AD-A056 806 SOUTHWEST RESEARCH INST SAN ANTONIO TX ARMY FUELS AN--ETC F/G 11/8
U.S. ARMY/ENVIRONMENTAL PROTECTION AGENCY RE-REFINED ENGINE OIL--ETC(U)
MAY 78 E A FRAME, T C BOWEN DAAK70-78-C-0001
UNCLASSIFIED AFLRL-98 NL

| OF |
ADA
056806

END
DATE
FILMED
9 78
DDC

LEVEL II

12

AD

U.S. ARMY/ENVIRONMENTAL PROTECTION AGENCY RE-REFINED ENGINE OIL PROGRAM

AFLRL REPORT No. 98

by

Edwin A. Frame
U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas

and

Thomas C. Bowen, Jr.
U.S. Army Mobility Equipment Research and Development Command
Energy and Water Resources Laboratory
Fort Belvoir, Virginia

Approved for public release; distribution unlimited

Contract No. DAAK70-78-C-001

May 1978

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Trade names cited in this report do not constitute an official endorsement or approval of the use of such commercial hardware or software.

DDC Availability Notice

Qualified requestors may obtain copies of this report from Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

Disposition Instructions

Destroy this report when no longer needed. Do not return it to the originator.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFLRL 98	2. GOVT ACCESSION NO.: AD
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE *(and Subtitle)*: U.S. Army/EPA Re-refined Engine Oils Program	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER: AFLRL No. 98
7. AUTHOR(s): Edwin A. Frame (USAFLRL); Thomas C. Bowen (USAMERADCOM)	8. CONTRACT OR GRANT NUMBER(s): DAAG 53-76-C-00[illegible]; DAAK 70-78-C-001, DAAG53-76-C-0003
9. PERFORMING ORGANIZATION NAME AND ADDRESSES: U.S. Army Mobility Equip. Res. & Dev. Command, Energy & Water Resources Lab, Fort Belvoir, VA 22060	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: May 78
	13. NUMBER OF PAGES: 30
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*: U.S. Army/Environmental Protection Agency Re-Refined Engine Oil Program.	15. SECURITY CLASS. *(of this report)*
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

Rept. for Oct 76 – May 78.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Engine Oil	Engine deposits	Gasoline Engines
Recycled oil	MIL-L-46152	Diesel engines
Re-refined oil	Lubricant Additives	

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

Re-refined base oils were obtained and analyzed. Based on the analyses, six oils were formulated to MIL-L-46152 quality level using the same concentration of a single additive package. The formulated oils were tested against the requirements of MIL-L-46152. One oil passed all the engine tests. Vehicles from City of San Diego which operated on re-refined oil were disassembled and inspected for deposits.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

387339

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL), located at Southwest Research Institute, San Antonio, Texas, under contract DAAG53-76-C-0003 during the period October 1976 through September 1977 and contract DAAK70-78-C-001 through May 1978. The U.S. Environmental Protection Agency participated in the program under Interagency Agreement EPA- IAG-D6-0957. The EPA project officer was Mr. H.B. Kaufman, while Mr. T.C. Bowen, Jr. of the U.S. Army Mobility Equipment Research and Development Command (USAMERADCOM, DRDME-GL) was the Army project officer. Mr. F.W. Schaekel of USAMERADCOM, DRDME-GL was the contract monitor.

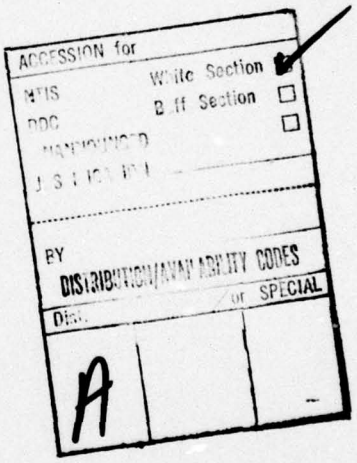

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

A. Background

Over two billion gallons of lubricating oils are used annually in the United States. Of this amount, about one-half is consumed or otherwise lost in use. The other one billion gallons remain as waste products and require disposal.[1]* When improper methods such as uncontrolled burning or dumping are used for disposal, these materials represent an environmental hazard. For example, the uncontrolled burning of used crankcase lubricant results in harmful emissions which pollute the atmosphere. Also, when dumped on land, this material can contaminate groundwater through leaching or waterways by runoff.

These waste products need not represent a hazard, but rather can be a significant potential resource. With the proper processing, waste oil can be used as fuel. Thus, energy is recovered which would otherwise be lost. Also, these materials can be used in cement manufacturing, asphalt road applications, or re-refined for reuse as base stock components of lubricating oils. The later re-refining option appears to be an efficient method of extending the useful life of petroleum products.

Based on the potential environmental benefits to be derived from re-refining waste oil, the Environmental Protection Agency (EPA) became interested in a program to investigate the feasibility of using re-refined base stock in engine lubricants of the type covered by Military Specification MIL-L-46152[2], i.e., oils meeting the American Petroleum Institute (API) performance classifications SE and CC.[3-5] This interest led to an interagency agreement, EPA-IAG-D6-0957, with the Department of Defense (DoD) covering the joint "EPA-DoD Re-Refined Engine Oil Program" being reported herein.

B. Program Objectives and Methodology

The objectives of the program were:

(1) To demonstrate the feasibility of producing MIL-L-46152 quality lubricants using re-refined base oils and suitable additive treatment.

(2) To generate technical data which will increase the understanding of re-refined lubricants.

Accomplishment of these objectives employed the following methodology. First, re-refined stocks were obtained and analyzed using standard laboratory techniques. Based on the analyses, six stocks were selected and each was formulated with the same additives to provide a finished engine oil. The finished lubricants were then subjected to the engine dynamometer tests used to define oil performance under the MIL-L-46152 specification and API classification system. In addition to this effort, the field performance of a re-refined product was evaluated through engine teardown inspections.

*Superscript numbers in parentheses refer to the List of References at the end of this report.

II. RE-REFINED BASE OILS

Representative re-refined base oils were obtained with the assistance of the Association of Petroleum Re-Refiners (APR). APR contacted 36 member and nonmember companies requesting them to consider participating in the re-refined oil program. A copy of this request letter is shown in Appendix A. Of the companies contacted, 17 participated in the program. These companies furnished 30 samples, 17 re-refined base stocks, 12 feedstocks, and a finished product.

