.2	0.1	0.2	0.3	0.3
Wear Metal Analysis	D-5185										
ICP 16 – Ca & Na	Ca	1510	1498	1511	1492	1446	1442	1632	1567	1765	1517
ppm	Mg	513	547	547	549	530	546	554	547	542	617
	P	1361	1473	1500	1460	1256	1239	1412	1426	1378	1403
	Zn	1825	1559	1559	1581	1710	1768	1592	1679	1563	1557
	Al	2	1	1	2	2	4	3	2	44	2
	B	13	3	<1	3	1	4	14	<1	6	8
	Ba	1	<1	<1	<1	1	1	1	1	7	<1
	Cr	1	<1	1	1	1	4	2	3	7	2
	Cu	6	7	4	5	25	12	7	7	10	7
	Fe	7	6	7	6	29	43	37	29	113	28
	Ni	<1	<1	<1	<1	<1	<1	<1	<1	1	<1
	Pb	7	11	7	6	93	32	49	38	42	31
	Si	10	5	12	4	54	75	41	15	89	16
	Sn	<1	1	<1	<1	1	10	14	2	<1	2
	Na	17	12	13	22	64	14	14	18	18	10
	Mo	x	x	x	x	x	x	x	x	x	x
	Mn	x	x	x	x	x	x	x	x	x	x
	Sb	x	x	x	x	x	x	x	x	x	x
	Ag	x	x	x	x	x	x	x	x	x	x
	S, %wt.	1.122	0.796	0.795	0.777	0.771	0.755	0.761	0.82	0.81	0.806

Table 34. Preservative Oil Tests, USMC Batch #1

data	A	B	C	K	L	M	N	O	P	Q	R	S	T	U	V
1		**Preservative Oil Data Spreadsheet**													
2	Created: 10-14-97 mv														
3	Updated: 2-4-98 mv														
4															
5	**Work**			Corrosion Tests											
6	Instruction N	**Source**	**Sample**	HC				SW				AC			
7				1	2	3	avg	1	2	3	avg	1	2	3	avg
44															
45	18346	field sx	**24960**	2	1	1	1.3	3	3	3	3.0	4	4	4	4.0
46		(various AL-)	**24961**	1	1	1	1.0	4	4	2	3.3	5	5	5	5.0
47		Batch 1 USMC	**24962**	2	1	1	1.3	3	2	1	2.0	1	1	1	1.0
48		Blount Isl FLA	**24963**	1	1	1	1.0	2	1	1	1.3	4	4	5	4.3
49			**24964**	2	1	1	1.3	2	1	1	1.3	4	4	4	4.0
50			**24965**	1	1	1	1.0	2	1	2	1.7	4	4	4	4.0
51			**24966**	1	1	1	1.0	3	3	2	2.7	1	2	1	1.3
52			**24967**	1	1	1	1.0	1	1	1	1.0	1	1	1	1.0
53			**24968**	1	1	2	1.3	1	1	2	1.3	1	1	1	1.0
54			**24969**	1	1	1	1.0	1	1	1	1.0	2	2	1	1.7
55			**24970**	1	1	2	1.3	2	2	2	2.0	1	1	1	1.0
56			**24971**	1	2	2	1.7	1	3	1	1.7	2	3	4	3.0
57			**24972**	1	1	1	1.0	1	2	1	1.3	2	2	1	1.7
58			**24973**	1	2	1	1.3	3	2	2	2.3	4	4	4	4.0
59			**24974**	2	2	1	1.7	2	2	1	1.7	5	5	5	5.0
60			**24975**	9	9	9	9.0	9	9	9	9.0	9	9	9	9.0
61			**24976**	1	3	2	2.0	2	2	2	2.0	4	4	4	4.0
62			**24977**	1	1	1	1.0	3	3	1	2.3	4	4	4	4.0
63			**24978**	9	8	9	8.7	9	9	9	9.0	7	7	7	7.0
64			**24979**	1	1	1	1.0	1	1	1	1.0	1	1	1	1.0
65			**24980**	1	1	1	1.0	2	2	2	2.0	1	1	2	1.3
66			**24981**	9	9	9	9.0	7	7	7	7.0	6	6	6	6.0
67			**24982**	9	8	9	8.7	7	7	7	7.0	6	6	6	6.0
68			**24983**	8	8	8	8.0	7	7	7	7.0	6	6	6	6.0
69			**24984**	1	1	1	1.0	1	2	1	1.3	1	1	1	1.0
70			**24985**	2	2	1	1.7	1	1	1	1.0	5	4	4	4.3
71			**24986**	8	8	8	8.0	1	1	1	1.0	5	5	5	5.0
72			**24987**	8	8	8	8.0	2	2	2	2.0	6	6	6	6.0
73			**24988**	8	8	8	8.0	1	1	2	1.3	6	6	6	6.0
74			**24989**	8	8	4	6.7	2	1	1	1.3	7	7	7	7.0

