U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-251 716

A Technical and Economic Study of Waste Oil Recovery Parts IV, V and VI

Teknekron, Inc.

Prepared For
Environmental Protection Agency

October 1975

A TECHNICAL AND ECONOMIC STUDY OF WASTE OIL RECOVERY

EPA No. 68-01-2904

PART IV ENERGY CONSUMPTION IN WASTE OIL RECOVERY

by Peter M. Cukor and Timothy Hall Report No. EEED 109

PART V A FIELD TEST OF THE QUALITY OF RE-REFINED LUBE OILS

by Peter M. Cukor Report No. EEED 109

PART VI A REVIEW OF RE-REFINING ECONOMICS

by Peter M. Cukor Report No. EEED 109

Prepared for

Office of Solid Waste Management
Programs
U.S. Environmental Protection Agency
Washington, D.C.

Project Officers:

Mr. Laurence B. McEwen, Jr.
Dr. John H. Skinner

ENERGY AND ENVIRONMENTAL ENGINEERING DIVISION
Teknekron, Inc.
2118 Milvia Street
Berkeley, CA 94704 (415)848-1464

October 25, 1975

BIBLIOGRAPHIC DATA SHEET

1. Report No.
EPA/530/SW-90 C.4

2.

3. Recipient's Accession No.

4. Title and Subtitle
A Technical and Economic Study of Waste Oil Recovery
Parts 4, 5 and 6: Energy consumption in waste oil recovery, a field test of re-refined lube oil quality, a review of re-refining economics.

5. Report Date
October, 1975

6.

7. Author(s)
Peter M. Curor and Timothy Hall

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Teknekron, Inc. and the Institute of Public Administration
2118 Milvia Street
Berkeley, Calif. 94704

10. Project/Task/Work Unit No.

11. Contract/Grant No.
EPA Contract No: 68-01-2904

12. Sponsoring Organization Name and Address
Office of Solid Waste Management Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

13. Type of Report & Period Covered
Final 1 year

14.

15. Supplementary Notes
Part 1 printed as PB-237 618; Part 2 printed as PB-237 619; Part 3 printed as PB-237.620

16. Abstracts

Part 4: An energy balance of waste oil recycling as lube oil and waste oil recovery as fuel oil.

Part 5: A description of a potential field test re-refined lube oil utilizing motor vehicles on a federal facility.

Part 6: An update of re-refining economies reflecting increased prices of petroleum products (1974-75).

17. Key Words and Document Analysis. 17a. Descriptors

Secondary Oil Recovery, Economic Analysis

17b. Identifiers/Open-Ended Terms

Waste Oil re-refining, recycling, re-refining industry analysis.

17c. COSATI Field/Group

18. Availability Statement

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page
UNCLASSIFIED

21. No. of Pages

FORM NTIS-35 (REV. 3-72)

USCOMM-DC 14952-P72

A TECHNICAL AND ECONOMIC STUDY OF WASTE OIL RECOVERY

This final report (SW-90c.4) describes work performed for the Federal solid waste management programs under contract no. 68-01-2904 to TEKNEKRON, INC. and is reproduced as received from the contractor

U.S. ENVIRONMENTAL PROTECTION AGENCY

1976

ACKNOWLEDGEMENT

Teknekron, Inc. wishes to acknowledge the Resource Recovery Division, Office of Solid Waste Management Programs, U.S. Environmental Protection Agency, for support of this study. In particular we are grateful to Mr. Laurence B. McEwen, Jr., the Project Officer and Dr. John H. Skinner, Deputy Director, Resource Recovery Division for their guidance and assistance in the conduct of this research.

Teknekron, Inc. would also like to acknowledge the assistance of Mr. Joseph Urbanek, Special Assistant for Environmental Quality and Ms. Paula McLain, Staff Assistant for Environmental Quality, Property Disposal Division, Defense Supply Agency for their assistance in providing data concerning waste oil disposal by military facilities.

We would also like to express our sincere appreciation to the following individuals and organizations whose assistance was vital in completing this project.

The six re-refiners interviewed

Mr. Belton R. Williams, President, Association of Petroleum Re-refiners

Mr. Thomas Sheahan, Mr. Curtis Gordon and Mr. Donald Eriksen, the Lubrizol Corporation

Mr. George Weamer, Chevron Research Company, Standard Oil Company of California.

EPA Review Notice

A TECHNICAL AND ECONOMIC STUDY
OF WASTE OIL RECOVERY

PART IV *Energy Consumption in Waste Oil Recovery*

by Peter M. Cukor and Timothy Hall

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION AND SUMMARY

1.1 Introduction

Studies of the disposition of waste lubricating oils have shown that burning for energy recovery and re-refining to produce recycled lubricants are two possible methods for utilizing the resource value of these materials. This chapter analyzes material balances, energy requirements and the energy conservation potential of these alternatives by considering the following cases:

Case A Waste lube oils are dried and used for fuel. The potentially recoverable lube oil which has been lost is replaced by manufacture of virgin lube oil from atmospheric reduced crude oil using standard refining processes.

Case B Lubricating oils are recovered and recycled by re-refining the waste oils using the acid/clay process. Virgin lube oil production, in Case A, is reduced by the amount of oil recycled.

1.2 Summary

The results of the material balance and energy consumption calculations are summarized in Table 1. In Case A, where waste crankcase oils are converted to fuel oil, and Case B, where waste crankcase oils are re-refined to produce lube oil, the total lube oil production (equal to the sum of production figures for virgin lube oil and re-refined lube oil) is 4,950 barrels per day. Since virgin lube oil production in Case A is nearly three times that in Case B, the process energy consumed is nearly three times as great. Although the process energy consumed in recovery of fuel oil or lube oil from waste crankcase oils is small, significant losses of hydrocarbons occur during re-refining. Losses of lube oil during use in automobiles are the same for the two cases.

Comparison of the figures for total energy consumption for the two cases reveals that production of lubricating oils by re-refining waste oils shows a net energy savings of about 20,970 Btu per gallon of oil produced over production of a like amount of lube oils from virgin atmospheric reduced crude, assuming in both cases that all products other than the produced lubes are burned as fuel.

Re-refining the 221 million gallons per year of waste crankcase oils burned as fuel plus the 290 million gallons (1972 volumes) disposed of by methods not involving energy recovery would result in an annual energy savings of at least 1.5 million barrels of crude oil equivalent. This is equal to an annual savings of fuel oil expense and currency outflow for foreign crude of about $18 million.

Table 1

SUMMARY OF MATERIAL BALANCE AND ENERGY CONSUMPTION CALCULATIONS

Disposition of Waste Lube Oils	Case A to Fuel Oil	Case B to Re-Refining
Production of Lube Oil (barrels/day)		
By refining of atmospheric reduced crude	4,950	1,790
By re-refining of waste crankcase oils	-	3,160
Total lube oil production	4,950	4,950
Energy Consumption (Btu's/day)		
Process energy consumed in virgin lube oil production	15.28×10^9	5.52×10^9
Process energy consumed in recovery of fuel oil (Case A) or recovery of re-refined lube oil (Case B) from waste oil	0.26×10^9	0.86×10^9
Hydrocarbon losses		
During lube oil use in automobiles	5.94×10^9	5.94×10^9
During re-refining	-	4.80×10^9
Total Energy Consumption (Btu's/day)	21.48×10^9	17.12×10^9

$$\frac{\text{Energy Consumed in Case A} - \text{Energy Consumed in Case B}}{\text{Total Lube Oil Production}}$$

$$= \frac{(21.48 \times 10^9 - 17.12 \times 10^9)\ \text{Btu's/day}}{4.950\ \text{b/d} \times 42\ \text{gal/b}} = 20{,}970\ \text{Btu's/gal}$$

The advantages of re-refining waste lube oils over burning, cited above, are based on the presently used acid/clay techniques. Any new technology, such as combinations of solvent-extraction, vacuum distillation, hydrotreating, etc., which increases lube oil recovery without an offsetting increase in process energy consumption would improve the energy conservation aspects of re-refining.

2.0 ASSUMPTIONS

This study is based on the following assumptions:

A. A reduced crude is charged to vacuum distillation followed by deasphalting of vacuum residuum, solvent extraction, hydrotreating and dewaxing of lube charge stock. The overall yield based on reduced crude is 21.8 volume percent base lube stocks.

B. Lube oil losses during use (in automobiles) are 20 volume percent*.

C. During use, the lube oil becomes contaminated with water and gasoline. As a result, the waste lube oil contains 6.8 volume percent water and 3.2 volume percent gasoline plus light fuel oils[3]. The gasoline and light fuel oils are recoverable as fuel oil.

D. Lube oil recovery in re-refining is 80 percent of the lube oil fraction in the waste oil feed. This is equivalent to an overall yield of 72 percent of the waste oil feed[4]. All calculations are based on re-refining by the acid/clay process.

E. Both cases assume 4,950 barrels per day of lube oil are charged to the "users." Based on assumptions B and C, 4,400 b/d of waste oil are available for use as feedstock for re-refining or for fuel recovery. This figure includes water and gasoline plus light fuel oil.

* These losses result from burning in the engine and spillage.

Preceding page blank

3.0 ANALYSIS OF CASE A:
LUBE OIL PRODUCTION AND WASTE OIL DISPOSAL BY BURNING

Figure 1 is a flowsheet typical of modern lube oil plants. The general process described is capable of producing high quality lube oils from a wide range of crude oil sources. Certain crudes which are especially suitable for use in lube manufacture (e.g., Pennsylvania and Mid-Continent crudes) can be used with either less intensive processing at each step, or with elimination of some steps. Conversely, use of crudes high in aromatics, asphaltenes or sulfur will require more intensive processing in some of the steps. Further, different lube oil feedstocks will yield different volumes of products per barrel of throughput. Hence, the process energy requirements to produce a gallon of lube oil depend strongly on the physical and chemical properties of the crude oil fractions which are being processed and the selection of processing steps and sequence. The effect of lube oil yield on process energy requirements is examined in some detail in Section 6.2.

Also, for a given crude oil, the fraction which is converted to lube oil varies from firm to firm depending on the pattern of demand for the company's products and the relative economics of producing lube oil or fuels. For example, in the early part of 1974, price controls were removed from petroleum fuels, but not from lube oils. Hence, it became more profitable to crack the light and medium lube distillates than to process these materials to lube oils. As a result, lube oil stocks were drawn down. In some instances, oil companies put large consumers on lube oil allocation.