A. Analytical Characterization

The analytical characterization consisted of the following three major areas:

(1) Physical Properties

- Viscosity
- Gravity
- Pour Point
- Flash Point
- Color

(2) Re-Refining Level

- Total Acid Number
- Total Base Number
- Saponification Number
- Carbon Residue
- Total Ash
- Insolubles
- Copper Strip Corrosion
- Trace Metals

(3) Composition

- Aniline Point
- Boiling Point Distribution by Gas Chromatographic Technique
- Elemental Content
- Aromaticity
- Characteristic Groups (Column Chromatography)

Fifteen re-refined base oils were received in time to be analyzed and considered for selection to be blended to finished product. Some materials were late arrivals, and the analyses for these are given in Appendix C. Table 1 shows most of the analytical inspection data for the 15 re-refined base oils, and a virgin base oil denoted AL-6755 which AFLRL had obtained previously. It was later determined that the virgin stock was a hydrotreated base oil which explained some of its compositional characteristics such as very low sulfur content and very light color. Table 2 gives the characteristic groups' (D2007) determina-

TABLE 1
INSPECTION OF RE-REFINED BASE OILS

Sample I.D.																	
AL No.		6688	6689	6690	6691	6692	6693	6694	6695	6696	6697	6698	6699	6700	6701	6702	6755
IR Trace No.		992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1019
Inspection	ASTM No.																
K. Viscosity	D445																
@ 100°F, cSt		63.82	50.51	64.66	70.27	70.90	88.52	58.95	60.50	67.08	76.93	50.64	119.60	50.75	80.26	45.67	46.60
@ 210°F, cSt		8.36	7.23	8.02	8.75	8.81	10.13	7.86	7.92	8.54	9.23	6.84	12.09	6.83	9.33	6.63	6.59
Viscosity Index	D2270	110	116	98	105	104	101	108	105	105	103	98	99	97	100	110	108
SAE Grade		20	20	20	20	20	30	20	20	20	20	20	30	20	20	20	20
API Gravity, °	D287	29.7	30.4	29.1	29.6	29.4	29.1	30.0	30.5	29.6	29.5	29.8	28.7	29.6	28.5	28.8	31.6
ASTM Color	D1500	4.5	4.5	5.5	7.0	7.0	4.5	4.5	2.5	3.5	3.5	2.5	2.5	2.5	6.0	6.5	0.5
Carbon Residue, wt %	D524	0.14	0.13	0.13	0.09	0.15	0.24	0.06	0.05	0.05	0.08	0.06	0.10	0.06	0.14	0.34	0.07
Pour Point, °F	D97	−15	10	5	10	−25	10	15	5	10	10	15	15	15	0	−5	−5
Flash Point, °F	D92	425	380	425	410	440	430	385	415	415	435	440	465	450	435	365	440
Aniline Point, °F	D611	222	221	221	225	225	226	222	225	225	227	220	242	221	225	207	228
TAN	D664	0.09	0.16	0.16	0.05	0.11	0.22	0.05	0.17	0.10	0.08	0.04	0.04	0.09	0.11	0.17	0.03
TBN	D2896	0.00	0.06	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.06	0.00	0.27	0.06	0.00	0.00	0.16
Copper Cor., 3hr @ 212°F	D130	1B	1B	1B	1B	1B	1B	1B	1B	1B	1B	1B	1B	1B	1B	1B	1A
Chlorine, ppm	XRF	<100	<100	<100	<100	<100	1250	<100	<100	<100	<100	<100	<100	<100	<100	1010	<100
Sulfur, wt %	XRF	0.21	0.16	0.31	0.18	0.34	0.19	0.14	0.16	0.12	0.15	0.16	0.14	0.15	0.24	0.29	0.05
Phosphorus, ppm	D1091	7	24	3	25	65	25	30	33	5	17	14	9	5	5	70	7
Elemental, ppm	MOD.																
Calcium	AA	10	10	<5	10	111	10	<5	15	<5	44	<5	16	<5	75	<5	<5
Barium	AA	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zinc	AA	<2	15	<2	<2	11	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Lead	AA	<1	<1	<1	<1	47	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Magnesium	AA	<1	12	<1	<1	3	<1	<1	<1	<1	2	<1	<1	<1	11	<1	<1
Copper	AA	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chromium	AA	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Iron	AA	6	13	<2	<2	13	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sodium	AA	<2	<2	<2	<2	9	<2	<2	<2	<2	<2	4	5	5	5	<2	<2
Silicon	AA	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Aluminum	AA	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Saponification No.	D94	0.43	0.37	0.49	0.36	0.52	0.7	0.35	0.39	0.24	0.21	0.25	0.22	0.38	0.45	4.1	ND
Total Ash, wt %	D482	<0.001	0.014	<0.001	<0.001	0.036	0.004	<0.001	0.005	0.002	0.009	0.001	0.004	0.001	0.022	0.004	ND
Nitrogen, wt %	PE	0.03	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.02
Oxygen, wt %	PE	0.66	0.51	0.70	0.80	0.76	0.82	0.65	0.53	0.41	0.55	0.59	0.55	0.40	0.55	0.68	0.44
Benzene Insolubles (uncoagulated), wt %	D893	0.022	0.016	0.014	0.013	0.022	0.018	0.033	0.022	0.032	0.016	0.017	0.020	0.026	0.024	0.030	0.016
GC BP Distribution % Off @ °C																	
1		224	295	346	330	298	346	240	257	276	314	337	355	338	270	226	383
5		370	366	377	383	366	382	339	370	371	383	380	397	380	368	326	400
10		388	384	394	403	390	405	377	388	390	400	395	414	397	397	357	414
50		444	441	448	466	455	465	452	443	447	452	450	483	453	463	434	450
90		535	545	540	574	537	563	551	539	550	532	518	600	518	564	555	488
Residue, wt %>600°C		5	5	5	6	3	5	5	3	4	1	<1	10	<1	5	5	0 (557 EP)

XRF = X-Ray Fluorescence.
AA = Atomic Absorption.
ND = Not Determined.
PE = Perkin Elmer.

tions, while Table 3 shows the aromaticity by ultraviolet spectroscopy data. The UV aromaticity procedure is shown in Appendix B.

TABLE 2
CHARACTERISTIC GROUPS ASTM D2007

Sample ID		Weight Percent		
AL-	CCL-	Saturates	Polars	Aromatics
6688	844	78.4	2.8	18.8
6689	845	88.8	2.5	8.7
6690	846	77.3	2.6	20.1
6691	847	79.7	10.9	9.4
6692	848	71.2	3.0	25.8
6693	849	84.4	7.0	8.6
6694	850	84.4	2.7	12.9
6695	851	82.9	2.6	14.5
6696	852	80.7	2.7	16.6
6697	853	74.9	2.5	22.6
6698	863	75.1	2.5	22.4
6699	864	82.0	9.8	8.2
6700	865	83.9	8.1	8.0
6701	873	79.8	1.5	18.7
6702	879	75.0	2.3	22.7
6755	–	88.7	2.0	9.3

TABLE 3
RE-REFINED BASE OILS

	Aromaticity by UV Spectroscopy wt %, Ring Carbon		
AL-	Mono-Ring	Di-Ring	Tri-Ring
6688	3.1	0.89	0.22
6689	3.0	1.0	0.23
6690	3.6	1.3	0.36
6691	3.2	1.1	0.32
6692	3.5	1.2	0.36
6693	3.0	0.86	0.21
6694	3.1	0.98	0.20
6695	2.7	0.67	0.10
6696	2.9	0.96	0.24
6697	3.0	0.85	0.19
6698	3.0	1.0	0.27
6699	2.8	0.85	0.20
6700	3.1	1.1	0.28
6701	3.2	1.0	0.24
6702	3.7	1.3	0.27
6755	2.2	0.33	0.02

Significant items from Table 1 relating to re-refined stocks include:

(1) Two base oils had rather high chlorine contamination levels (AL-6693—1250 ppm and AL-6702—1010 ppm).