Table 35. Sample Identity, Blount Island, Fla., Batch #2

Oil Number	Equipment Model	Component Serial Number	T.A.M.C.N.	U.S.M.C.	Date Taken	Hours/Miles	Comm.	Type Oil
1 AL-25095	Caterpillar/3306	49502527	B1045	R202408	Oct 20, 1997	0.9 hr	Engr.	PEO30
2 AL-25096	Allis-Cham/3500-A	3D-69115	B1016	MEP115A/R250613	Oct 20, 1997	0.5 hr	Engr.	PEO30
3 AL-25097	White/D298ER	B0953	B0953	MEP115A/R250613	Oct 20, 1997	0.2 hr	Engr.	PEO30
4 AL-25098	White/D298ER	B0953	B0953	MEP005A/R250534	Oct 20, 1997	0.8 hr	Engr.	PEO30
5 AL-25099	Trans/MK-48	2510102291	00209	551050	Oct 17, 1997	145 mi	Heavy	PEO10
6 AL-25100	Trans/MK-48	2510119976	00209	563390	Oct 17, 1997	143 mi	Heavy	PEO10
7 AL-25101	Trans/M923	2420105251	D1059	541024	Oct 17, 1997	346 mi	Medium	PEO10
8 AL-25102	Trans/M923A1	2420105248	D1059	541025	Oct 17, 1997	507 mi	Medium	15W40
9 AL-25103	Cummins/NHC250	11341878	D1059	541024	Oct 17, 1997	346 mi	Medium	15W40
10 AL-25104	Cummins/NHC250	11341716	D1059	541025	Oct 17, 1997	507 mi	Medium	15W40
11 AL-25105	6.2 Detroit/M998	H1121714	D1158	580991	Oct 17, 1997	1082 mi	Light	15W40
12 AL-25106	Detroit Silver 92/MK-48	08VF112337	D0209	551050	Oct 17, 1997	145 mi	Heavy	15W40
13 AL-25107	Detroit Silver 92/MK-48	08VF125577	D0209	563390	Oct 17, 1997	143 mi	Heavy	15W40
14 AL-25108	Lull/Mlull10K	ROM10F7-393	B2561	571646	Oct 17, 1997	32 hr	Engr.	15W40
15 AL-25109	Lull/Mlull		B2561	571395	Oct 17, 1997	37.7 mi	Engr.	15W40
16 AL-25110	Lull/Mlull10K	335391 (John Deere)	B2561	571772	Oct 17, 1997	45 hr	Engr.	15W40
17 AL-25111	John Deere/6359T		B2561	571908	Oct 17, 1997	30 hr	Engr.	15W40
18 AL-25112	John Deere/644612	RG-6076A 119254	B2567	568538	Oct 17, 1997		Engr.	15W40
19 AL-25113	J.I. Case/MC1155E	JAK0009861	B2464	572265	Oct 17, 1997	24 hr	Engr.	15W40
20 AL-25114	AAVP7A1	00724 Trans	E0846	522932	Oct 17, 1997	16/60	Ordnance	15W40
21 AL-25115	AAVP7A1	3M7198 Trans	E0846	522548	Oct 17, 1997	367 hr.70 mi	Ordnance	15W40
22 AL-25116	AAVP7A1	3M7446 Trans	E0846	523248	Oct 17, 1997	305 hr/1620 mi	Ordnance	15W40
23 AL-25117	AAVP7A1	11102341 Eng	E0846	522435	Oct 17, 1997	51 hr/340 mi	Ordnance	15W40
24 AL-25118	AAVP7A1	11177108 Eng	E0846	522706	Oct 17, 1997	52 hr/340 mi	Ordnance	15W40
25 AL-25119	AAVP7A1	11222099 Eng	E0846	522923	Oct 17, 1997	16/60	Ordnance	15W40
26 AL-25120	AAVP7A1	11180861 Eng	E0846	522548	Oct 17, 1997	367 hr/70 mi	Ordnance	15W40
27 AL-25121	AAVP7A1	3M7446 Trans	E0846	522706	Oct 17, 1997	52 hr/340 mi	Ordnance	15W40
28 AL-25122	AAVP7A1	00235 Trans	E0846	522435	Oct 17, 1997	51 hr/295 mi	Ordnance	15W40
29 AL-25123	AAVP7A1	37110676 Eng	E0846	523248	Oct 17, 1997	305 hr/1620	Ordnance	15W40
30 AL-25124	Trans/M998	89MAA48563	D1158	580911	Oct 17, 1997	1082 mi	Light	15W40

Table 36
Chemistry Lab Report Sheet
Blount Island, Fla. Batch #2

WO #18432
Project #02-5137-582

Report Date: 2-4-98	Sample	1 **AL 25095 L**	2 **AL 25096 L**	3 **AL 25097 L**	4 **AL 25098 L**	5 **AL 25099 L**	6 **AL 25100 L**	7 **AL-25101 L**	8 **AL-25102 L**	9 **AL 25103 L**	10 **AL 25104 L**
Acid Neutralization Test		3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail
Sea Water Corrosion		3 fail	3 fail	1 pass/2 fail	1 pass/2 fail	1 pass/2 fail	1 pass/2 fail	1 pass/2 fail	3 fail	3 fail	1 pass/2 fail
Humidity Cabinet Test	(30 days)	3 fail	3 fail	3 fail	2 pass-1 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail
FTIR Trace		25095	25096	25097	25098	25099	25100	25101	25102	25103	25104
ICP 16W plus Ca, Na	D-5185										
(Div 08)	Ca	1405	1513	1336	1874	966	1294	1103	1008	1275	243
	Mg	560	508	387	130	1146	461	288	306	565	1000
	P	1400	1365	1248	1075	1185	1139	958	934	1212	976
	Zn	1520	1525	1390	1535	1162	1227	967	908	1233	1130
	Al	2	9	2	2	3	2	3	3	1	1
	B	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Ba	1	1	3	1	<1	4	9	10	2	1
	Cr	1	1	1	1	<1	<1	1	1	1	1
	Cu	16	6	13	21	379	493	1036	1012	18	12
	Fe	5	9	14	21	36	8	27	33	11	10
	Ni	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Pb	5	1	13	9	1	1	7	7	16	9
	Si	6	7	7	6	6	6	5	5	5	4
	Sn	4	3	4	4	2	1	3	2	2	3
	Na	8	8	21	16	6	10	7	7	11	5
	Mo	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Mn	1	2	2	1	1	1	2	2	3	2
	Sb	<1	<1	<1	<1	<1	<1	<1	<1	<1	3
	Ag	<1	<1	<1	1	5	15	5	9	<1	<1