3.1 Atmospheric and Vacuum Distillation

Atmospheric (not shown) and vacuum distillation are the first two processing steps in a typical refinery. The heavy crude fraction (reduced crude) from the bottom of the atmospheric distillation unit is vacuum distilled to produce light, medium and heavy distillates. The residuum from the vacuum unit may be used in heavy fuel oil or processed further, as in this case, to yield a heavy lube charge stock.

Although atmospheric and vacuum distillation of crude oil are energy intensive processes, it is quite difficult to justify assigning a given portion of the energy consumed to the manufacture of lube oil. Even if no lube oil were produced, these two steps might be carried out with the same energy consumption and the distillates produced would be converted to fuels. Hence energy consumed in the atmospheric and vacuum distillation steps has been omitted from the present calculation.

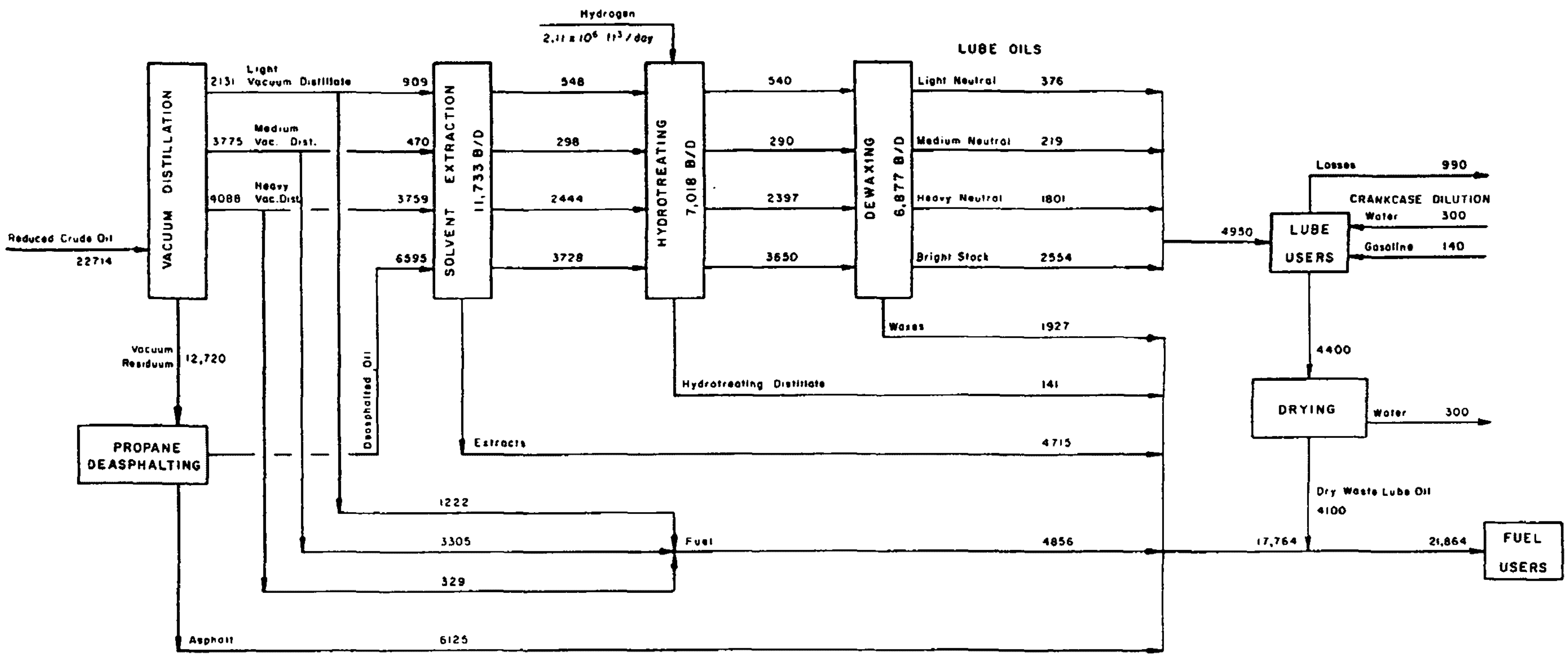
Preceding page blank

Figure I

CASE A

LUBE OIL PRODUCTION and WASTE OIL DISPOSAL by BURNING

All Throughputs expressed in Barrels per Stream Day



3.2 Propane Deasphalting

The residuum from the vacuum distillation tower is treated with propane to separate asphalt from the heavy oil. The separation is based upon the difference in the solubility of the asphalt and the heavy oil in propane. The products are deasphalted oil solution and an asphalt solution. The exit solutions are processed through evaporation and steam stripping to recover the propane from the oil and asphalt products.

3.3 Solvent Extraction

Lube distillates from the vacuum tower and the deasphalted oil are separately extracted in a blocked operation with furfural, a commonly used organic compound which has a high solvent power for those components of petroleum which are relatively unstable to oxygen as well as other undesirable materials including color bodies, resins, carbon-forming constituents and sulfur compounds. A typical furfural extraction unit consists of an extraction or treating section, sections for the recovery of furfural from the refined oil and extract solutions, water removal facilities, process surge tanks, and pumping equipment.

3.4 Hydrotreating

The oil raffinate from the furfural extraction unit, together with hydrogen, are fed to a reactor. Hydrotreating improves the viscosity index and color stability of the processed oils and serves to remove sulfur, nitrogen and metal bearing compounds and carbon residues from the lube oil feedstocks.

3.5 Hydrogen by Steam Reforming

The hydrogen consumed in the hydrotreating process is typically manufactured by passing sulfur-free natural gas and superheated steam through nickel catalyst tubes at a temperature of 1400°F to 1600°F. The reformed gas contains hydrogen, carbon monoxide, carbon dioxide and excess steam. This gas is cooled and passed through shift converters where the carbon monoxide is reacted with steam in the presence of a catalyst to produce hydrogen and carbon dioxide. The carbon dioxide is removed by scrubbing, and the residual carbon dioxide is removed by methanation. The product gas typically contains 95-97% hydrogen.

3.6 Solvent Dewaxing

The wax-bearing oil stream from the hydrotreater is diluted with a solvent and chilled. The solvent is introduced in such amounts at selected points in the chilling cycle so as to insure a wax crystal structure and liquid viscosity most suitable for filtration. The filtrate is purified by evaporation of solvent from the dewaxed oil solution. The wax mix may be heated by either steam or fuel-fired heaters.

The solvent employed generally consists of a mixture of methyl ethyl ketone and an aromatic solvent (benzol, toluol, or a mixture of the two). Because of its relatively low boiling point, the solvent can readily be recovered from the dewaxed oil and wax solutions in simple evaporating and steam stripping equipment.

3.7 Waste Oil Drying

Waste oils are dried by heating and flashing off the water. Any hydrocarbons carried overhead with the water are decanted from the condensed water and returned to the dry oil. The waste oils are then cooled and filtered to remove solids.

3.8 Feed

22,714 barrels per day of reduced crude are charged to the vacuum unit to meet the fixed demand of 4,950 barrels per day of lube oils sent to the users.

4.0 DESCRIPTION OF CASE B:

LUBE OIL PRODUCTION AND WASTE OIL RECOVERY BY RE-REFINING

The Case B process block flow diagram is shown in Figure 2. The lube oil refining processing sequence is the same as in Case A. The difference is in the processing of waste lube oils. In Case A, waste lubricating oils are treated only to remove water and solids. The remaining oils (lubes plus gasoline and light fuel) are assumed to be blended with other fuels and burned for energy recovery.

In Case B, crankcase drainings are re-refined to recover lube oils which are recycled to the users. In this case only 1,790 b/d of virgin make-up lube oils are required. This reduces the atmospheric reduced crude charge to vacuum distillation from 22,714 b/d in Case A to 8,214 b/d in Case B. However, since in Case B waste crankcase oils are not a source of fuel supply, total fuel oil production is reduced by 15,300 b/d. In order to maintian a constant supply of fuel oils, an additional stream of 15,300 b/d of reduced crude has been added. Since the heating value of reduced crude oil is only slightly greater than the heating value of dry waste oil (see Table 2, lines 6 and 8), this addition has a negligible effect on the energy balance calculations.

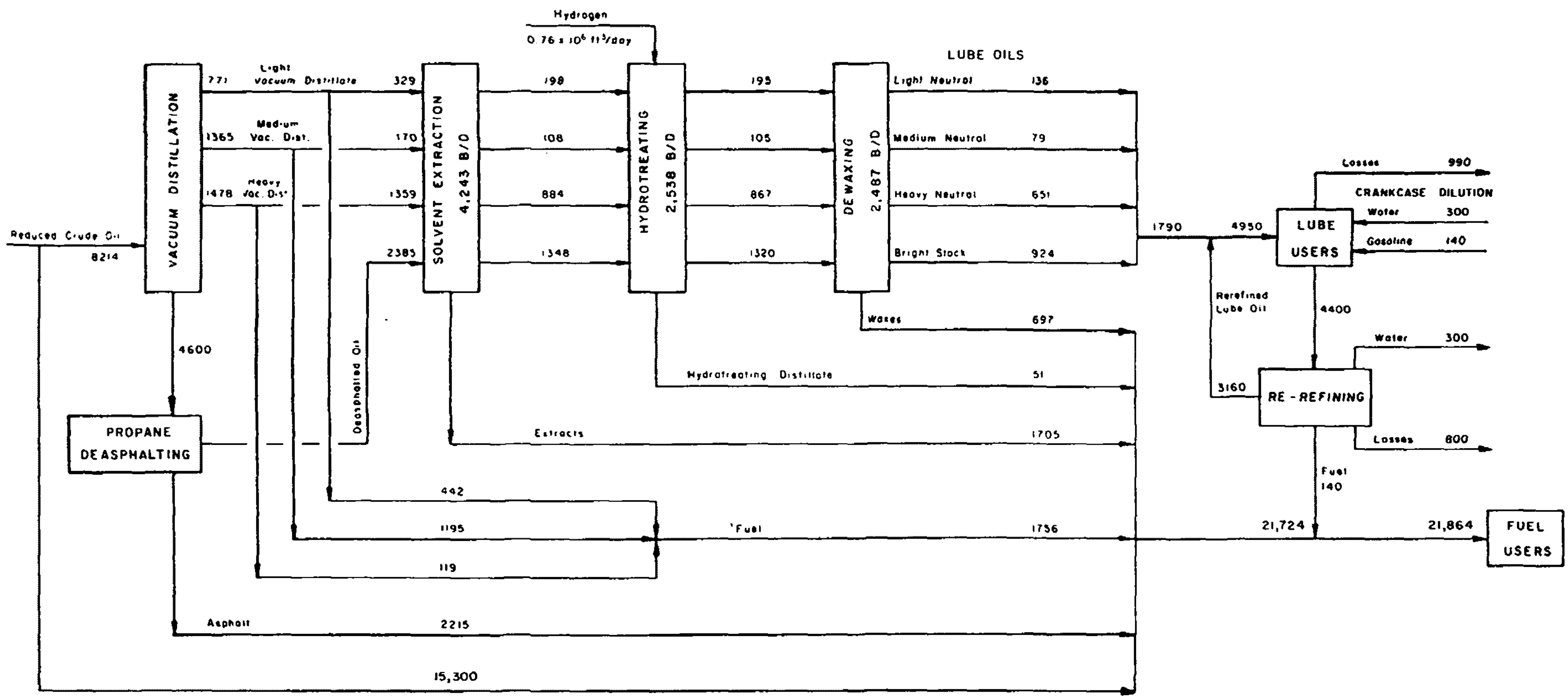
The re-refining process considered here consists of a flash dryer, acid and clay treating, redistillation and filtering. This process is typical of most installations in the United States[5]. No provision has been made in this study for disposal of acid sludge or spent clay.