(2) With the exception of two stocks, all base oils fell within a Society of Automotive Engineers (SAE) classification for Grade 20 motor oil. The two remaining products were in SAE Grade 30.

(3) Three base oils had flash points less than 400°F (AL-6689, AL-6694, and AL-6702).

(4) Total acid numbers were all fairly low (0.04—0.22) as were total base numbers (0.00—0.27).

(5) Sulfur contents were typical of virgin lube oil stocks and ranged from 0.12 to 0.34 percent.

(6) All stocks exhibited high viscosity index values.

(7) The following summary table shows the significant trace elemental contaminations which were observed:

Sample AL-	Element	PPM
6692	Cu	111
	Zn	11
	P	65
	Pb	47
	Fe	13
6701	Ca	75
	Mg	11
6697	Ca	44
	P	17
6689	Ca	10
	Zn	15
	P	24
	Mg	12
	Fe	13
6699	Ca	16
6695	Ca	15
	P	33
6691	P	25
6693	P	25
6694	P	30
6702	P	70

The zinc, phosphorus, calcium, and magnesium are probably residual additive components, while the iron and copper are wear-related contaminants. The lead is either left from leaded gasoline or results from engine wear/corrosion.

In comparing the percent of aromatics of Table 2 with the aromaticity values of Table 3, it should be remembered that the D2007 method (Table 2) considers *any molecule* which has an aromatic carbon atom as entirely aromatic. For the UV aromaticity, only those *carbon atoms* which are in aromatic rings are regarded as aromatic. This difference in methods accounts for the difference between values presented in Tables 2 and 3.

B. Feedstocks of Re-Refined Base Oils

As previously mentioned, the participating companies furnished 12 samples of feedstocks. Table 4 shows the data obtained for these stocks. Also indicated is the corresponding re-refined base stock. All samples contained lead, chlorine, and bromine contamination which is indicative of used crankcase drainings obtained from vehicles operated on leaded gasoline. In addition, the feedstock contained phosphorus, barium, calcium, and zinc which is typical of engine oil additive systems. Therefore, it is believed that in all cases the feedstocks came at least in part from vehicle crankcase drainings.

TABLE 4
FEEDSTOCKS ANALYSES

AL-	7028	7029	7030	7031	7032	7033	7034	7035	7036	7037	7038	7039
Related Base-oil AL-	6696	6688	6702	6694	6695	6693	6689	6691	6697	None	6690	6698
TAN	2.11	2.58	3.00	3.74	2.53	1.05	2.90	4.11	2.79	2.95	2.11	4.06
TBN	3.95	3.05	3.32	3.80	4.30	0.90	4.28	4.41	4.00	4.14	3.73	3.73
Nitrogen, wt %	0.064	0.045	0.009	0.074	0.030	0.049	0.052	0.078	0.052	0.078	0.056	0.083
KVIS, cSt												
100°F	48.9	55.7	38.3	67.2	62.4	75.0	68.6	56.2	72.4	69.2	52.3	66.2
210°F	7.53	8.47	6.48	10.00	9.71	9.25	10.31	8.77	9.29	10.11	7.91	10.27
Viscosity Index	128	138	134	144	150	110	147	145	115	141	130	154
Water, %	2.7	0.2	0.6	5.3	6.0	0.2	10.1	10.2	0.8	2.8	7.4	3.6
Specific Gravity	0.8953	0.8877	0.8887	0.8960	0.8968	0.8857	0.9067	0.8993	0.8876	0.8956	0.8961	0.8981
Carbon Residue, wt %	1.35	1.40	1.12	1.94	1.35	0.46	1.56	2.07	1.21	1.78	1.20	2.20
Total Ash, wt %	0.70	0.82	0.62	1.07	0.86	0.25	1.14	1.14	0.68	1.13	0.74	0.68
Flash Point, °F	*	350	205	*	*	365	*	*	300	*	*	*
Pour Point, °F	−45	−35	−40	−30	−25	−10	−30	−30	−25	−30	−40	−30
Elements by XRF, wt %												
P	0.083	0.130	0.088	0.120	0.108	0.116	0.35	0.123	0.098	0.138	0.150	0.133
S	0.36	0.54	0.38	0.51	0.42	0.49	0.44	0.52	0.43	0.60	0.49	0.59
Cl	0.135	0.072	0.385	0.20	0.068	0.182	0.08	0.34	0.048	0.064	0.44	0.135
Ca	0.105	0.086	0.058	0.088	0.104	0.06	0.080	0.069	0.135	0.080	0.14	0.07
Ba	<0.010	0.024	0.018	0.023	0.046	<0.010	0.018	0.020	<0.010	0.031	<0.010	<0.010
Fe	0.0135	0.0190	0.0575	0.021	0.0190	0.029	0.0190	0.018	0.0105	0.03	0.0515	0.021
Zn	0.05	0.075	0.026	0.055	0.059	0.035	0.062	0.046	0.068	0.068	0.048	0.068
Pb	0.205	0.185	0.179	>0.33	0.147	0.215	0.22	>0.33	0.11	0.245	0.221	>0.33
Cu	0.003	0.004	0.002	0.0045	0.003	<0.003	0.0035	0.002	0.0045	0.0045	0.0065	0.0025
Other Elements	Br	Br	Br	Br	Br	Ti, Br, Al, Si	Br	Br	Br	Br	Br	Br

*Water content too high.

C. Selection of Re-Refined Base Oils for Formulation

The selection of six representative re-refined base oils, to be formulated into finished engine oil, was made with the assistance of the ASTM task force on re-refined oils, and various other interested parties. The group met on February 24, 1977, at EPA headquarters, Washington, D.C. and selected the six base oils. Attendees and their organizations are shown in Table 5. The re-refined base oil analyses presented in Tables 1 and 3 were reviewed and used as the basis for selecting oils to be formulated. The group sought to select base oils which represented a range of potential quality. The selected base oils were grouped in the following three broad categories:

(1) "Excellent" quality (L-6697, AL-6698)

(2) "Good" quality (AL-6696, AL-6690, AL-6094)

(3) "Lesser" quality (AL-6692)

The six stocks were similar in physical properties. From a viscosity standpoint, the stocks would be classified as SAE 20W-20 oils and generally would be comparable with 250-350 neutral high VI virgin base stocks. Two dissimilarities which should be noted are the low flash point for stock AL-6694 and the low pour point value of stock AL-6692. These are probably related to the re-refining level used in their production.