Table 36
Chemistry Lab Report Sheet
Blount Island, Fla. Batch #2

WO #18432
Project #02-5137-582

Report Date: 2-4-98	Sample	11 **AL 25105 L**	12 **AL 25106 L**	13 **AL 25107 L**	14 **AL 25108 L**	15 **AL 25109 L**	16 **AL 25110 L**	17 **AL-25111 L**	18 **AL-25112 L**	19 **AL 25113 L**	20 **AL 25114 L**
Acid Neutralization Test		3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail
Sea Water Corrosion		3 pass	3 pass	3 pass	3 fail	3 fail	3 fail	3 fail	3 pass	3 pass	3 pass
Humidity Cabinet Test	(30 days)	3 pass	3 pass	3 fail	3 fail	3 fail	3 fail	3 fail	3 fail	3 pass	3 fail
FTIR Trace		25105	25106	25107	25108	25109	25110	25111	25112	25113	25114
ICP 16W plus Ca, Na	D-5185										
(Div 08)	Ca	1259	1194	1400	1643	1560	1678	1529	1543	1477	745
	Mg	562	610	544	543	539	542	546	553	492	1084
	P	1183	1222	1376	970	942	974	1436	1446	1191	1172
	Zn	1689	1720	1486	1075	1040	1073	1547	1621	1729	1395
	Al	2	1	2	3	3	5	1	1	1	2
	B	4	<1	<1	72	69	73	<1	<1	<1	58
	Ba	<1	<1	<1	1	1	1	1	1	<1	1
	Cr	<1	2	1	1	1	1	<1	<1	<1	1
	Cu	11	37	43	18	23	32	2	47	1	201
	Fe	24	27	31	25	18	21	5	8	5	11
	Ni	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Pb	5	9	8	2	5	8	3	<1	<1	95
	Si	58	16	51	15	12	14	5	7	6	14
	Sn	5	3	8	5	2	4	4	1	3	<1
	Na	8	6	14	11	11	10	10	9	6	11
	Mo	<1	<1	<1	1	1	2	2	<1	1	<1
	Mn	1	1	1	2	2	2	<1	1	<1	<1
	Sb	<1	<1	<1	<1	<1	<1	<1	1	1	<1
	Ag	<1	<1	<1	<1	<1	<1	<1	<1	<1	1

Table 36
Chemistry Lab Report Sheet
Blount Island, Fla. Batch #2

WO #18432
Project #02-5137-582

Report Date: 2-4-98	Sample	21 **AL 25115 L**	22 **AL 25116 L**	23 **AL 25117 L**	24 **AL 25118 L**	25 **AL 25119 L**	26 **AL 25120 L**	27 **AL-25121 L**	28 **AL-25122 L**	29 **AL 25123 L**	30 **AL 25124 L**
Acid Neutralization Test		3 fail	3 pass	3 pass	3 pass	3 fail	3 pass	3 pass	1 pass/2 fail	3 pass	3 fail
Sea Water Corrosion		3 pass	3 pass	3 pass	3 pass	2 pass/1 fail	3 pass	3 pass	3 pass	3 pass	2 pass/1 fail
Humidity Cabinet Test	(30 days)	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass	3 pass	3 fail
FTIR Trace		25115	25116	25117	25118	25119	25120	25121	25122	25123	25124
ICP 16W plus Ca, Na	D-5185										
(Div 08)	Ca	1524	1495	1502	1564	1520	1399	1510	1409	1348	53
	Mg	574	550	537	521	536	521	518	516	474	3
	P	1363	1353	1302	1365	1322	1262	1366	1256	1159	577
	Zn	1744	1756	1903	1875	1613	1739	1841	1805	1635	301
	Al	3	6	5	2	6	2	2	3	1	1
	B	<1	<1	<1	<1	<1	<1	<1	<1	<1	118
	Ba	2	3	<1	<1	2	<1	1	<1	<1	1
	Cr	1	<1	6	7	12	4	<1	<1	4	<1
	Cu	257	652	178	392	543	323	166	137	43	93
	Fe	15	25	22	14	50	16	9	11	12	15
	Ni	<1	<1	<1	<1	<1	<1	<1	1	<1	<1
	Pb	127	77	6	10	5	15	165	43	4	6
	Si	14	21	7	18	11	8	11	9	12	9
	Sn	2	3	1	2	3	1	2	1	2	5
	Na	27	20	6	10	18	10	12	11	6	8
	Mo	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Mn	1	1	1	1	1	1	<1	<1	1	1
	Sb	<1	<1	<1	<1	<1	1	<1	1	<1	<1
	Ag	1	2	<1	<1	<1	<1	<1	1	<1	<1