Figure 2

CASE B

LUBE OIL PRODUCTION and WASTE OIL RECOVERY by RE-REFINING

All Throughputs expressed in Barrels per Stream Day



5.0 MATERIAL AND ENERGY BALANCES

Feed and product material and potential energy balances are shown in Table 2. For this study, the potential energy is the high (gross) heating value (HHV) of the various streams. In each case, the material and potential energy inputs in the form of reduced crude oil plus gasoline from cylinder leakage must equal the material and energy outputs in the form of virgin fuels plus losses. The entries in Table 2 verify the consistency of the data used in this analysis.

5.1 Consumed Energy

Each process step in the refining of crude oil or re-refining of waste oils requires energy in some combination of electricity, steam and fuel. In order to make energy comparisons between the various processing steps, the electricity and steam requirements have been converted to Btu equivalents. This permitted the calculation of the total energy input for each process, expressed in Btu per barrel of unit charge. The conversion factors used are:

KWH x 10,000 = Btu

High pressure steam (above 150 psi); lb x 1450 = Btu*

Low pressure steam (150 psi and less); lb x 1400 = Btu*

Energy consumed in each of the processes considered in this study is shown in Table 3. Table 4 summarizes the energy consumed in the various processing steps for the two cases.

5.2 Comparison

Table 5 summarizes the material balance and potential and process energy consumed for the two cases. The energy balance shows that the total sum of potential energy loss plus energy consumed is 4.36 x 10^9 Btu/day higher for Case A than for Case B. Based on the 4,950 b/d of lube oil required, the additional energy consumption is 20,970 Btu/gallon of lube oil used.

5.3 Discussion

The two cases analyzed in this study were selected in order to determine how energy consumed changes when a fixed amount of lube oil and a fixed amount of fuel oil are supplied in two different ways. The results of the material and energy balance calculations for both methods of supply are summarized in Table 5. Justification for the entries in Table 5 is provided in Tables 2, 3 and 4.

*Assumes a heater efficiency of 80 percent.

Table 2
MATERIAL AND POTENTIAL ENERGY BALANCE

			CASE A		CASE B	
	Stream	Heating Value Btu/gal	Throughput b/d*	Potential Energy Btu/day	Throughput b/d*	Potential Energy Btu/day
1.	Waxes	142,000	1,927	11.49×10^9	697	4.16×10^9
2.	Hydrotreating Unit Distillate	142,000	141	.84	51	.30
3.	Extract from Furfural Unit	154,400	4,715	30.58	1,705	11.06
4.	Vacuum Gas Oil	142,850	4,856	29.13	1,756	10.53
5.	Asphalt	163,600	6,125	42.09	2,215	15.22
6.	Reduced Crude	150,750	-	-	15,300	96.87
7.	Total Virgin Fuels		17,764	114.13×10^9	21,724	138.14×10^9
8.	Re-refining Fuel	142,700(A)	4,100	24.57	-	-
		140,000(B)	-	-	140	.82
9.	Total Fuel		21,864	138.70×10^9	21,864	133.96×10^9
	Hydrocarbon Losses					
10.	Losses During Use in Automobiles	142,800	990	5.94	990	5.94
11.	Losses During Re-refining	142,800	-	-	800	4.80
12.	Total Losses		990	5.94	1,790	10.74
13.	Total Fuel and Losses		22,854	144.64×10^9	23,654	149.70×10^9
	Feed					
14.	Atmospheric Reduced Crude	150,750	22,714	143.82×10^9	23,514	148.88×10^9
15.	Gasoline from Cylinder Leakage	140,000	140	.82	140	.82
			22,854	144.64×10^9	23,654	149.70×10^9

* 1 barrel = 42 gallons

Table 3

ENERGY CONSUMED IN PROCESS UNITS

All utilities are per barrel of charge except in the case of the hydrogen plant where utilities are expressed per million standard cubic feet of H_2

Process	Electricity kilowatt hours	Steam-lb HP	Steam-lb LP	Fuel Btu	Total Energy Btu
Propane De-asphalting(1)	-	290	-	90,000	511,000
Solvent Extraction(1)	1	40	-	285,000	353,000
Hydrotreating(2)	3	-	13	26,000	74,000
Dewaxing(1)	12	40	-	290,000	468,000
Waste Lube Drying(2)	½	-	-	55,000	60,000
Waste Lube Re-refining(2)	1½	-	65	90,000	196,000
Hydrogen Plant(2) (Btu/MM scf H_2)	600	(35,000)	-	470×10^6	426×10^6

* Fuel includes natural gas feed.

( ) = export steam

Table 4
PROCESS ENERGY CONSUMPTION

	Consumed Energy Btu/bbl	CASE A Capacity b/d	CASE A Energy Btu/day	CASE B Capacity b/d	CASE B Energy Btu/day
Propane De-asphalting	511,000	12,720	6.50×10^9	4,600	2.35×10^9
Solvent Extraction	353,000	11,733	4.14	4,243	1.50
Hydrotreating	74,000	7,018	.52	2,538	.19
Dewaxing	468,000	6,877	3.22	2,487	1.16
Hydrogen Plant (Btu/MM scf H_2)	426×10^6	2.11 (MM scf H_2)	.90	0.76 (MM scf H_2)	.32
Total Process Energy Consumed in Lube Production			15.28×10^9		5.52×10^9
Waste Oil Drying	60,000	4,400	.26	-	-
Re-Refining	196,000	-	-	4,400	.86
Total Process Energy Consumption			15.54×10^9		6.38×10^9

Table 5

MATERIAL AND ENERGY BALANCE SUMMARY

Case	A	B
Disposition of waste lube oils	to fuel oil	to re-refining
Reduced crude charge to vacuum unit (see Figure 1 and Figure 2)	22,714	8,214
Products, b/d		
Virgin lube oil	4,950	1,790
Re-refined lube oil	–	3,160
Total lube oils	4,950	4,950
Virgin fuel oil	17,764	6,424
Waste lube fuel oil	4,100	140
Reduced crude oil	–	15,300
Total fuel oils	21,864	21,864
Energy Balance		
Total potential energy losses, Btu/day (from Table 2)	5.94×10^9	10.74×10^9
Total process energy consumed, Btu/day (from Table 4)	15.54×10^9	6.38×10^9
Total	21.48×10^9	17.12×10^9

Case A - Case B = 4.36×10^9 Btu/day

$$\frac{4.36 \times 10^9 \text{ Btu/d}}{4{,}950 \text{ b/d} \times 42 \text{ gal/b}} = 20{,}970 \text{ Btu/gal}$$

In Case A, where waste crankcase oils are converted to fuel oil, the entire 4,950 b/d of lube oil are produced from virgin atmospheric reduced crude oil. In Case B, where waste crankcase oils are re-refined to produce lube oil, 1,790 b/d of lubes are produced from virgin oils and 3,160 b/d of lubes are produced by waste oil re-refining. Since the process energy consumed in the production of virgin lube oil is about 3.09 x 10^6 Btu's per barrel of virgin product, while the process energy consumed in waste crankcase oil re-refining is only 0.27 x 10^6 Btu's per barrel of re-refined product (see Table 4), total process energy consumed in Case A is much higher than in Case B. However, since considerable hydrocarbon losses (equal to 1.52 x 10^6 Btu's per barrel of re-refined product) occur during the acid treating step in re-refining (see Table 2), the net energy losses in Case B are much higher than in Case A. As mentioned earlier, in both Case A and Case B, the lube oil losses during use in automobiles (shown in Table 2) are assumed to be equal. Process energy consumed in recovery of fuel oil from waste crankcase oils is a very small contribution to total energy consumed (see Table 4).

The net result of these calculations is shown at the bottom of Table 5. The energy consumption for Case A is 4.36 x 10^9 Btu/day greater than the energy consumption for Case B. Based on lube oil production of 4,950 b/d, the energy savings realized by re-refining is 20,970 Btu's per gallon of lube oil produced.

The Waste Oil Report to Congress(4) presents figures for the generation, destination and disposition of waste automotive oils for 1972. Of the 616 million gallons of waste automotive oil generated, only 105 million were re-refined†. Of the remaining 511 million gallons, 221 million were used for fuel and 290 million were disposed of in ways which did not involve energy recovery (e.g., road oiling, asphalt manufacture, surreptitious dumping). If all of the remaining 511 million gallons of waste automotive oil had been re-refined, the net production of re-refined lube oil would have been about 409 million gallons. The energy savings would have been about 20,970 Btu per gallon for the 177 million gallons of lube oil that could have been produced from the waste automotive oil that was used for fuel and perhaps a like amount per gallon for the 232 million gallons of lube oil that could have been produced from the waste oil that was disposed of in ways which did not involve energy recovery††. On the basis of 5.8 million Btu's per barrel, the total annual energy savings would have amounted to about 1.5 million barrels of crude oil equivalent. Since domestic petroleum production is in a period of decline this extra energy savings would reduce crude oil imports by 1.5 million

---

† The 616 million gallons does not include dilution of waste oil by water, sediment or light fuels.