TABLE 5
ATTENDEES AT RE-REFINED ENGINE OIL MEETING
FEBRUARY 24, 1977

Name	Organization
Mr. H.B. Kaufman	EPA
Mr. W.W. Crouse	ASTM (Suntech)
Mr. H.F. Hitchcox	Exxon Research
Mr. C.J. Thompson	BERC/ERDA
Mr. D.M. Stehouwer	GM Research
Mr. H.E. Tiffany	API
Mr. M. Willingham	FEA-State Programs
Mr. M.L. Kerran	Double Eagle Refining
Mr. R.F. Pedall	Motor Oils Refining
Mr. D. Ekedahl	Assoc. of Petroleum Re-refiners
Mr. J. Swain	Consultant (EPA)
Mr. C.F. Schwarz	Consultant
Mr. D.A. Becker	National Bureau of Standards
Mr. T.C. Bowen	MERADCOM
Mr. E.A. Frame	USAFLRL

Although similar in physical properties, the six stocks show significant variation in their chemical makeups. There is a fair range in TAN between stocks, two stocks (AL-6690 and AL-6692) contain high sulfur levels, and a significant difference in trace element content can be observed. The higher level of trace elements in sample 6692 tends to confirm a lesser re-refining level for this stock.

Also, moderate variation was observed in the boiling point distribution and characteristic group analyses. Most significant is the lower 1- and 5-percent point values for sample 6694 and the higher saturate-lower aromatic contents shown for samples 6694 and 6696. The low 1- and 5-percent point values indicate that some of the light ends may not have been removed in the re-refining process and tend to confirm the comment made concerning the low flash point of this sample.

One last point that should be made is that the data for several re-refined stocks reflected values similar to that of the virgin stock. In other words, it would not be possible using these data to distinguish several of the re-refined stocks from a virgin stock.

III. FORMULATION OF RE-REFINED LUBRICANTS

The next phase of the program was the formulation of the selected stocks into finished engine lubricants. The major additive suppliers were contacted and asked for an additive system recommendation to meet MIL-L-46152 requirements. It was desired, but not required, that a single additive package be used for all six stocks. Also, the manufacturers were asked when making a recommendation to consider both the performance and economics of the finished products. A copy of the letter requesting additive company participation is included in Appendix A. Responses from the various additive suppliers are summarized as follows:

(1) All manufacturers recommended a package currently used in qualified MIL-L-46152 oils.

(2) With one exception, the additive system was recommended for use in all stocks at the same treatment level. One manufacturer, however, did recommend supplementing the basic system with additional inhibitors for three of the stocks.

(3) Except when additional inhibitors were recommended, the treating cost for the re-refined oils was the same as for virgin-based products.

In a meeting held on June 17, 1977, at EPA headquarters, the additive recommendations were reviewed with the ASTM task force. Table 6 gives the meeting attendees and their affiliations. One recommendation involving a single additive package for use in all stocks was selected. Drum quantities of the six re-refined stocks were shipped to the additive manufacturer for blending with the selected additive system. Table 7 shows the inspection/properties of the six formulated lubricants which were *all* treated with 7.7 vol % (8.76 wt %) of the recommended additive package. The additive elements show very close agreement among the six lubricants and reflect the excellent blending technique used by the additive manufacturer. In addition, the six oils were tested in accordance with FTMS 791B Method 3470 for compatibility. The test results indicate that the oils are compatible with products qualified under various military engine oil specifications.

TABLE 6
ATTENDEES AT RE-REFINED ENGINE OILS MEETING
JUNE 17, 1977

	Name	Affiliation
1.	Mr. H.B. Kaufman	EPA
2.	Mr. Jack Swain	EPA Consultant
3.	Mr. Don Becker	National Bureau of Standards
4.	Mr. Bob Pedall	National Bureau of Standards
5.	Mr. Duane Ekedahl	Association of Petroleum Re-refiners
6.	Mr. Michael L. Kerran	Double Eagle Refining Co.
7.	Mr. Michael Willingham	FEA
8.	Mr. C.J. Thompson	ERDA/BERC
9.	Mr. Harold Tiffany	API
10.	Mr. David M. Stehouwer	GM Research
11.	Mr. Thomas C. Bowen	MERADCOM
12.	Mr. Charles F. Schwarz	Consultant
13.	Mr. Leslie Mayot	Exxon
14.	Mr. William Crouse	Sun Oil Co. (ASTM)
15.	Mr. William Sanjoon	EPA

TABLE 7
FINISHED OIL INSPECTION DATA

Finished Oil	AL-	7067	7068	7069	7070	7071	7072
Re-refined Base	AL-	6692	6698	6690	6694	6696	6697
Properties	**Method**						
Vis., 210°F, cSt	D445	10.2	8.2	9.3	9.2	9.8	10.6
Vis., 100°F, cSt	D445	86.3	62.7	79.1	72.5	80.8	92.4
Vis., 0°F, cSt (Ext.)	D341	7125	4364	7084	5136	6321	8159
VI	D2270	107	107	103	111	109	106
API Gravity, °	D287	27.2	28.0	26.9	28.4	27.9	27.9
Carbon Residue, wt %	D524	1.17	1.02	1.15	1.11	1.10	1.09
Sulfated Ash, wt %	D874	0.98	0.96	0.95	0.95	0.97	0.96
Pour Point, °F	D97	5	10	10	10	15	10
Elemental:							
Ca, wt %	XRF	0.21	0.21	0.22	0.21	0.22	0.22
Ba, wt %	XRF	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Mg, ppm	AA	9	6	6	7	6	7
Zn, wt %	XRF	0.14	0.14	0.14	0.14	0.15	0.14
P, wt %	XRF	0.12	0.12	0.12	0.12	0.12	0.12
N, wt %	PE	0.019	0.027	0.026	0.025	0.023	0.026
S, wt %	XRF	0.64	0.46	0.59	0.47	0.46	0.46
Base oil S, wt %	XRF	0.34	0.16	0.31	0.14	0.12	0.15

IV. STANDARD ENGINE DYNAMOMETER TESTS

The finished re-refined lubricants were subjected to the standard engine dynamometer tests used to define oil performance under the MIL-L-46152 specification. This specification describes oils intended for use in both gasoline and in low- to medium-output, diesel-powered commercial vehicles which are operated by the military and other federal agencies. Oils that meet MIL-L-46152 specifications satisfy all the requirements of API service SE and CC. Custody of this specification is maintained by USAMERADCOM.

Table 8 summarizes the standard engine dynamometer tests required by MIL-L-46152 and shows the primary performance areas determined by each test. All engine tests were

TABLE 8
ENGINE TESTS OF MIL-L-46152

Engine Test	Primary Performance Areas
L-38	Bearing corrosion Piston varnish Multiviscosity oil-shear stability
Sequence IIC	Engine rust
Sequence IIIC	Oil Oxidation/Thickening Engine varnish Engine wear
Sequence VC	Engine sludge Engine varnish
Caterpillar 1-H2	Diesel engine piston deposits

performed by Southwest Research Institute (Division of Engines, Fuels and Lubricants), San Antonio, Texas.