Table 37. Preservative Oil Tests, USMC Batch #2

Sample	Test length/days	HC				SW				AC			
		1	2	3	avg	1	2	3	avg	1	2	3	avg
AL-25095	6	8	8	8	8.0	7	5	5	5.7	7	7	7	7.0
AL-25096	18	8	8	8	8.0	7	7	5	6.3	7	7	7	7.0
AL-25097	30	8	8	8	8.0	2	4	3	3.0	7	7	7	7.0
AL-25098	30	2	4	2	2.7	3	4	2	3.0	4	4	4	4.0
AL-25099	6	8	8	8	8.0	3	4	1	2.7	7	7	7	7.0
AL-25100	6	8	8	8	8.0	2	2	4	2.7	7	7	7	7.0
AL-25101	6	8	4	8	6.7	4	2	4	3.3	7	7	7	7.0
AL-25102	6	8	8	8	8.0	4	4	4	4.0	5	5	5	5.0
AL-25103	6	8	8	8	8.0	4	4	4	4.0	7	7	7	7.0
AL-25104	6	8	8	8	8.0	4	2	4	3.3	7	7	7	7.0
AL-25105	30	1	2	1	1.3	2	2	1	1.7	4	4	4	4.0
AL-25106	30	1	2	1	1.3	1	1	1	1.0	4	4	4	4
AL-25107	5	8	4	8	6.7	2	2	2	2.0	7	7	7	7
AL-25108	5	9	8	9	8.7	9	9	8	8.7	9	9	9	9
AL-25109	5	8	8	8	8.0	9	8	9	8.3	9	9	9	9
AL-25110	5	8	8	8	8.0	9	9	9	9.0	9	9	9	9
AL-25111	5	8	9	8	8.3	2	2	2	2.0	7	7	7	7
AL-25112	30	9	8	8	8.3	2	2	2	2.0	7	7	7	7
AL-25113	30	1	2	1	1.3	1	1	1	1.0	1	1	1	1
AL-25114	30	8	4	5	5.7	1	1	1	1.0	7	7	7	7
AL-25115	30	1	1	2	1.3	1	1	1	1.0	4	4	4	4
AL-25116	30	1	1	1	1.0	1	1	1	1.0	1	2	1	1.3
AL-25117	30	1	1	1	1.0	1	1	2	1.3	1	1	1	1
AL-25118	30	1	2	1	1.3	1	2	1	1.3	2	2	2	2
AL-25119	30	1	2	2	1.7	2	4	1	2.3	6	6	6	6
AL-25120	30	2	2	2	2.0	1	1	1	1.0	1	1	1	1
AL-25121	30	1	2	1	1.3	1	1	1	1.0	1	1	1	1
AL-25122	30	1	2	2	1.7	1	1	1	1.0	4	2	2	2.7
AL-25123	30	1	1	1	1.0	1	2	2	1.7	1	1	1	1
AL-25124	30	4	5	4	4.3	2	2	8	4.0	9	9	9	9

B. Field Evaluation of PEO at Ft. Bliss, Tx

Field demonstrations were conducted from August 1997 through November 1998 at the following Ft. Bliss, Tx locations: McGregor Missile Range Basecamp, U.S. Army Reserve Equipment concentration Site (ECS) No. 87, and the Intermediate Maintenance Division (IMD), 1st Combined Arms Support Battalion (IMD Motor Pool, Mesa Grande Range and Dona Ana Range). Photographs of representative equipment are presented in Figures 20-22. A total of 27 vehicles and equipment were converted to PEO in the crankcase, and used engine oils were periodically sampled. The used oil samples were analyzed for preservation properties by conducting AN, SW and HC tests.

Eight additional used oil samples were taken at Ft. Bliss, Tx during the final visit in November 1998. The used oil analyses are presented in Table 38. The results revealed that preservation properties measured by HC and SW were retained for as long as 3800 miles in an M931A2 truck and 215 hours in a road grader. Protection in the AN test was generally lost early, even at low equipment utilization levels (1 to 3 months). Based on the field demonstration data, the minimum operation time at which a used oil failed the HC and SW tests was 84 hours. The field demonstration confirmed that extended oil drain intervals are acceptable for preserved vehicles and equipment.