†† Use of waste oil as road oil or in asphalt manufacture replaces petroleum products normally used in these applications. Separate energy balance calculations would be required to specify the net energy savings that would result if waste oil now used on these applications were re-refined to produce lube oil.

barrels per year. This is enough to operate a modern 1000 megawatt oil burning power plant for over 6 ½ weeks at full load. In financial terms, at a price of $12 per barrel of crude, the annual savings in fuel expense and currency outflow would have been $18 million. An investment of this magnitude in re-refining facilities would be nearly sufficient to provide the capacity to process an additional 64 million gallons of waste oil.

6.0 SENSITIVITY ANALYSIS

Although the above analysis shows that re-refining of waste lube oils yields a substantial energy savings over alternative disposal methods, the results are dependent on a number of variables including the energy consumed in refining process units, the lube oil yield from reduced crude oil, and the lube oil losses during re-refining. In order to verify the energy conservation potential of waste oil recycling, a sensitivity analysis was made by increasing and decreasing the values of each of these three variables.

6.1 Refining Process Energy

As discussed above, lube oil plants may vary considerably in the design and type of process units utilized. For certain premium crudes, less intensive processing at each step may be required. Some processing steps might be eliminated. On the other hand, use of crudes high in aromatics, asphaltenes, or sulfur requires more intensive processing. The sensitivity of the energy balances for Case A and Case B was tested by arbitrarily increasing the refining process energy by 50 percent and by reducing the refining process energy sufficiently to equalize total energy consumption in the two cases.

Table 6 shows the results of this analysis. Increasing the refining process energy by 50 percent results in a net energy savings for Case B (re-refining) over Case A (burning) of about 44,500 Btu per gallon of lube oil produced. This is an increase of nearly 112 percent over the net energy savings, 20,970 Btu per gallon, determined in the base case (Table 5).

In order to equalize the total energy consumed in Case A and Case B, the refining process energy must fall by slightly more than 55 percent. Although the variations in process energy considered here may be extreme, it can be safely concluded that under assumptions A through E, waste oil recovery by re-refining (Case B) requires significantly less total energy than waste oil disposal by burning (Case A).

6.2 Lube Oil Yield from Reduced Crude

The overall lube oil yield determines the volume of reduced crude which must be processed to produce a given quantity of lube oil. In the base case, this yield was 21.8%. Since different crude oils will yield different fractions of lube oil, the sensitivity of total energy consumption in Case A and Case B to lube oil yield was tested assuming a change in yield of plus or minus 25 percent. This means that the new overall yields were 27.2 and 16.4 percent, respectively.

Preceding page blank

Table 6

SENSITIVITY OF ENERGY BALANCE TO CONSUMPTION OF REFINING PROCESS ENERGY (Btu/day x 10^9)

1. Increase Refining Process Energy Consumption by 50%

	Case A	Case B
Net change in potential energy	5.94	10.74
Energy consumed in waste oil drying	0.26	–
Energy consumed in re-refining	–	0.86
Refinery process energy	22.92	8.28
Total	29.12	19.88

$$\text{Energy saved by re-refining} = \frac{(29.12 - 19.88) \times 10^9 \text{ Btu}}{4950 \text{ b/d} \times 42 \text{ gal/b}}$$

= 44,444 Btu/gal

2. Decrease Refining Process Energy Sufficiently to Equalize Total Energy Consumed in Case A and Case B

If X = required percent reduction in process energy consumption then:

$$15.28\,(X/100) + 5.94 + 0.26 = 5.52\,(X/100) + 10.74 + 0.86$$

$$9.76X = 540 \qquad X = 55 \text{ percent}$$

Changing the lube oil yield requires that the material and energy balance calculations be repeated in order to determine the required capacities of the lube treating units and the process energy consumed. These calculations are shown in Tables 7, 8 and 9. All non-lube oil throughputs were taken to be proportional to the values for (reduced crude - lubes) shown in Table 7. Note that in all these calculations the volume of lube oil produced remains constant. Only the volumes of reduced crude required and fuel products produced change.

The effect on total energy consumption of changing the lube oil yield is summarized in Table 10. Except for the refining process energy, all entries in Table 10 are the same as for the base case. In all three instances, re-refining shows a net energy savings over burning. In the base case, the net energy savings of Case A over Case B is 20,970 Btu/gal of lube oil produced. An increase of 25 percent in the lube oil yield from reduced crude results in reducing this net energy savings for Case B over Case A to 13,997 Btu per gallon of lube oil produced. Reducing the lube oil yield by 25 percent increases this net energy savings for Case B over Case A to 32,419 Btu per gallon of lube oil produced.

6.3 Re-Refining Losses

Conventional acid/clay re-refineries have an overall yield of about 72 percent based on the waste oil feed. Based upon the assumption that the waste oil feed contains 10 percent water plus fuels, this means that typically 20 percent of the potentially recoverable lube oil is lost in the acid/clay process.

In order to test the effect of re-refining losses on the energy balance calculations, the material and energy balances shown in Tables 2, 4 and 5 were repeated under the following two assumptions:

1. Re-refining losses amount to only 10 percent of the lube contained in the waste oil feed.

2. Re-refining losses amount to 30 percent of the lube contained in the waste oil feed.

In these calculations, lube oil demand, lube oil losses during use, and waste oil feed to the re-refinery are held constant. Changing the re-refinery losses changes the production requirement for virgin lube oil and hence the process energy consumed. Of even greater importance, however, is the change in potential energy loss which accompanies a change in re-refinery yield. The relevant material and energy balances are summarized in Tables 11 and 12.

Table 7

SENSITIVITY ANALYSIS - ALTER LUBE YIELD BY ± 25%

Material Throughputs (b/d)

	Case A			Case B		
	Base	+25%	-25%	Base	+25%	-25%
Feed						
Reduced Crude	22,714	18,200	30,183	8,214	6,580	10,914
Virgin Lube	4,950	4,950	4,950	1,790	1,790	1,790
Reduced Crude minus Virgin Lube	17,764	13,250	25,233	6,424	4,790	9,124
Products						
Virgin Lube	4,950	4,950	4,950	1,790	1,790	1,790
Waxes	1,927	1,437	2,737	697	520	990
Hydrotreating Distillate	141	105	200	51	38	72
Extracts	4,715	3,517	6,698	1,705	1,271	2,422
Vacuum Gas Oils to Fuel	4,856	3,622	6,898	2,215	1,310	2,494
Asphalt	6,125	4,569	8,700	1,756	1,652	3,146
Total	22,714	18,200	30,183	8,214	6,581	10,914

Table 8

SENSITIVITY ANALYSIS - ALTER LUBE YIELD BY ± 25%

Required Processing Unit Capacities (b/d)

Processing Unit	Case A		Case B	
	+25%	-25%	+25%	-25%
Dewaxing	6,387	7,687	2,310	2,780
Hydrotreating	6,492	7,887	2,348	2,852
Solvent Extraction	10,009	14,585	3,619	5,274
Propane Deasphalting	10,137	16,990	3,665	6,144
Hydrogen (10^6 SCF/d)	1.95	2.37	0.70	0.86

Table 9

SENSITIVITY ANALYSIS - ALTER LUBE YIELD BY ± 25%

Process Energy Consumption (Btu/day)

Processing Unit	Case A		Case B	
	+25%	-25%	+25%	-25%
Dewaxing	2.99×10^9	3.60×10^9	1.08×10^9	1.30×10^9
Hydrotreating	0.48	0.58	0.17	0.21
Solvent Extraction	3.53	5.15	1.28	1.86
Propane Deasphalting	5.18	8.68	1.87	3.14
Hydrogen	0.83	1.01	0.30	0.37
	13.01×10^9	19.02×10^9	4.70×10^9	6.88×10^9

Table 10

SENSITIVITY ANALYSIS - ALTER LUBE OIL YIELD BY ± 25%

Energy Balance Summary (Btu/day x 10^9)

	Case A			Case B		
	+25%	Base	-25%	+25%	Base	-25%
Lube Oil Yield from Reduced Crude	27.2%	21.8%	16.4%	27.2%	21.8%	16.4%
Refining Process Energy	13.01	15.28	19.02	4.70	5.52	6.88
Energy Consumed in Waste Oil Drying	0.26	0.26	0.26	–	–	–
Energy Consumed in Re-refining	–	–	–	0.86	0.86	0.86
Total Process Energy Consumed	13.27	15.54	19.28	5.56	6.38	7.74
Potential Energy Loss	5.94	5.94	5.94	10.74	10.74	10.74
Total Energy Consumed	19.21	21.48	25.22	16.30	17.12	18.48

Summary of Energy Savings by Re-refining (Case B) over Burning (Case A); (Btu/gal of Lube Oil Produced)	+25%	Base Case	-25%
Net Energy Savings	13,997	20,970	32,419

Table 11

SENSITIVITY ANALYSIS - EFFECT OF CHANGING RE-REFINING LOSSES ON TOTAL ENERGY CONSUMPTION

Material Balance (b/d)

	Approximately 10% Loss	Approximately 20% Loss (Base Case)	Approximately 30% Loss
Waste Lube Feed to Re-refinery	4,400	4,400	4,400
Waste Lube Feed Free of Water and Fuels	3,960	3,960	3,960
Re-refining Losses	400	800	1,200
Re-refined Oil Produced	3,560	3,160	2,760
Virgin Lube Required	1,390	1,790	2,190
Ratio of Refinery Lube Production to Base Case	0.7765	1.0	1.2235
Reduced Crude Required	6,379	8,214	10,050
Virgin Fuel Oils Produced	4,988	6,424	7,860
Re-refining Fuel Produced	140	140	140
Total Fuel Oil Produced	5,128	6,564	8,000

Table 12

SENSITIVITY ANALYSIS - EFFECT OF CHANGING RE-REFINING LOSSES ON TOTAL ENERGY CONSUMPTION

Energy Balance (Btu/day x 10^9)

	Approximately 10% Loss	Approximately 20% Loss (Base Case)	Approximately 30% Loss
Refining Process Energy	4.28	5.52	6.75
Energy Consumed in Re-refining	0.86	0.86	0.86
Total Process Energy Consumed	5.14	6.38	7.61
Potential Energy Losses:			
Re-refining	2.40	4.80	7.20
Lube Oil Use in Automobiles	5.94	5.94	5.94
Total Potential Energy	8.34	10.74	13.14
Total Energy Consumed	13.48	17.12	20.75
Total Energy Consumed in Case A (Burning)	21.48	21.48	21.48
Energy Savings by Re-refining over Burning, Btu/gal	38,480	20,970	3,510

The results of this analysis show that the energy balance is strongly affected by altering the lube oil yield from the re-refinery. Increasing the overall yield (based on waste oil feed) from 72 percent to 80 percent increases the net energy savings for Case B over Case A by 88 percent. Hence national policies aimed at stimulating investment in new re-refining technologies would be consistent with energy conservation goals. Conversely, increased re-refining losses can result in little or even no net energy savings over waste oil disposal by burning.