Table 9 compares engine test results to the requirements of MIL-L-46152. The data are single test results which have been adjusted for laboratory severity effects observed during the testing period. The results have also been adjusted for accuracy as reviewed at the initial meeting of the SAE Interim Engine Oil Review Committee in Chicago, Illinois, October 31-November 2, 1977. It should be noted that data adjustments did not affect the results in regard to meeting specifications. All oils performed satisfactorily in the single-cylinder CLR L-38 and the Sequence IIC tests. In the Sequence IIIC test, all oils passed except

TABLE 9
SUMMARY OF PERFORMANCE TESTS ON REFINED ENGINE OILS

		Lubricant Formulation					
		Finished Lube					
		AL-7069	AL-7067	AL-7070	AL-7071	AL-7072	AL-7068
	MIL-L-	Base					
Test	46152	AL-6690	AL-6692	AL-6694	AL-6696	AL-6697	AL-6698
		L-38					
BWL, mg	40 max	28.4	22.0	14.9	4.8	8.2	20.9
Piston Varnish	–	9.7	9.7	9.7	9.7	9.7	9.7
		Sequence IIC					
Avg. Rust	8.4 min	8.4	8.7	8.7	8.9	8.5	8.7
Lifter Sticking	None	None	None	None	None	None	None
		Sequence IIIC					
% Vis. Increase							
@ 40 hr	400 max	105	111	126	88	69	62
@ 64 hr	–	166	173	4774	117	114	103
Sludge	9.2 min	9.8	9.8	9.6	9.7	9.7	9.7
Piston Varnish	9.3 min	9.3	9.2	9.5	9.4	9.5	9.4
Ring Land Deposit	6.0 min	7.95	8.1	7.6	8.3	8.0	8.1
Ring Sticking	None	None	None	None	None	None	None
Wear (Cam & Lifter)							
Scuffing	None	None	None	None	None	None	None
Average, in × 10^{-4}	10	2	2	3	4	3	3
Maximum, in × 10^{-4}	20	6	6	6	7	6	5
		Sequence VC					
Piston Varnish	7.9 min	7.9	8.0	7.9	8.2	8.1	7.9
Avg. Engine Varnish	8.0 min	7.9	8.3	8.2	8.3	8.6	8.4
Avg. Sludge	8.7 (8.5) min	9.6	9.6	9.6	9.6	9.6	9.6
Screen Clogging, %	5 max	0	0	0	0	0	0
Oil Ring Clogging, %	5 max	0	0	0	0	0	0
Compression Ring Sticking	None	None	None	None	None	None	None
		1-H2					
Top Groove Filling, %	45 max	9	1	24	2	12	10
Weighted Total Demerit	140 max	80.4	73.6	176.0	67.8	188.3	155

Value in parentheses indicates Manual No. 10 rating, other values by Manual No. 12 rating.

AL-7067 which was borderline fail in piston varnish. In the Sequence VC test, a potential problem was revealed in varnish deposits. Many average piston varnish results are at or just above the minimum MIL-L-46152 requirement level. Oil AL-7069 was a borderline fail, missing the required average engine varnish by 0.1 merits. In other VC areas such as sludging, clogging, and ring sticking, all oils performed satisfactorily. In the 1-H2 test, all oils showed acceptable performance in controlling top groove deposits. Piston cleanliness (lacquer deposits) resulted in three of the oils (AL-7070, AL-7072, AL-7068) failing to meet the specifications.

Oil AL-7071 passed *all* the engine performance tests of MIL-L-46152 (API service SE-CC). Oils AL-7070, AL-7071, AL-7068, and AL-7072 met the requirements for API service SE, while oils AL-7069, AL-7067 and AL-7071 met the API CC service requirements. These findings are summarized in Table 10.

TABLE 10
SUMMARY OF PERFORMANCE

Lubricant	MIL-L-46152	API Service	
		SE	CC
AL-7069	F	F	M
AL-7067	F	F	M
AL-7070	F	M	F
AL-7071	M	M	M
AL-7072	F	M	F
AL-7068	F	M	F

M = Met Requirements
F = Failed to meet requirements.

V. FIELD EVALUATION OF RE-REFINED ENGINE OIL

A portion of the joint EPA/DoD program involved a limited field evaluation of a re-refined oil. Specifically, the evaluation involved the teardown inspection of engines from six police cruisers operated by the city of San Diego, CA where re-refined oil had been used since February 1974. The complete results of this evaluation were reported in AFLRL Report No. 92, "Inspection of Police Cruiser Engines Operated Using Re-Refined and Virgin-Based Crankcase Lubricants" which is available through the Defense Documentation Center, Cameron Station, Alexandria, VA under accession number AD A045330.

Table 11 shows a summary of the vehicles inspected and the observed deposit ratings. To briefly summarize these data, the San Diego (SD) vehicles had moderate engine varnish, light sludge, and very light rust. It is believed these data indicate the re-refined product provided satisfactory performance under the operating conditions encountered by the city of San Diego police cruisers.

TABLE 11
1974 FORD TORINOS
SAN DIEGO, CA POLICE CRUISERS
OPERATED ON RE-REFINED ENGINE OILS[a]

SDPD Unit No.	Veh. ID No.	Eng. Type	Manuf. Date	Odometer Miles	Avg. Deposit Ratings, Merits				
					Varnish		Sludge	Rust	Int.
					Pistons	Engine	Engine	Lifters	Valves
701	4H27H178785	351C	3-74	96,590	5.7	7.0	9.3	9.8	7.8
712	4H27H178853	351C	3-74	91,328	6.3	6.8	9.5	9.8	8.0
723	4H27H178864	351C	3-74	109,703	6.4	5.7	9.2	9.8	9.4[b]
730	4H27H178851	351C	3-74	104,514	6.3	6.3	9.3	9.8	8.1
764	4H27H178820	351C	3-74	88,267	6.3	6.8	9.3	9.8	9.2
742	4H27H178798	351C	3-74	91,395	6.0	6.2	9.3	9.8	8.1

[a]Oil and filter changed at 4,000-mile intervals.
[b]Recond. heads@ 84,664, 5/76.
Deposit ratings made in accordance with standard CRC techniques where 10 = clean.

VI. SUMMARY/CONCLUSIONS

Overall, the test work produced encouraging results for the future use of re-refined engine oils. Based on the single test evaluations of the six formulated oils, four passed the performance requirements of API service SE, three met the API CC classification, and one oil passed all the performance tests of specification MIL-L-46152 (API service SE and CC). Although variations in specific pass/fail results could be expected with further testing or reformulation, the data as reported demonstrate the technical feasibility of producing SE, CC, and MIL-L-46152 quality level lubricants from re-refined base stocks.

Characterization of the base stocks using standard laboratory analytical techniques showed significant variation between physical and chemical makeup of these samples. Although these differences were noted and could be related to re-refining treatment, they could not be effectively correlated with the performance demonstrated by the finished engine oils. Therefore, further research needs to be conducted to establish characterization techniques and quality conformance tests for both virgin and re-refined base stocks.

VII. RECOMMENDATIONS

Considering the encouraging results of this program, the following recommendations are made:

(1) Develop baseline data concerning the feasibility of formulating MIL-L-2104C lubricants from re-refined components.

(2) Conduct a *well-controlled* fleet test of administrative service vehicles at a government installation using commercially available re-refined engine oil and/or

a re-refined oil of the same type as was engine tested in the current program. The test should include a qualified MIL-L-46152 virgin-base lube which uses the same additive treatment as the re-refined oils. This fleet test will provide a *direct performance comparison* between re-refined engine oil and a qualified MIL-L-46152 oil in administrative-type service.