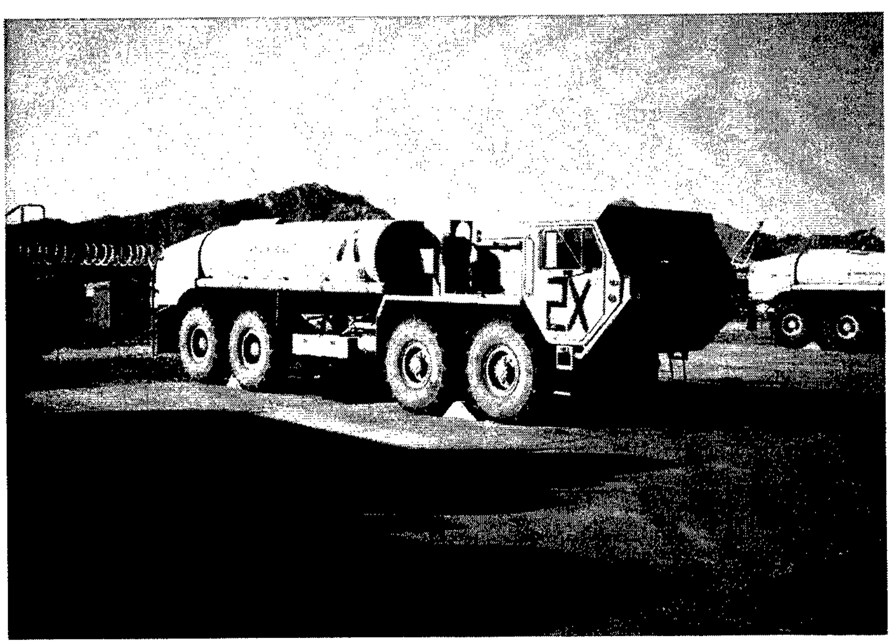

Figure 20. Representative Vehicle from Ft. Bliss

Figure 21. Representative Vehicle from Ft. Bliss

Figure 22. Representative Vehicle from Ft. Bliss

Table 38. Field Demonstration Data

No.	Vehicle	Engine Model	Serial No.	Bumper Tag	Original Miles	Original Hours	Location	Sample AL-	Date	Accum. Miles	Accum. Hours	Acid Neutralization Panels	Acid Neutralization Rating	Sea Water Immersion Panels	Sea Water Immersion Rating	Humidity Cabinet Panels	Humidity Cabinet Rating	TBN D	KV 100C D443
1	Dump Trk Int	D90	1756DCAL2392		46462		MG	None	Sep 97	0	0								
							MG	25079	Oct 97	203		3 P	1.0	3 P	1.3	3 P	1.0	7.5	14.08
							MG	25218	Nov 97	283		3 P	2.0	3 P	1.3	3 P	1.0	7.3	13.70
							MG	25328	Jan 98	474		2P, 1F	2.7	3 P	2.0	3 P	1.0	7.1	13.70
							MG	25447	Apr-98	1444		3 F	5.3	3 P	2.0	3 P	1.0	6.3	13.66
							SR	25535	Jul-98	1576		3 F	5.0	3 P	1.3	3 P	1.3	7.4	13.31
2	Dump Trk Int	D90	1751DCA12381		65903		MG	None	Sep 97	0	0								
							MG	25084	Oct 97	157		3 F	4.0	3 P	1.3	3 P	1.3	7.3	14.10
							MG	None	Nov 97	208									
							MG	25329	Jan 98	332		2P, 1F	2.7	3 P	1.7	3 P	1.0	7.2	14.36
							MG	25448	Apr-98	907		3 F	5.0	3 P	2.0	3 P	1.0	5.7	13.22
							SR	25534	Jul-98	1095		3 F	5.0	3 P	2.0	3 P	1.3	7.4	13.53
3	Dump Trk GMC	67D042	7DIF4FV52111		42388		MG	None	Sep 97	0	0								
							MG	25082	Oct 97	137		3 F	4.0	2 P, 1 F	2.0	3 P	1.0	7.0	14.11
							MG	None	Nov 97	187									
							MG	25330	Jan 98	291		3 P	2.0	3 P	1.7	3 P	1.0	6.7	12.58
							MG	25446	Apr-98	1829		3 F	5.0	3 P	1.0	3 P	1.3	4.5	8.74
					44367.5		SR	25536	Jul-98	0		3 P	1.0	3 P	2.0	3 P	1.7	7.5	13.04
4	Road Grader 130 G	Cat 3304	7GB01224			1055	MG	None	Sep 97	0	0								
							MG	25081	Oct 97		9	3 P	2.0	3 P	1.7	3 P	1.3	7.6	13.91
							MG	25217	Nov 97		49	1 P, 2 F	3.0	3 P	1.3	3 P	1.0	7.4	13.95
							MG	25331	Jan 98		124	3 F	4.0	3 P	1.7	3 P	1.0	7.2	14.13
							MP	25540	Jul-98		189	3 F	7.0	3 F	3.7	1P,2F	2.7	6.0	15.23
5	Road Grader 130 G	Cat 3304	7GB00867			2804	DA	None	Sep 97	0	0								
							DA	25071	Oct 97		50	3 P	1.0	3 P	1.0	3 P	1.0	7.7	13.75
							DA	25213	Nov 97		115	3 F	5.0	3 P	1.0	3 P	1.0	6.6	12.75
							DA	None	Jan 98		*								
							DA	25451	Apr-98		215	3 F	7.0	3 P	2.0	3 P	1.7	3.7	11.95
							DA	25541	Jul-98		255	3 F	7.0	1P, 2F	3.3	2P. 1F	2.3	6.5	11.79
6	Road Grader 130 G	Cat 3304	7GB01221			99	MP	None	Sep 97		0								
							MP	25071	Oct 97		14	1 P. 2 F	3.3	3 P	1.0	3 P	1.3	7.1	14.02
							MP	25216	Nov 97		44	3 F	4.0	3 P	1.0	3 P	1.0	7.2	13.74
							MP	25332	Jan 98		80	3 F	5.0	2P, 1F	2.3	3 P	1.3	7.8	13.70