7.0 References

1. 1972 refining processes handbook. Hydrocarbon Processing, 9:111-222, Sept. 1972.

2. Personal communication. T. Hall to P. M. Cukor, Jan. 1975.

3. Environmental Quality Systems, Inc. Waste oil recovery practices; state-of-the-art, 1972. Washington, U.S. Environmental Protection Agency, Dec. 1972 250 p. (Distributed by National Technical Information Service, Springfield, Va., as PB-229 801.

4. Waste oil study; report to the Congress. Washington, U.S. Environmental Protection Agency, Apr. 1974. 402 p.

5. Cukor, P., M. J. Keaton, and G. Wilcox (Teknekron, Inc., and the Institute of Public Administration.) A technical and economic study of waste oil recovery. pt.3. Economic, technical and institutional barriers to waste oil recovery. Environmental Protection Publication SW-90c.3. U.S. Environmental Protection Agency, 1974. 143 p. (Distributed by National Technical Information Service, Springfield, Va., as PB-237 620.)

A TECHNICAL AND ECONOMIC STUDY
OF WASTE OIL RECOVERY

PART V A Field Test of the Quality of Re-refined Lube Oils

by Peter M. Cukor

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION AND SUMMARY

1.1 Objectives

This report presents a plan for conducting a field test of the quality of re-refined lube oil under controlled conditions. The goal of the program is to provide the re-refining industry with an opportunity to demonstrate the quality of its products in order to revise lube oil specifications established by the Federal government. Since these specifications prohibit the purchase of re-refined oils by government agencies, many commercial/industrial consumers have been reluctant to use these products. Demonstration of the quality of re-refined oil at a Federal facility could lead to revision of these specifications to permit procurement of re-refined engine oils by government agencies. This in turn would reduce barriers to sales of re-refined oil in high quality commercial and industrial markets.

1.2 Background

Previous research has described the economic, technical, environmental and institutional barriers to recovery of waste oil by re-refining. Briefly stated, these studies have determined that:

1. Waste Oil recovery by re-refining is desirable because:
   - Valuable resources are conserved[2]
   - Energy is conserved[3]
   - Pollution risk can be reduced[1]
2. Production of re-refined oil has fallen sharply and the re-refining industry has contracted because:
   - Between 1960 and 1973 many re-refiners, faced with increased costs and competition from suppliers of virgin lube oils, were unable to increase prices in order to maintain profitable operations. A large number of these firms went out of business[8].
   - Re-refiners have failed to provide the public with products of consistently high quality[1,2].

- The lack of quality assurance has restricted most sales of re-refined oil to low quality markets; in these markets profitability is subject to wide fluctuations depending on the supply of virgin lube oils and general economic conditions(2).

- Equipment modifications to meet environmental regulations have been beyond the financial capability of some re-refiners(2).

3. Since late 1973, when world petroleum prices rose by a factor of four, the re-refining industry has enjoyed a period of increased profitability. Nevertheless,

   - High prices and depressed economic conditions have curtailed the demand for lubricants to the point where market prices for re-refined lube oils have recently begun to fall.

   - Increased production costs, due to competition from fuel reprocessors for waste oil feedstocks and inflation in the cost of raw materials, are also contributing to a decline in the profitability of re-refining.

4. One strategy for prevention of recurrence of a cost/price squeeze in re-refining is the development of high quality markets for re-refined oil.

   - The profitability of sales in these markets is considerably higher than sales in the low quality markets to which re-refined oil is now restricted.

   - The few re-refining companies which have been successful in penetrating high quality lube oil markets have, without exception, experienced long periods of continued profitability(2).

5. The major difficulties faced by re-refiners in penetrating high quality commercial/industrial lube oil markets is the poor public image of the quality of re-refined oils.

   - A successful demonstration of the use of re-refined oil in a high quality commercial application could well provide the industry with an opportunity to increase sales to the commercial/industrial sector.

   - Lube oil specifications established by the Federal government are a major influence in the selection of lubricants for use in the commercial/industrial sector. Since these specifications prohibit the purchase of re-refined oils by government agencies, many commercial/industrial consumers are reluctant to use these products.

6. New investment in waste oil recovery and an increase in the production of re-refined oil could result if:

   - A field test of the quality of re-refined oil at a Federal facility was successfully accomplished.

   - Following the successful demonstration, current Federal specifications were revised to permit procurement of re-refined engine oils by government agencies.

1.3 Description of the Program

Since military bases operate vehicle types similar to those owned by potential commercial/industrial users of re-refined oil, one or more of these facilities would be suitable locations for conduct of such demonstrations. The selection of candidate facilities is, however, limited by the volume of waste oil generated on site and the distance of the base from a reputable re-refiner. The first limitation is imposed by the requirement that the properties of the waste oil feedstock to the re-refinery be held reasonably constant in order to assure that the performance of the lube oil so produced will always fall within specified limits. One way of meeting this requirement is to re-refine the waste oil drained from vehicles operated by the participating facility. This arrangement, which is called a "closed-cycle system," provides the customer with assurance that the properties of the lube oil purchased will not be affected by changes in the feedstock from which the oil is produced. Normally between 2000 and 3000 gallons of waste oil are required for economic batch operation of a re-refinery. Hence participating facilities are limited to those with relatively large lube oil requirements. The economics of waste oil and lube oil transport pose additional restrictions on the locations where closed-cycle demonstrations are feasible. However, a number of military facility-re-refiner combinations have been identified which meet these restrictions.

A field test of the quality of re-refined oil will require the cooperation of a number of persons including facility personnel involved in purchasing, waste disposal and vehicle maintenance. A systems engineer familiar with lube oil service requirements and the additive response of base oils will provide technical assistance to the re-refiner and, in cooperation with representatives of EPA, will be responsible for selection of participating facilities and re-refiners, coordination of the demonstration and establishment of policies and procedures for program implementation.

Policies and procedures for program implementation define the responsibilities of key personnel involved in the field test and the conditions for conduct of the demonstration under closed-cycle conditions. Thus, waste oils drained from facility vehicles must be segregated from other wastes and made available to the re-refiner in volumes adequate for batch operation of his plant. Re-refining must be carried out under specified operating conditions in order to assure product quality. Laboratory testing of each batch is necessary to provide evidence of constancy of base oil properties. Suitable additive packages will be selected on the basis of engine sequence tests performed on the first batch of re-refined oil produced in any demonstration. Lube oils produced must meet the specifications established for relevant service applications. Facility personnel responsible for vehicle maintenance will monitor the performance and lube oil consumption of test vehicles.

For each vehicle type which is used in the field test, four units will be operated using re-refined oil and four units will be operated using a qualified virgin oil. Measurements of the wear of key engine parts and ratings for rust, sludge, and varnish formation will provide the basis for comparing the performance (quality) of the re-refined oil and the virgin oil.

Successful completion of the field test will lead to a second phase of the program in which the restriction against the use of outside sources of waste oil would be removed. Successful completion of the second phase will lead to the establishment of new government specifications which allow the procurement of re-refined oil. Revision of government specifications and the favorable publicity which will result from successful demonstrations will aid in establishing the confidence of commercial/industrial consumers in the quality of properly re-refined oils. This will enable re-refiners to sell their products for use in high quality applications. The magnitude and stability of profit margins in these markets should encourage new investment in waste oil recovery.

2.0 CONCEPTUAL FRAMEWORK FOR THE EXPERIMENT

A field test for demonstrating the quality of re-refined oil could logically be conducted at any location where an adequate number of vehicles is available to provide for statistically significant test results. The program proposed here is, however, considerably more constrained than a normal product field test; in order to meet the goals of the demonstration, a number of restrictions must be placed on the experiment.

Since a goal of the demonstration is to encourage acceptance of re-refined crankcase oil by commercial and industrial customers, the vehicles involved in the demonstration must be similar to those operated by these potential users of re-refined oil. The service classifications of lube oils used in the demonstration vehicles will then be the same as the service classifications of lube oils used in vehicles operated by commercial and industrial consumers. A large military base where vehicles such as light and heavy trucks, buses and motor pool passenger cars are operated is one type of facility which meets these requirements.

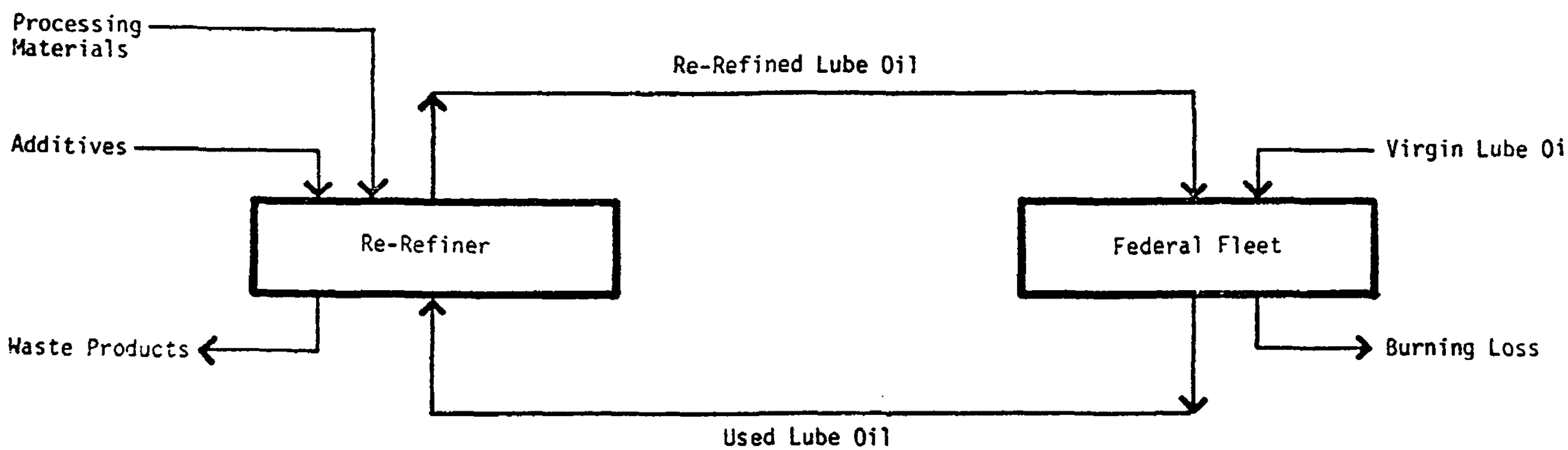
However, in order to carry out a demonstration at a military base (or any other government facility), the lube oil used must pass the physical, chemical and performance tests which are a part of military specifications. While there is evidence to indicate that properly re-refined oils blended with appropriate additives can pass these tests, military specifications also require that once a lube oil has been qualified, no changes in the feedstock, refining process or additive package can be made. This requirement places an additional restriction on the proposed demonstration since re-refined oil is normally produced from waste oils collected from a variety of sources.