(3) Perform additional research to better define base stock characterization techniques and quality conformance tests which correlate with engine performance for both virgin and re-refined base stocks.

VIII. REFERENCES

(1) Kimball, V.S., "Waste Oil Recovery and Disposal," Noyes Data Corporation, 1975.

(2) U.S. Military Specification MIL-L-46152, "Lubricating Oil, Internal Combustion Engine, Administration Service," November 1970.

(3) API Publication 1509 (sixth edition).

(4) ASTM Research Report D2:1002, January 1971.

(5) SAE J183a, Engine Oil Performance and Engine Classification.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance provided by Mr. S.J. Lestz of AFLRL, SwRI Division of Engines, Fuels and Lubricants, to all additive suppliers who participated in the program, and especially to the supplier whose package was used. Special recognition is made of the Association of Petroleum Re-Refiners and companies who submitted samples for the program. The review and guidance of the ASTM Re-Refined Oils Task Force was greatly appreciated.

APPENDIX A

CORRESPONDENCES

Association of Petroleum Re-refiners

1730 Pennsylvania Avenue, N.W.
Washington, D. C. 20006 202 / 785-05[illegible]

July 7, 1976

Mr. Larry McEwen
Environmental Protection Agency
401 M Street S.W.
AW 463
Washington DC 20460

Dear Larry:

Enclosed for your files are copies of the mailing sent to the members of the Association of Petroleum Re-refiners and all othe. re-refiners on your list encouraging full cooperation with your test program. A copy has also been sent to Tom Bowen at Fort Belvoir.

We should have a good idea of the number of companies participat. as the return forms are received, and we will keep you posted on this.

Let us know if we can help in any other way.

Attached is the list of Canadian re-refiners requested.

With best regards,

Duane H. Ekedahl
Executive Director

DHE/jl
Enclosures

cc: Mr. Tom Bowen, Fort Belvoir, Virginia

Association of Petroleum Re-refiners

1730 Pennsylvania Avenue, N.W.
Washington, D.C. 20006

June 30, 1976

Subject: Test Program By Environmental Pr... Agency

Gentlemen:

This letter, by request of EPA, is being addressed to the membe... of APR, including Canadian members, and other re-refiners from ... list submitted by EPA.

The purpose of the EPA test program as described in the enclosed materials is to reevaluate federal procurement policies which di... criminate against re-refined products.

> "The purpose of this effort is to examine variations in re... refined oil base stock and to estimate the effect of these variations on the ability of the blended product to qualify under existing military specifications. The results of this contract will be used in re-evaluating Federal lubricating oil procurement specifications which currently prohibit the purchase of re-refined products."

At the meeting of the Board of Directors of APR in Washington in February, and at our October annual meeting in Las Vegas, the EPA test plan was reviewed and it was decided that the Association would give its full support to this effort.

Although changing the federal specifications may not seem to di... affect your business, it is clear that this prohibition has hu... industry in many ways which go far beyond the mere selling of ... refined oil to government agencies. It has cast into question ... quality of re-refined products for all purposes. We see this as ... opportunity for the industry to bury this issue once and for all. Positive results will not only lead to greater acceptance of re... broadly by industry and the public, but will enhance our chance... gaining a national program for waste oil collection and re-refi... and help our efforts toward the acceptance of federal and state ... lations to encourage the growth of the industry.

the results of the EPA tests will be incorporated in the Bureau's Standards testing program. As you know, the Bureau has now begun to develop tests to demonstrate the equivalency of re-refined oil with new oil as mandated in the Energy Conservation and Oil Policy Act of 1975, which API is following closely.

The enclosed materials describe the EPA test program. You will see the testing is in two stages. First is a laboratory analysis on oil samples and second the engine sequence test on selected samples. In total, you are being asked to prepare three samples:

1. Ten gallons of base stock for the laboratory analysis

2. A 55 gallon drum of base stock for possible engine sequence testing.

3. Five gallons of feed stock from which the base stock is produced.

Upon completion of the laboratory analysis, we are told that each re-refiner will be advised of the findings on his product. At that time he will have the opportunity of declining to have his material subjected to the engine sequence test if he wishes.

We ask that you now do the following:

A. Return the enclosed form to this office, indicating you have received this letter and whether or not you intend to participate.

B. Prepare the 5 gallon feedstock sample and 10 gallon base stock sample to be sent by July 30, if possible, to:

Mr. Tom Bowen
U.S. Army Mobility Equipment Research &
Development Command
Building 335
Fort Belvoir VA 22060
Attention: DRXFB-GL

C. Send these samples to Mr. Bowen with a letter giving information as to the intended use of the base stock, where the feed stock originated if available, and any information you wish to submit regarding blending operations, including bright stock and additive packages which would be helpful in the evaluation.

D. Also, set aside and hold 55 gallons of the same base stock for possible engine sequence test at a future date.

PLEASE RETURN THE ENCLOSED FORM TODAY.

PLEASE SEND THE TWO SAMPLES TO MR. BOWEN BY JULY 30, IF POSSIBLE.

Thank you for giving this your attention. Call us if you have any questions.

Very truly yours,

Duane H. Ekedahl
Executive Director

DHE/jj
Enclosures

LETTER RETYPED FOR REPRODUCTION PURPOSES

June 30, 1976

Subject: Test Program By The Environmental Protection Agency

Gentlemen:

This letter, by request of EPA, is being addressed to the members of APR, including Canadian members, and other re-refiners from a list submitted by EPA.

The purpose of the EPA test program as described in the enclosed materials is to reevaluate federal procurement policies which discriminate against re-refined products.

> "The purpose of this effort is to examine variations in re-refined oil base stock and to estimate the effect of these variations on the ability of the blended product to qualify under existing military specifications. The results of this contract will be used in re-evaluating Federal lubricating oil procurement specifications which currently prohibit the purchase of re-refined products."

At the meeting of the Board of Directors of APR in Washington in February, and at our October annual meeting in Las Vegas, the EPA test plan was reviewed, and it was decided that the Association would give its full support to this effort.

Although changing the federal specifications may not seem to directly affect your business, it is clear that this prohibition has hurt the industry in many ways which go far beyond the mere selling of re-refined oil to government agencies. It has cast into question the quality of re-refined products for all purposes. We see this as an opportunity for the industry to bury this issue once and for all. Positive results will not only lead to greater acceptance of re-refining broadly by industry and the public but will enhance our chances of gaining a national program for waste oil collection and re-refining and nelp our efforts toward the acceptance of federal and state regulations to encourage the growth of the industry.

The results of the EPA test will be incorporated in the Bureau of Standards testing program. As you know, the Bureau has now begun to develop tests to demonstrate the equivalency of re-refined oil with new oil as mandated in the Energy Conservation and Oil Policy Act of 1975, which APR is following closely.

The enclosed materials describe the EPA test program. You will see the testing is in two stages. First is a laboratory analysis on all samples and second the engine sequence test on selected samples. In total, you are being asked to prepare three samples:

1. Ten gallons of base stock for the laboratory analysis.

2. A 55 gallon drum of base stock for possible engine sequence testing.

3. Five gallons of feedstock from which the base stock is produced.

Upon completion of the laboratory analysis, we are told that each re-refiner will be advised of the findings on his product. At that time he will have the opportunity of declining to have his material subjected to the engine sequence test if he wishes.