Table 38. Field Demonstration Data

No.	Vehicle	Engine Model	Serial No.	Bumper Tag	Original Miles	Original Hours	Location	Sample AL-	Date	Accum.		Acid Neutralization		Sea Water Immersion		Humidity Cabinet		TBN D	KV 100C D443
										Miles	Hours	Panels	Rating	Panels	Rating	Panels	Rating		
							MP	25452	Apr-98		107	3 F	5.3	3 P	2.0	3 P	1.3	4.4	13.40
							MP	25542	Jul-98		115	3 F	5.0	2P,1F	2.7	3 P	1.0	4.5	13.13
7	Backhoe	IH D69L	9105460			3713	DA	None	Sep 97		0								
	680CK-B						DA	25073	Oct 97		50	3 F	5.3	3 P	2.0	3 P	1.7	7.8	13.46
							DA	25219	Nov 97		84	3 F	6.0	3 P	1.3	3 P	1.7	7.6	13.30
							DA	25333	Jan 98		153	3 F	7.0	3 F	5.0	3 F	4.0	6.2	12.11
							DA	25543	Jul-98		553	3 F	9.0	2P, 1F	2.3	3 F	3.0	4.9	10.66
8	Backhoe	JD4219DT	342570			436	MP	None	Sep 97	0	0								
	JD-410						MP	None	Oct 97		0								
							MP	25224	Nov 97		18	1 P. 2F	3.3	3 P	1.7	3 P	1.0	7.3	13.66
							MP	25334	Jan 98		36	3 F	4.7	3 P	2.0	3 P	1.0	7.1	13.50
						527	MP	25545	Jul-98		0	3 P	1.7	3 P	1.0	3 P	1.3	7.6	14.23
9	Loader Scoop	504BD-T	Y9157388			1225	MG	25083	Sep 97	0	0								
	Case MW24C						MG	None	Oct 97		3	3 F	4.0	3 P	1.7	1 P, 2	3.3	7.3	15.51
							MG	None	Nov 97		7								
							MG	25335	Jan 98		35	3 F	5.0	3 P	2.0	3 P	1.3	7.4	14.44
							MG	25450	Apr-98		132	3 F	7.0	2P 1F	2.7	2P. 1F	2.3	4.2	13.88
							MP	25544	Jul-98		162	3 F	9.0	3 P	1.7	1P. 2F	3.0	1.4	13.94
10	Trk Wrecker	NHC250	C127-1073		39760	1621	MP	25072	Sep 97	0	0								
	M816						MP	25220	Oct 97	139	5	3 P	1.7	3 P	1.3	1 P, 2	3.7	7.2	14.46
							MP	25336	Nov 97	310	11	3 P	1.0	3 P	1.0	3 P	1.0	7.0	14.23
							MP	None	Jan 98	517		2F, 1P	3.3	3 P	2.0	3 P	1.0	7.3	14.14
							MP	25449	Apr-98	1682		3 F	5.0	3 P	2.0	3 P	1.0	4.9	13.72
							MP	25533	Jul-98	1814		3 F	5.0	3 P	1.3	3 P	1.3	7.2	13.68
11	Trk Tractor	6CTA8.3	31/03784	E-15	3253		MP	25090	Sep 97	0									
	M931A2						MP	25222	Oct 97	995		3 F	4.7	3 P	1.3	2 P, 1	2.3	7.2	13.93
							MP	None	Nov 97	1800		3 F	4.7	3 P	1.7	3 P	1.0	7.4	13.78
							MP	25337	Jan 98	1800		3 F	4.0	3 P	1.0	3 P	1.0	7.2	13.93
							MP	25443	Apr-98	3822		3 F	5.7	3 P	2.0	3 P	2.0	6.5	13.50
							MP	25686	Nov-98	4165		3 F	6.0	3 P	1.0	3 P	1.7	7.5	11.52
12	Trk Tractor	6CTA8.3	31/03218	E-05	9511	293	MP	25091	Sep 97	0	0								
	M931A2						MP	25221	Oct 97	723	18	3 F	4.7	3 P	1.3	3 P	2.0	7.2	14.43
							MP	None	Nov 97	1425	35	3 F	4.3	3 P	1.3	3 P	1.0	7.3	14.19