However, if the demonstration is arranged so that the waste oil which is re-refined is collected from the vehicles which will use the re-refined oil, then the restriction against variations in feedstock can be met. This type of arrangement, which is depicted in Figure 1, is called a closed-cycle re-refining system. Closed-cycle systems have economic as well as quality control benefits. A number of re-refiners have, for many years, produced re-refined oil under closed-cycle conditions for industrial and commercial clients, especially railroads(2).

Although a closed-cycle demonstration offers control over possible variations in feedstock properties, additional restrictions must be imposed on the experiment. Since waste oils supplied by the facility must be kept separate from waste oils collected elsewhere, the volume of feedstock required will be fairly large. This is because the charge to a re-refinery must, in general, be at least 2,000-3,000 gallons for economic operation. Assuming that most vehicles require about one gallon of lube oil and that dilution of crankcase oil with fuel and water is compensated for by losses during vehicle operation, the crankcase drainings from approximately 2,000-3,000 vehicles will be needed to produce the minimum volume of re-refinery feedstock. Further, since waste oil

Figure 1

CLOSED-CYCLE RE-REFINING SYSTEM



cannot be economically transported over great distances, the facility must be located within reasonable proximity to the re-refiner. Hence, candidate facilities for the proposed demonstration should meet the following criteria:

1. Be willing to participate

2. Have a large number of vehicles whose lube oil requirements and operating conditions are similar to those of vehicles owned by potential commercial and industrial users of re-refined oil

3. Be located near a qualified re-refiner

A qualified re-refiner must be capable of producing lube oils which can be qualified under the rigid quality control standards set forth in military specifications. In addition, the re-refiner must have established a reputation for consistently producing high quality crankcase oils. This performance should be documented by references from his existing commercial and industrial clients and by laboratory tests of the physical and chemical properties of re-refined base oils produced by his company (see Section 4.3 and Appendix A for a discussion of appropriate laboratory tests). Preferably, the re-refiner should have experience in lube oil production under closed-cycle conditions. Further, it is essential that the participating re-refiner recognize the need for maintaining the highest standards of product quality and professional services. For if an attempt at demonstrating the quality of re-refined oil should fail, it would be extremely difficult to persuade any government or private facility to participate in future demonstrations. Moreover, barriers to acceptance of re-refined oil in high quality markets would remain intact. Thus the participating re-refiner must be willing to accept this responsibility and the fact that he has a stake in the successful completion of the demonstrations.

3.0 THE PARTICIPANTS IN A CLOSED-CYCLE DEMONSTRATION

This chapter provides a description of the duties and qualifications of the key personnel representing the Government and the re-refiner who will participate in the field test of re-refined oil. In addition, the criteria for selection of the participating facility and re-refiner are developed in some detail in order to insure that the restrictions described in Section 2.0 are met. Estimated volumes for lube oil consumption and waste oil generation for major military facilities are presented; locations of these bases are then matched with nearby re-refiners in order to minimize transport costs and provide a preliminary listing from which the choice of the facility and re-refiner can be made.

3.1 Key Personnel and Their Roles

A successful closed-cycle demonstration of the use of re-refined oil will require the cooperation of a number of participants. These people will include representatives of the participating Federal facility; the re-refiner; the Environmental Protection Agency; the Department of Defense; and a systems engineer who is acquainted with the response of base lube oils to additive formulations, the lube oil requirements of a wide range of vehicle types and the testing procedures for evaluation of lube oil quality.

3.1.1 Federal Facility Personnel

The participating activity will provide both the source of the waste oil and the vehicles which will use the re-refined product. Consequently, personnel concerned with property disposal, oil purchases, quality assurance and vehicle maintenance will be involved. In addition, an oversight officer should be assigned to monitor the progress of the demonstration and coordinate the activities of the facility personnel.

The property disposal personnel will have responsibility for assuring that waste lube oils available for collection by the re-refiner are kept separate from other wastes and free of undesirable contaminants. Since current practice at many Federal facilities is to mix waste lube oils with other wastes including gear oil, fuel oils, grease, paint, solvents, etc., modification of waste management practices and acquisition of separate storage facilities will probably be required. Property disposal personnel will keep records of the sources and volumes of waste lube oil which are added to the storage containers, and the volumes of used oil which are removed for re-refining. Samples of waste oil should be withdrawn and examined prior to removal for re-refining in order to assure the re-refiner that the feedstock is free of undesirable contaminants.

Preceding page blank

Personnel responsible for lube oil purchase will monitor the quantities, specification types, viscosities and container sizes of lube oils recycled to the facility. The brand name of these products must be clearly marked in order that they be distinguished from other lubricants in use at the facility. Records should be kept which include prices, dates of purchase and delivery as well as the information mentioned above.

Samples from each shipment of re-refined lube oil should be sent to the quality assurance personnel who will be responsible for obtaining data on the physical and chemical properties of the recycled oil. If laboratory facilities are not available on site, it will be the responsibility of the quality assurance group to obtain test results from a nearby independent laboratory.

The cooperation and support of personnel responsible for vehicle maintenance are essential to the conduct of closed cycle demonstrations. These persons, including shop foremen and mechanics, have responsibility for the mechanical performance of facility motor pools and may, therefore, be somewhat reticent to substitute re-refined oils for lubricants which have provided satisfactory performance. Close contact should be maintained between maintenance personnel, the systems engineer and the re-refiner in order that any questions concerning lube oil performance, specifications, additives and physical and chemical properties be quickly resolved. The close working relationships which exist between re-refiners and their quality conscious commercial and industrial customers should serve as examples for the closed-cycle demonstration.

The maintenance personnel should keep records of vehicle service including dates, oil change intervals in miles and weeks, quantities and types of oil added, oil filter types and change intervals, incidence of engine maintenance, etc. Any mechanical problems should be reported immediately in order that a determination of the probable causes can be made. If any vehicles in use at the facility are believed to suffer from manufacturing defects, these vehicles should be excluded from the demonstration.

3.1.2 Re-Refining Personnel

Success of the closed-cycle demonstration is highly dependent upon the integrity and diligence of the participating re-refiners. Although a successful demonstration will provide re-refiners with a valuable opportunity to expand sales of re-refined oil to quality conscious customers, participation in a demonstration may result in little or no immediate financial return. Thus it is essential that the participating re-refiner be willing to accept the longer term marketing benefits that can result.

The re-refiner must pay strict attention to feedstock quality and segregation. Collection vehicles and storage facilities must be free of contaminants. Re-refining process conditions must be strictly monitored. The properties of the base oils produced must be tested for compliance with physical, chemical and performance standards established under existing specifications.

Recommended additive packages must be blended in required proportions. Determination of the proper amounts and types of additives should be made by the systems engineer.

Packaging of lube oils for use in a demonstration should reflect the needs of the participating facilities. Service classifications, specifications, viscosity and brand name should be clearly marked. Container sizes should be as specified by the purchasing agent at the Federal facility.

3.1.3 The Systems Engineer

The systems engineer should possess extensive knowledge of lube oil requirements of internal combustion engines operating under a wide range of service conditions. He should be intimately familiar with the "additive response" of base lube oils and the testing procedures for lube oil qualification under existing specifications. He should have extensive experience in providing technical services to re-refiners and to producers and compounders of virgin lube oils. Above all he must be capable, as an independent expert, of providing technical advice to the vehicle maintenance and quality assurance personnel as well as to the re-refiner.

3.1.4 Representatives of EPA and the Department of Defense

Representatives of EPA and the Defense Department will have responsibility for selection of the participating facility and re-refiner, for initiation of the closed-cycle demonstration, for close monitoring of the program, for resolving any difficulties that may arise and for disseminating the results of the demonstration to all interested parties.

It is particularly important that these representatives maintain close contact with the other key personnel in order to assure the success of the program. They must be familiar with lube oil purchase, vehicle maintenance and waste oil disposal procedures at the participating facility. They must have knowledge of re-refining technology and the performance properties of various lube/oil additive blends. Finally, they must have a grasp of the roles and concerns of each of the key personnel and how these persons must cooperate in order to effect a successful demonstration.

3.2 Selection of the Participating Facility and Re-Refiner

3.2.1 Lube Oil Consumption and Waste Oil Generation

Table 1 is a summary of the estimated volume of crankcase oils procured by major military facilities in fiscal 1975. The figures must, however, be viewed as only rough estimates of the actual quantities of lube oil consumed. This is because a military facility may order lube oils either directly from qualified suppliers whose bids have been accepted by the Defense Fuel Supply Center (DFSC) located at Cameron Station, Virginia, or from military service depots which are located throughout the country. Data on lube oil procurement may be found in the Oil Contract Bulletin, which is published annually by DFSC(4). The data in Table 1 reflect volumes of lube oil procured (but not actually ordered) by DFSC under indefinite quantity contracts which have not been funded. Lube oils procured in this manner are, upon request, delivered by the supplier directly to the ordering activity. Large orders are handled in this way in order to reduce costs associated with warehousing. Table 1 does not account for smaller lube oil orders which are handled by military service depots. Thus the estimated lube oil needs for each facility do not reflect quantities of oil actually purchased. Data on actual lube oil purchases by military facilities are not publicly available.