We ask that you now do the following:

A. Return the enclosed form to this office, indicating you have received this letter and whether or not you intend to participate.

B. Prepare the 5 gallon feedstock sample and 10 gallon base stock sample to be sent by July 30, if possible to:

Mr. Tom Bowen
U.S. Army Mobility Equipment Research &
Development Command
Building 335
Fort Belvoir VA 22060
Attention: DRXFB-GL

C. Send these samples to Mr. Bowen with a letter giving information as to the intended use of the base stock, where the feedstock originated if available, and any information you wish to submit regarding blending operations, including bright stock and additive packages which would be helpful in the evaluation.

D. Also, set aside and hold 55 gallons of the same base stock for possible engine sequence test at a future date.

PLEASE RETURN THE ENCLOSED FORM TODAY.

PLEASE SEND THE TWO SAMPLES TO MR. BOWEN BY JULY 30, IF POSSIBLE.

Thank you for giving this your attention. Call us if you have any questions.

Very truly yours,

Duane H. Ekedahl
Executive Director

DHE/jl
Enclosures

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

Bowen/1t/43576

EAI 4-18-77

DRDME-GL

7 April 1977

SEE DISTRIBUTION

Gentlemen:

The purpose of this letter is to solicite your assistance in the EPA-DoD Re-refined Oil Program. To date, fifteen (15) samples of re-refined base stocks have been collected and their physical and chemical characteristics determined using standard laboratory techniques. Through cooperative effort with the ASTM Re-refined Oil Task Force, the six (6) stocks described in the inclosed table have been selected for formulation with additives and performance testing of the finished products. We would appreciate your recommendations for an optimum additive system (s) to be used with the selected stocks and your assistance in blending the finished products.

It is desired to formulate the finished oils to meet the performance requirements of Military Specification MIL-L-46152. Since only re-refined stocks will be used, the viscosity and flash point requirements of the specification need not be considered. Although a single additive system for use in all stocks is preferred, recommendations for several systems are acceptable. It is noted that consideration should be given to both the performance characteristics and economics of the finished products. Samples of the re-refined stocks and additional information as necessary to provide a recommendation may be obtained by contacting Mr. Bowen of this office, (703-664-4595).

DRDME-GL 7 April 1977

It is envisioned that all products will be formulated with additive systems obtained from a single supplier. Selection of a recommendation will be made in cooperation with the ASTM Task Force. To assist in this selection, we would appreciate being provided as much of the background information as possible on which you based your recommendation. Also, it is desired that data be provided relating your recommendation to systems used with virgin stocks from an economical and general compositional basis. Since there are time constraints on completing the program, it is requested that all recommendations be received by this office no later than 30 April 1977.

In October 1978, Public Law 94-580 will require Federal Agencies to "Procure items composed of the highest percent of recovered materials practicable". With the guidelines provided, it is clear this legislation is intended to include re-refined engine oil. Therefore, your participation in this program will provide valuable assistance in addressing this complex technological problem.

Thank you for your consideration in this matter.

Sincerely yours,

Maurice E. LePera

MAURICE E. LEPERA
Chief, Fuels & Lubricants Division

CF: EPA, (Mr. Kaufman)
AFLRL, (Mr. Lestz)
AFLRL, (Mr. Frame)
Sun Oil (Mr. Crouse)

DISTRIBUTION LIST

Amoco Chemicals Company, Mr. G.D. Barth
Chevron Chemicals Company, Mr. W.F. Wagner
Edwin Cooper Incorporated, Mr. D.W. Dinsmore
The Lubrizol Corporation, Mr. James Creedon
Paramins Laboratories, Mr. A.A. Schetelich
Texaco, Incorporated, Mr. R.E. Paggi

APPENDIX B

PROCEDURE FOR THE AROMATICITY DETERMINATION (wt % ring carbon) BY UV SPECTROSCOPY

This is a procedure developed at USAFLRL (See AFLRL Report No. 103, 2/78)

(1) Weigh to the nearest 0.1 mg, approximately 50 mg of sample and dilute to 10 ml with spectroscopic grade cyclohexane.

(2) Scan in a variable path length cell* from 350-190 nm.

(3) The mono-, di-, and tri-aromatics have absorbance maxima at 195, 225, and 255 nm respectively.

(4) Using Beer's Law: A = abc, where

A = absorbance
a = absorption coefficient, ml/mg-cm
b = path length
c = concentration

(5) Standards were scanned to calculate average absorption coefficients.

*The variable cells are used so that path length may be varied, thus eliminating the error which accompanied dilution methods. Also, off-the-shelf spectrograde solvents may be used without further purification because of the short paths possible in the deep UV region.

APPENDIX C
ANALYSES OF LATE ARRIVING OILS

Sample I.D.	Method			
AL-		7040	7041	7042
Inspections				
KVis @ 40°C	D445	85.06	85.26	56.13
KVis @ 100°C	D445	10.31	10.38	7.77
VI	D2270	103	104	102
API°	D287	29.1	29.4	29.9
ASTM Color	D1500	4.5	4.5	4.5
Carbon Residue, wt %	D524	0.16	0.13	0.12
Pour Point, °C	D97	−13	−24	−12
Flash Point, °C	D92	240	246	240
TAN	D664	0.01	0.01	0.09
TBN	D2896	0.00	0.00	0.00
Saponification No.	D94	0.15	0.15	0.35
Elemental Analyses				
Barium, ppm	AA	<5	<5	<5
Calcium, ppm	AA	<5	<5	<5
Chlorine, ppm	XRF	<100	<100	<100
Lead, ppm	AA	2	2	2
Copper, ppm	AA	<1	<1	<1
Iron, ppm	AA	6	<2	<2
Sodium, ppm	AA	515	508	511
Silicon, ppm	AA	<1	<1	<1
Magnesium, ppm	AA	<1	<1	<1
Nitrogen, ppm	PE	26	33	45
Sulfur, wt %	XRF	0.14	0.14	0.36
Phosphorus, ppm	XRF	<100	<100	<100
GC BP Distribution				
wt % off @ °C				
1		358	358	325
5		395	395	371
10		415	415	391
50		498	502	476
90		–	–	555
Residue, wt % >600°C		11	12	0 (598 EP)