Table 38. Field Demonstration Data

No.	Vehicle	Engine Model	Serial No.	Bumper Tag	Original Miles	Original Hours	Location	Sample AL-	Date	Accum.		Acid Neutralization		Sea Water Immersion		Humidity Cabinet		TBN D	KV 100C D443
										Miles	Hours	Panels	Rating	Panels	Rating	Panels	Rating		
							MP	25338	Jan 98	2324	59	3 F	5.0	2P, 1F	2.7	3 P	1.0	7.8	14.60
							MP	25442	Apr-98		83	3 F	6.0	3 P	1.7	3 P	1.3	5.5	14.06
							MP	25530	Jul-98		102	3 F	7.0	3 P	2.0	2P,1F	2.0	7.4	14.02
13	CUCV	6.2L	34JOGF434703	IMD-106	22794		MP	None	Sep 97	0	0								
	M1031						MP	25080	Oct 97	328		3 F	5.0	3 P	2.0	3 P	2.0	7.3	15.25
							MP	None	Nov 97	367									
							MP	25339	Jan 98	2061		3 F	6.0	3 P	1.7	3 P	1.3	7.3	15.73
							MP	25454	Apr-98	3693		3 F	7.0	2P 1F	3.0	3 P	2.0	4.8	16.72
					27657		MP	25524	Jul-98	0									
14	CUCV	6.2L	34JOEE362566	IMD-102	93060		MP	None	Sep 97	0	0								
	M1038						MP	25074	Oct 97	325		3 F	4.7	3 P	1.0	3 P	1.0	7.7	15.36
							MP	None	Nov 97	335									
							MP	25340	Jan 98	420		3 F	5.0	3 P	2.0	3 P	1.0	7.3	15.33
							MP	25453	Apr-98	1380		3F	6.0	3 P	2.0	3 P	1.7	5.1	23.11
					95600.6		MP	25525	Jul-98	0									
15	HMMWV	6.2L	161012	ECS-K-02	2581		EC	None	Aug 97	0	0								
	M998A1						EC	None	Oct 97	0.2	0								
							EC	None	Nov 97	1.3	0								
							EC	None	Jan 98	2									
							BF	25519	Jul-98	835		3 F	5.3	3 P	2.0	3 P	1.0	7.2	13.64
							EC	25690	Nov-98	1028		3 F	6.0	3 P	2.0	3 P	2.0	7.7	13.56
16	HMMWV	6.2L	161013	ECS-K-03	2399		EC	None	Aug 97	0	0								
	M998A1						EC	None	Oct 97	85									
							EC	25223	Nov 97	85		3 F	4.0	3 P	1.7	3 P	1.0	7.5	13.70
							EC	25341	Jan 98	201		3 F	5.2	3 P	1.7	3 P	1.0	7.3	13.81
							EC	25445	Apr-98	579		3 F	5.0	3 P	1.3	3 P	1.7	5.8	13.82
							BF	25521	Jul-98	1935		3 F	5.7	3 P	1.7	3 P	1.7	7.6	13.97
17	HMMWV	6.2L	158384	ECS-K-38	5393		EC	None	Aug 97	0									
	M998A1						EC	25075	Oct 97	180		3 F	6.0	3 P	1.3	3 F	4.7	7.0	14.00
							EC	None	Nov 97	180									
							EC	25342	Jan 98	180		3 F	7.0	3 P	2.0	3 P	1.0	5.5	14.05
							EC	25444	Apr-98	904		3 F	7.0	3 P	2.0	1P 2F	2.7	4.5	13.41
							EC	25520	Jul-98	967		3 F	7.0	3 P	2.0	3 F	3.7	6.1	13.53
							EC	25691	Nov-98	967									

Table 38. Field Demonstration Data

No.	Vehicle	Engine Model	Serial No.	Bumper Tag	Original Miles	Original Hours	Location	Sample AL-	Date	Accum.		Acid Neutralization		Sea Water Immersion		Humidity Cabinet		TBN D	KV 100C D443
										Miles	Hours	Panels	Rating	Panels	Rating	Panels	Rating		
18	HMMWV	6.2L	158330	ECS-K-40	9242		EC	None	Aug 97	0	0								
	M1025						EC	None	Oct 97	0									
							EC	None	Nov 97	0									
							EC	None	Jan 98	0									
							EC	25523	Jul-98	269		3 F	5.0	3 P	1.7	3 P	1.7	7.3	14.32
							EC	25692	Nov-98	369		3 F	6.0	3 P	1.3	3 P	1.3	7.5	14.36
19	HMMWV	6.2L	158312	ECS-K-41	9008		EC	None	Aug 97	0									
	M1025						EC	25078	Oct 97	292		3 F	5.0	3 P	2.0	3 P	1.7	7.5	14.62
							EC	None	Nov 97	292									
							EC	None	Jan 98	293									
							EC	25522	Jul-98	304		3 F	5.3	3 P	1.3	3 P	1.0	5.8	14.50
							EC	25693	Nov-98	304									
20	Tanker	DD8V92T	KIJ24J1034104	4104	10585	1746	EC	None	Aug 97	0	0								
	M978						EC	None	Oct 97	4	0.1								
							EC	None	Nov 97	6	4								
							EC	None	Jan 98		7								
							EC	25538	Jul-98		12	3 F	4.0	3 P	1.0	3 P	1.3	7.6	11.69
21	Tanker	DD8V92T	KIJ28H1032527	2527	11363	2040	EC	None	Aug 97	0	0								
	M978						EC	25085	Oct 97	2	6	3 F	4.0	3 P	1.7	3 P	1.3	7.7	14.38
							EC	None	Nov 97	4	11								
							EC	None	Jan 98		13								
							EC	25537	Jul-98		18	3 F	4.0	3 P	1.0	3 P	1.0	7.2	13.42
22	Tanker	DD8V92T	KIJ23E1023746	3746	8678	2301	EC	None	Aug 97	0	0								
	M978						EC	None	Oct 97	0	0								
							EC	None	Nov 97	0	0								
							EC	None	Jan 98	0	0								
							EC	25539	Jul-98	0	0	3 F	7.0	3 P	2.0	3 P	1.0	5.1	7.55
23	Tractor	NHC250	C531-02177	ECS-J-09	24781	704	EC	None	Aug 97	0	0								
	M931						EC	None	Sep 97	0	0								
							EC	None	Nov 97	0.2	0.5								
							EC	None	Jan 98		1								
							EC	25526	Jul-98		17.5	3 P	1.0	3 P	1.0	3 P	1.7	7.4	12.78
							EC	25688	Nov-98	343	18								