Data on waste crankcase oil generation at military facilities are also not available to the public. The Naval Supply Systems Command did commission a study by Exxon Research and Engineering Company of waste oil generation and disposal at nine major Navy terminal complexes(5). This research was completed in 1973 but distribution of the results has been restricted. Studies of waste crankcase oil generation at Army and Air Force facilities have not been made. An estimate of annual volumes of waste crankcase oil generated at a given facility can be made by applying a "waste oil generation factor" to the figures for estimated procurement shown in Table 1. A waste oil generation factor is that fraction of lube oil purchases which is not consumed or lost in use and is, therefore, available for ultimate disposal. If one assumes that for a government fleet eighty percent of oil purchased is used for oil changes and that the oil drained is equal to eighty percent of filled capacity, then the appropriate waste oil generation factor is 0.64. Thus, a rough approximation of the waste oil that might be made available for re-refining in a closed-cycle demonstration at a given facility can be obtained by multiplying the procurement volumes shown in Table 1 by this factor. Based on this method, about 1.27 million gallons of waste oil were generated in fiscal 1975 at the 21 military facilities listed in the table.

Table 1

ESTIMATED PROCUREMENT OF INTERNAL COMBUSTION ENGINE LUBRICATING OILS FOR MILITARY FACILITIES FOR FISCAL YEAR 1975*

	Name and Location	Estimated Lube Oil Procurement (gallons)
1.	Fort Riley, Kansas	320,000
2.	Fort Hood, Texas	260,000
3.	Fort Lewis, Washington	144,000
4.	Fort Bragg, North Carolina	129,000
5.	Camp Lejeune, North Carolina	128,000
6.	Fort Carson, Colorado	128,000
7.	Fort Sill, Oklahoma	86,000
8.	U.S. Marine Corps, 4th Amtrac Battalion, Tampa, Florida	89,000
9.	Naval Ship Compound, Norfolk, Virginia	89,000
10.	Fort Campbell, Kentucky	70,000
11.	Fort Bliss, Texas	68,000
12.	Fort Benning, Georgia	56,000
13.	Camp McCoy, Wisconsin	54,000
14.	Camp Shelby, Mississippi	54,000
15.	Marine Corps Air Station, Cherry Point, North Carolina	53,000
16.	Fort Eustis, Virginia	48,000
17.	Travis Air Force Base, California	40,000
18.	Fort Knox, Kentucky	40,000
19.	Elgin Air Force Base, Florida	36,000
20.	Tinker Air Force Base, Oklahoma	35,000
21.	Fort Meade, Maryland	34,000
22.	McClellan Air Force Base, California	32,000
	TOTAL	1,993,000 gallons

* All lube oils listed were procured under specifications MIL-L-2140C and MIL-L-46152. Of the oil procured, more than 90 percent was procured under specification MIL-L-2104C.

Source: Oil Contract Bulletin - Fiscal Year 1975; DSA 600-74-0100; Defense Fuel Supply Center, Cameron Station, Alexandria, Virginia.

3.2.2 Waste Oil Disposal

The Defense Supply Agency (DSA) has established a detailed set of policies and procedures for disposal of surplus property by military facilities. In the case of waste lubricating oils the Defense Disposal Manual specifies that (6):

> Disposition...may be by one of the following methods if in accordance with local pollution abatement rules:
>
> 1) Burning as fuel oil
>
> 2) Spraying on roads, parking areas, etc., to control dust
>
> 3) Use in experimental fire fighting practices
>
> 4) Use as a spray for insect control
>
> 5) Any other authorized use on the activity
>
> 6) Donation to authorized recipients
>
> 7) Sale
>
> 8) Abandonment or destruction of oils which have no sale value

If waste lube oils are not disposed of by methods 1-6, these materials are supposed to be offered for sale by the local Defense Property Disposal Office (DPDO). There are 190 DPDO's located throughout the country. These DPDO's are divided into three sales regions having headquarters offices in Ogden, Utah, Columbus, Ohio and Memphis, Tennessee. Upon request from a local DPDO, the headquarters office issues an Information for Bid (IFB). Awards are made on the basis of the highest price bid for each item listed in the IFB. Thus, if large volumes of waste lube oil are not disposed of on site, data as to the location and quantity of these wastes should be available from DSA.

In order to test this hypothesis, copies of all IFB's issued during the calendar year 1973-1974 were obtained from the Market Research Group at Defense Property Disposal Headquarters, Battle Creek, Michigan. Table 2 summarizes the data collected for sales of waste crankcase oils. Approximately 345,000 gallons of waste oil were sold through local DPDO's during this period. Since this figure is less than 30 percent of the volume of waste oil estimated in Section 3.1.1 (and a much smaller fraction of total waste oil generated annually by all military facilities in the continental United States), it is clear that if specified disposal procedures have been followed then only a very small fraction of these materials have been made available for recycling. Further, in most cases the waste crankcase oils sold through the DPDO's were contaminated with a number of other waste petroleum products. Hence the actual volumes of recoverable lube oil are much lower than the volumes listed in Table 2.

Table 2

SALES OF WASTE CRANKCASE OILS BY DEFENSE PROPERTY DISPOSAL SERVICE

Date of Sale	Volume (gallons)	Location	Successful Bid (cents per gallon)	Comments
November 14, 1973	50 drums containing 2750 gallons	Fort Gordon, Georgia	rejected	Drums included in sale. High bid of $1.06 per drum rejected as too low.
December 19, 1973	800 drums containing 44,000 gallons	Fort Devens, Mass.	3.6	Drums included in sale. Oil contaminated with solvents, sludge, etc.
January 3, 1974	15,000	Letterkenny Army Depot, Chambersburg, Pennsylvania	2.3	
February 27, 1974	198 drums containing 5940 gallons	DPDO, Portsmouth, Rhode Island	N.A.	Drums leaking.
February 27, 1974	85 drums containing 4655 gallons	DPDO, Naval Training Center, Great Lakes, Illinois	N.A.	Used engine oil from aircraft and reciprocating engines.
February 27, 1974	507 drums containing 25,350 gallons	DPDO, Fort Meade, Maryland	N.A.	Contaminated oil and fuel mixed with water.
March 5, 1974	25,000	Naval Air Station, Corpus Christi, Texas	none received	Contaminated aircraft and automotive lube oils.
March 5, 1974	35 drums containing 1750 gallons	Fort Huachuca, Arizona	3	Drums included in sale.
March 21, 1974	218 drums containing 12,000 gallons	DPDO, Fort Belvoir, Virginia	N.A.	
April 16, 1974	91 drums containing 5,000 gallons	DPDO, Grissom Air Force Base, Peru, Indiana	1.1	Drums included in sale. Used automotive and aircraft and engine oils.
April 16, 1974	273 drums containing 15,000 gallons	Luke Air Force Base, Arizona	1	Automotive and hydraulic oils, solvents, carbon remover. Drums included in sale.
May 3, 1974	750 drums containing 41,250 gallons	Naval Air Station, Norfolk, Virginia	N.A.	Fuel oil, hydraulic oil, lubricating oil and jet fuel.
May 21, 1974	1525	Lockbourne Air Force Base, Lockbourne, Ohio	N.A.	Jet and automotive engine oil, jet fuel, aviation gasoline, hydraulic fluid, solvents.
June 25, 1974	30 drums containing 1,650 gallons	Camp Pendelton, California	none received	

Table 2 (continued)

SALES OF WASTE CRANKCASE OILS BY DEFENSE PROPERTY DISPOSAL SERVICE

Date of Sale	Volume (gallons)	Location	Successful Bid (cents per gallon)	Comments
July 2, 1974	10,000	Otis Air Force Base, Falmouth, Mass.	none received	
July 17, 1974	8,000	Fort Campbell, Hopkinsville, Kentucky	4.5	
July 30, 1974	300 drums containing 16,500 gallons	Fort Devens, Mass.	rejected	Drums included in sale; high bid of 13.5¢ per drum rejected as too low.
August 20, 1974	100 drums containing 5,500 gallons	U.S. Coast Guard Yard, Curtis Bay Baltimore, Md.	N.A.	Lube oils from ships, boats, automobiles, trucks, cranes and powerhouses. Drums are dented and rusty.
August 20, 1974	111 drums containing 6,100 gallons	U.S. Naval Academy, Annapolis, Md.	N.A.	Oil, fuel and lubricants, waste.
August 20, 1974	250 drums containing 13,755 gallons	Norton Air Force Base, California	18	Aircraft and automotive engine oils, petroleum derivatives, dirt, and chemicals. Drums included in sale.
August 20, 1974	880 drums containing 48,400 gallons	Malstrom Air Force Base, Montana	3	Aircraft and reciprocating engine oils, antifreeze solvents, water, etc. Drums included in sale.
September 11, 1974	50 drums containing 2750 gallons	Fort Gordon, Georgia	7.4	Drums included in sale.
October 1, 1974	10,000	Otis Air Force Base, Falmouth, Mass.	N.A.	Used engine oil contaminated with solvents, water, etc.
October 1, 1974	17 drums containing 935 gallons	Plattsburgh Air Force Base, Plattsburg, New York	36.3	Drums included in sale.
October 1, 1974	365 drums containing 20,000 gallons	Wurtsmith Air Force Base, , Oscada, Michigan	rejected	Aircraft and reciprocating engine lube oils. Item withdrawn due to misdescription.
October 22, 1974	36 drums containing 2,000 gallons	Whiteman Air Force Base, Knob Noster, Missouri	3.75	Drums included in sale.

Total Volume 344,810 gallons

According to DSA personnel, waste crankcase oils which are not sold through DPDO's are generally disposed of by burning. This is especially true at facilities where fuel oil is used for heating. However, a number of large bases are located in regions, such as the south central states, where natural gas is still the principal boiler fuel. The data in Table 2 indicate that in 1974 very little waste oil was sold by DPDO's located in this region. Since waste lube oils could not be used for fuel at these installations it is possible that disposal is being accomplished by incineration without energy recovery or by some other environmentally undesirable method. Although it is possible that these facilities could be selling waste oils directly to independent collectors, this practice is prohibited under DSA regulations.