DISTRIBUTION LIST

	No. of Copies
DEFENSE DOCUMENTATION CENTER CAMERON STATION ALEXANDRIA VA 22314	12
HAZARDOUS WASTE MGMT DIV OFC OF SOLID WASTE MGMT PROGRAMS US ENVIRONMENTAL PROTECTION AGENCY 401 M STREET WASHINGTON DC 20460	5
NATIONAL BUREAU OF STANDARDS MGR, RECYCLED OIL PROGRAM US DEPARTMENT OF COMMERCE WASHINGTON DC 20234	3
BARTLESVILLE ENERGY RES CTR US ENERGY R&D ADMIN BOX 1398 BARTLESVILLE OK 74003	2
COMMANDER ATTN DRDME-GL US ARMY MOBILITY EQUIPMENT R&D COMMAND FORT BELVOIR VA 22060	60
SOUTHWEST RESEARCH INSTITUTE US ARMY FUELS AND LUBRICANTS RES LAB 6220 CULEBRA ROAD SAN ANTONIO TX 78284	10
COMMANDER ATTN DFSC-AE (MR C MARTIN) DEFENSE LOGISTICS AGENCY CAMERON STATION ALEXANDRIA VA 22314	2
HQ DEPT OF ARMY ATTN DALO-TSE DAMA-CSS-P (DR BRYANT) WASHINGTON DC 20310	1 1
COMMANDER ATTN DRCLDC (MR ZENTNER) DRCMM-SP (MR VANDIVIER) US ARMY MATERIEL DEVELOPMENT & READINESS COMMAND 5001 EISENHOWER AVE ALEXANDRIA VA 22333	1 1
COMMANDER ATTN DRDTA-R US ARMY TANK-AUTOMOTIVE R&D COMMAND WARREN MI 48090	1
COMMANDER ATTN DRSTA-G DRSTA-GBP (MR McCARTNEY) US ARMY TANK-AUTOMOTIVE MATERIEL READINESS COMMAND WARREN MI 48090	1 1
DIRECTOR ATTN DRXSY-CM (MR WOOMERT) US ARMY MATERIEL SYSTEMS ANALYSIS AGENCY ABDEEN PVG GD MD 21005	1
COMMANDER ATTN DAVDL-EU-MOR (MR BARTONE) US ARMY RES & TECH LABS APPLIED TECH LAB FORT EUSTIS VA 23604	1
HQ 172ND INFANTRY BRIGADE (ALASKA) ATTN AFZT-DI-L DIRECTORATE OF INDUSTRIAL OPERATIONS APO SEATTLE 98749	1
COMMANDER ATTN STSGP-FT STSGP-PE US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY NEW CUMBERLAND ARMY DEPOT NEW CUMBRLAND PA 17070	1 1
COMMANDER ATTN STSGP-PW US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY SHARPE ARMY DEPOT LATHROP CA 95330	1
COMMANDER ATTN DRXST-MT1 US ARMY FOREIGN SCI & TECH CTR FEDERAL BLDG CHARLTTESVILLE VA 22901	1
COMMANDER ATTN DRXMD-TP US ARMY MAINTENANCE MGMT CTR LEXINGTON KY 40511	1
HQ US ARMY TEST & EVALUATION COMMAND ATTN DRSTE-TO-O ABDEEN PVG GD MD 21005	1
HQ US ARMY ARMAMENT R&D COMMAND ATTN DRDAR-PMP DOVER NJ 07801	1
HQ US ARMY TROOP SUPPORT & AVIATION MATERIEL READINESS COMMAND ATTN DRSTS-MEG 4300 GOODFELLOW BLVD ST LOUIS MO 63120	2
COMMANDER ATTN ATCD US ARMY TRAINING & DOCTRINE COMMAND FT MONROE VA 23651	1

	No. of Copies
HQ US ARMY AVIATION R&D COMMAND ATTN DRDAV-EQ (MR CRAWFORD) BOX 209 ST LOUIS MO 63166	1
COMMANDER ATTN AFLG-REG (MR CARBO) US ARMY FORCES COMMAND FT McPHERSON GA 30330	1
COMMANDER ATTN STEAP-MT US ARMY ABERDEEN PROVING GROUND ABDEEN PVG GD MD 21005	1
COMMANDER ATTN STEYP-MT US ARMY YUMA PROVING GROUND YUMA AZ 85364	1
PROJ MGR M60 TANK DEVELOPMENT ATTN DRCPM-M60-TDT WARREN MI 48090	1
PROJ MGR MOBILE ELECTRIC POWER ATTN DRCPM-MEP-TM 7500 BACKLICK ROAD SPRINGFIELD VA 22150	1
PROJ MGR PATRIOT PROJ OFC ATTN DRCPM-MD-T-G US ARMY DARCOM REDSTNE ARSNL AL 35809	1
OFC OF PROJ MGR FAMECE/UET ATTN DRCPM-FM US ARMY MERADCOM FORT BELVOIR VA 22060	1
COMMANDER ATTN ATSM-CTD-MS (MAJ BREWSTER) ATSM-TNG-PT (LTC VOLPE) US ARMY QUARTERMASTER SCHOOL FORT LEE VA 23801	1 1
COMMANDER ATTN ATCL-MS US ARMY LOGISTICS CTR FORT LEE VA 23801	1
HEADQUARTERS USAF ATTN RDPS (MR EAFFY) WASHINGTON DC 20330	1
COMMANDER ATTN AFAPL/SFF (MR CHURCHILL) AFAPL/SFL (MR JONES) USAF AERO PROPULSION LAB WRT-PTRSN AFB OH 45433	1 1
COMMANDER ATTN SAALC/SFQ USAF SAN ANTONIO AIR LOGISTICS CTR KELLY AFB TX 78241	
COMMANDER ATTN AFML/MBT AFML/MXE USAF MATERIALS LAB WRT-PTRSN AFB OH 45433	1 1
COMMANDER ATTN MMEAP USAF WARNER ROBINS AIR LOGISTICS CTR ROBINS AFB GA 31098	1
COMMANDER ATTN PE-7 NAVAL AIR PROPULSION CTR TRENTON NJ 08628	1
COMMANDER ATTN CODE 6101F (MR R LAYNE) NAVAL SHIP ENG CTR WASHINGTON DC 20362	1
COMMANDER ATTN CODE 2830 (MR G BOSMAJIAN) CODE 2831 DAVID TAYLOR NAVAL SHIP R&D CTR ANNAPOLIS MD 21402	1 1
JOINT OIL ANALYSIS PROGRAM—TECH SUPPORT CTR ATTN CODE 360 (MR R LEE) NAVAL AIR REWORK FACILITIES PENSACOLA FL 32508	1
DEPT OF THE NAVY ATTN LMM (LTC BEASON) HQ US MARINE CORPS WASHINGTON DC 20380	1
COMMANDER ATTN CODE 52032E (MR WEINBURG) NAVAL AIR SYSTEMS COMMAND WASHINGTON DC 20361	1
COMMANDER ATTN CODE 30212 (MR L STALLINGS) NAVAL AIR DEVELOPMENT CTR WARMINSTER PA 18974	1
COMMANDER ATTN CODE 6170 (MR H RAVNER) CODE 6180 NAVAL RES LAB WASHINGTON DC 20375	1 1

	No. of Copies
CHIEF OF NAVAL RESEARCH ATTN CODE 473 (DR R MILLER) ARLINGTON VA 22217	1
DEPT OF DEFENSE ATTN DASA (MRA & L)-ES MR WJ HORTON WASHINGTON DC 20301	1
COMMANDER ATTN CODE 92724 (MR SENHOLZI) NAVAL AIR ENG CTR NAVAL AIR STATION LAKEHURST NJ 08733	1