Table 38. Field Demonstration Data

No.	Vehicle	Engine Model	Serial No.	Bumper Tag	Original Miles	Original Hours	Location	Sample AL-	Date	Accum.		Acid Neutralization		Sea Water Immersion		Humidity Cabinet		TBN D	KV 100C D443
										Miles	Hours	Panels	Rating	Panels	Rating	Panels	Rating		
24	Tractor	NHC250	C531-02156	ECS-J-28	29356	770	EC	None	Aug 97	0	0								
	M931						EC	None	Sep 97	0	0								
							EC	None	Nov 97	0	0.4								
							EC	None	Jan 98		1.5								
							EC	25527	Jul-98		3.4	3 P	1.0	3 P	1.3	3 P	1.3	7.8	14.08
25	Tractor	NHC250	C531-02175	ECS-J-27	39987	1012	EC	None	Aug 97	0	0								
	M931						EC	None	Sep 97	0	0								
							EC	None	Nov 97	0	0								
							EC	None	Jan 98	0	0								
							EC	25529	Jul-98	0	0	3 P	1.3	3 P	1.3	3 P	1.3	7.7	14.11
26	Tractor	NHC250	C531-02263	ECS-J-29	24837	733	EC	None	Aug 97	0	0								
	M931						EC	None	Sep 97	0	0.1								
							EC	None	Nov 97	0	0.5								
							EC	None	Jan 98		1								
							EC	25528	Jul-98		35.4	3 F	4.3	3 P	1.0	3 P	1.0	7.5	13.55
							EC	25689	Nov-98	929	37.5								
27	Trk Tractor	6CTA8.3	31/03765	E-16	9324	257.3	MP	25546	Jul-98	0	0								
	M931A2							25687	Nov-98	1475	43	3 F	5.3	3 P	1.3	3 P	1.3	7.8	14.02

* = Unable to locate vehicle to obtain sample

Location codes: DA=Donna Anna, EC=Equipment concentration site #87, MG=Mesa Grande, MP=Motor pool, SR=Shorad Range, BF=Biggs Field

VIII. CONCLUSIONS

The following overall conclusions were made from this project:

- Used Preservative Engine Oil (PEO) exhibited excellent retention of corrosion protection in the Sea Water Immersion (SW) and Humidity Cabinet (HC) Tests.
- Corrosion protection in the Acid Neutralization (AN) test often disappears rapidly.
- The AN test was designed to protect against corrosion specifically related to leaded gasoline combustion products.
- The AN test is not relevant today as unleaded gasoline is in use.
- FT-IR (Fourier Transform Infrared) analysis is an excellent technique for determining quantitative PEO additive concentration in new oil.
- FT-IR technique was not valid for PEO additive content of used oil.
- FT-IR and other methods investigated did not predict performance of used PEOs in bench corrosion tests.
- Corrosion protection was retained in the SW and HC tests for 12 months (end of test) under static aging conditions.
- Extended HC tests of used PEO revealed that HC protection was retained for 60 to 140 days (2-3 times the new oil requirement).
- The field demonstration at Ft. Bliss, Tx revealed that corrosion protection in the HC and SW test was retained for a maximum of 416.5 miles in an M931AZ and 215 hours in a road grader.
- The minimum equipment utilization time at which used PEO from the Ft. Bliss test failed the HC and SW tests was between 84 and 150 hours in a backhoe.

IX. RECOMMENDATIONS

Based on the results of this project, the following recommendations are offered:

- Retain Acid Neutralization (AN) test in MIL-PRF-21260 to ensure Preservative Engine Oil (PEO) quality.
- Do not base PEO drains on AN test.
- Extend PEO drains to at least 50 hours.
- Modify Technical Manuals (TM) 38-450 and 38-470 to reflect the new oil drain interval.
- Use PEO in active equipment for improved corrosion protection.
- Continue investigations to develop a Go-No-Go (GNG) test for PEO, although this is not as critical as previously thought because of the extended PEO drain interval.
- Follow Army Oil analysis Program (AOAP) oil drain recommendations for oil contamination criteria. AOAP does not address the remaining preservation characteristics of used PEO.
- Add the new panel rating procedure to MIL-PRF-21260 to better define oil performance.

X. COST-BENEFIT ANALYSIS

There are approximately 30,000 pieces of equipment in storage. Based on vehicle exercising schedules and a 5-hour oil drain criterion (2,3), 10,000 oil changes per year would be expected. By extending the oil drain interval from 5 hours to 50 hours, it is estimated that 80% (8,000) oil drains/year would be avoided. Saving 8,000 oil drains per year would save $526,500/yr, as shown in Table 39.

Table 39. Estimated Savings & Benefits for Preservative Engine Oil Life Program (Avoiding 8,000 oil changes/year)

a. reduced volume used oil/yr
est. 70,000 gal [approx 8,000 oil changes]
est. used oil disposal cost is $1/gal
70,000 gal x $1/gal = $70,000 70,000

b. reduced used oil filter disposal cost
8,000/yr x $0.5/unit = $4,000 4,000

c. reduced oil procurement cost
70,000 gal/yr x $3.75/gal = $262,500 262,500

d. reduced oil flter procurement cost
8,000 x $15/unit = $120,000 120,000

e. reduced maintenance labor
8,000 x changes x 0.5 hr x $17.50/hr = $70,000 .. 70,000

Total Cost Avoidance $525,500/yr

VIII. REFERENCES

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2. TM-38-450 "Storage and Maintenance of Prepositioned Material Configured to Unit Sets"
3. TM 38-470 "Storage of Army War Reserve (AWR) 3 Material Prepositioned Afloat"
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