3.2.3 Lube Oil Procurement by Military Facilities

Lubricating oils for use in motor vehicle engines are procured under two sets of specifications. Specification MIL-L-2104C is for "Lubricating Oil, Internal Combustion Engine, Tactical Service." Lubricating oils covered by this specification are intended for the crankcase lubrication of reciprocating spark ignition and compression ignition engines used in all types of military tactical ground equipment and for the crankcase lubrication of high speed, high output, supercharged compression ignition engines used in all ground equipment. Specification MIL-L-46152 is for "Lubricating Oil, Internal Combustion Engine, Administrative Service." Lubricating oils covered by this specification are intended for the crankcase lubrication of commercial-type vehicles used for administrative (post, station, and camp) service typical of: (1) gasoline engines in passenger cars and light to medium duty trucks operating under manufacturer's warranties; and (2) lightly supercharged diesel engines operated in moderate duty. Lubricating oils procured under either specification are intended for use when ambient temperatures are greater than -20°F. Further details of each specification are provided in Appendices A and B.

Since the goal of the field test is to demonstrate the performance of re-refined oils used in vehicles operated by commercial and industrial consumers, lube oils used in the test program should meet the requirements of Specification MIL-L-46152. However, an inspection of Table 1 reveals that only a small fraction of the lube oil requirements of major military facilities are met by administrative service oils. More than 90 percent of the lube oil procured in fiscal year 1975 met Specification MIL-L-2104C. Conversations with DFSC personnel revealed that in many cases it is likely that lube oil which meets both Specifications is being used in vehicles which require administrative service oil. Vehicles selected for use in the field test described in Chapter 4 must meet the definition of administrative service provided above.

Procedures and policies for lube oil qualification under military specifications have been presented in a previous study[8]. Lube oil procurement for all agencies of the Federal government is the responsibility of DFSC. Nearly all lube oil is procured in five gallon pails, 55 gallon drums or in bulk tank car loads. An exception is lube oil ordered by the Defense General Supply Center in Richmond, Virginia, some of which is procured in containers smaller than five gallons.

Each year DFSC prepares a list of the previous year's lube oil purchases for each government agency. Such a list is sent to all ordering activities who then respond with an estimate of the coming year's requirements. The various military and Executive Branch agencies submit to DFSC their total lube oil requirements. DFSC then distributes invitations to submit bids for lube oil supply to all firms listed on a bidder's mailing list. Any company may submit a bid provided the firm can prove that:

1. It is a qualified supplier (i.e., its lube oil meets the military specification under which the oil is being procured); or

2. It is supplying the product of a qualified supplier.

Bids received are evaluated solely on the basis of price, provided, of course, that the lowest bidder is a qualified supplier. Contracts are then prepared and a bulletin of successful bidders is printed and mailed to the ordering activities for all government facilities. This is the Oil Contract Bulletin described earlier. The ordering activities place their order directly with the contractors listed in the Bulletin. DFSC does not maintain an inventory of lube oil products. All the contracts are for indefinite quantities of oil and are unfunded with no prepayment clauses. Payment is made after delivery to the facility making the order. However, DFSC administers any problems which may arise between the ordering activity and the lube oil supplier.

Lube oil ordered by the Defense General Supply Center in packages smaller than five gallons is procured by DFSC on firm quantity, firm funded contracts. The Defense General Supply Center maintains inventories of these packaged lube oils at Defense Depots located throughout the United States.

3.2.4 Potential Participants - Military Facilities and Re-Refiners

Figure 2 is a map of the United States which shows the locations of the military facilities listed in Table 1 and the locations of existing re-refineries. The legend for this map is provided in Table 3 which shows the distances between each military facility and the two nearest re-refineries. Names, addresses and telephone numbers of the re-refining companies are listed in Table 4. The data in Table 3 provide a basis for a tentative matching of potential participants with re-refiners. Using the selection criteria discussed above, several facilities should be chosen. Once authorization has been received from the Defense Department, specific data for these bases should be collected which include the following information:

- Names and telephone numbers of the following base personnel:

  Base Commander
  Purchasing Agent
  Property Disposal Officer
  Vehicle Maintenance Foreman

- Actual lube oil requirements by viscosity and service classification
- Number and types of vehicles operated
- Current vehicle maintenance procedures
- Current waste oil disposal practices

All of this information can probably be obtained from the base personnel. One or more meetings should then be arranged between the base personnel, the re-refiner, the systems engineer and representatives of EPA and the Department of Defense. The purpose of these meetings will be to acquaint each person with the policies and procedures to be followed during the demonstration and his responsibilities in the conduct of the test program.

Figure 2

LOCATIONS OF KEY MILITARY FACILITIES AND NEAREST RE-REFINERIES

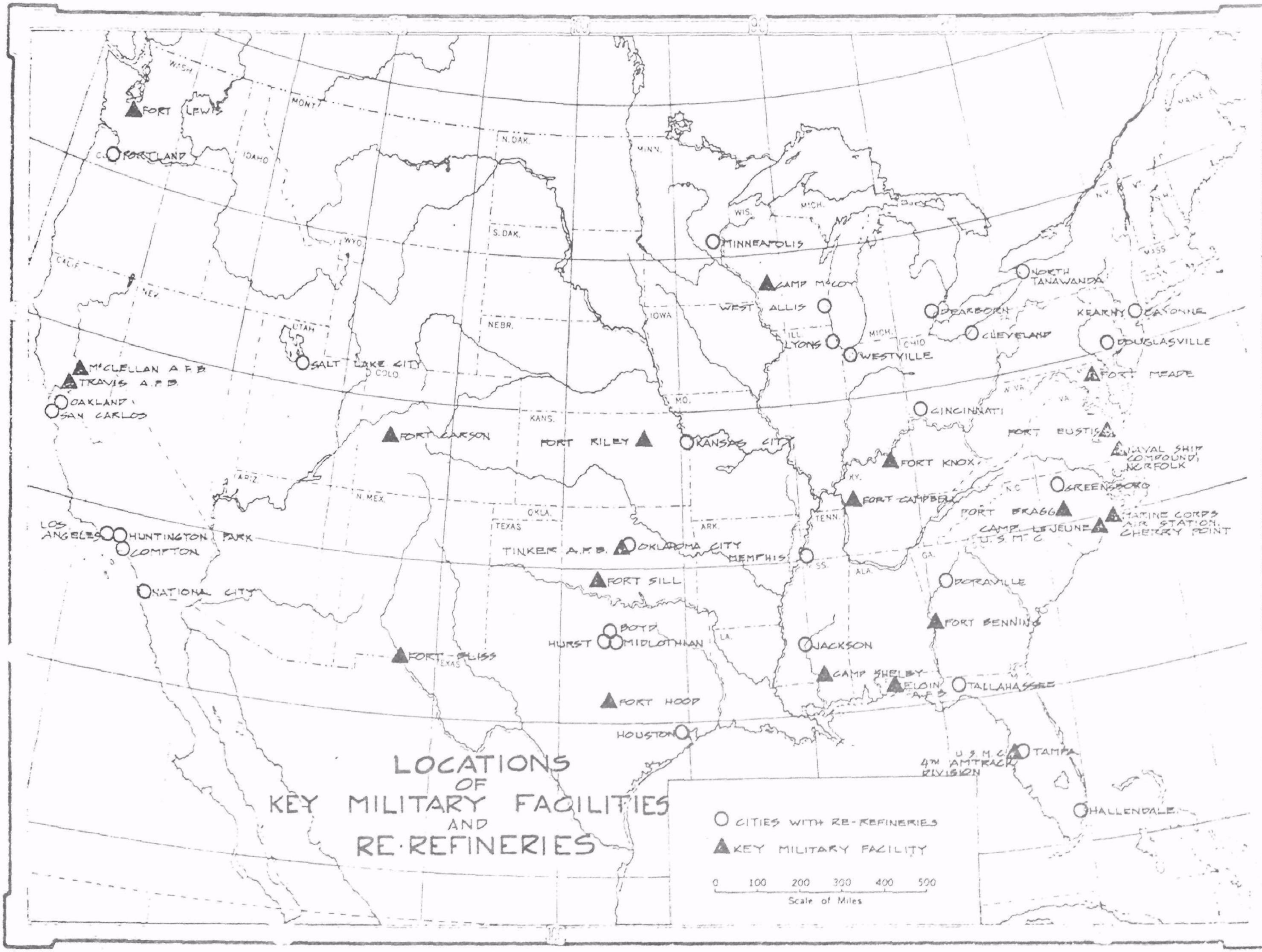


Table 3

LOCATIONS OF KEY MILITARY FACILITIES AND NEAREST RE-REFINERIES

Military Facility	Estimated Lube Oil Procurement Fiscal 1975 (gal)	Nearest Re-Refinery	Distance (Highway miles)
CALIFORNIA			
McClellan A.F.B., California	32,000	Fabian Oil Refining Company, Oakland, California	80
		Bayside Oil Corp., San Carlos, California	100
Travis A.F.B., California	40,000	Fabian Oil Refining Company, Oakland, California	80
		Bayside Oil Corp., San Carlos, California	100
COLORADO			
Fort Carson, Colorado	128,000	Alco Refining Co., Salt Lake City, Utah	555
FLORIDA			
Elgin A.F.B., Florida	36,000	Davis Oil Co., Tallahassee, Florida	157
		Jackson Oil Products Co., Jackson, Mississippi	298
U.S. Marine Corps, 4th Amtrack Division, Tampa, Florida	89,000	Peak Oil Co., Tampa, Florida	0
		Petroleum Products Co., Hallandale, Florida	234
		Davis Oil Co., Tallahassee, Florida	237
GEORGIA			
Fort Benning, Georgia	56,000	Seaboard Chemical Co., Doraville, Georgia	118
		Davis Oil Co., Tallahassee, Florida	157

Table 3 (continued)

LOCATIONS OF KEY MILITARY FACILITIES AND NEAREST RE-REFINERIES

Military Facility	Estimated Lube Oil Procurement Fiscal 1975 (gal)	Nearest Re-Refinery	Distance (Highway miles)
<u>KANSAS</u>			
Fort Riley, Kansas	320,000	Coral Refining Co., Kansas City, Kansas	124
		Double Eagle Refining Co., Oklahoma City, Okla.	273
<u>KENTUCKY</u>			
Fort Campbell, Kentucky	70,000	Gurley Oil Co., Memphis, Tennessee	198
		Keenan Oil Co., Cincinnati, Ohio	292
		Seaboard Chemical Co., Doraville, Georgia	301
Fort Knox, Kentucky	40,000	Keenan Oil Co., Cincinnati, Ohio	145
		Westville Oil and Mfg., Inc., Westville, Indiana	280
<u>MARYLAND</u>			
Fort Meade, Maryland	34,000	Berks Assoc., Inc., Douglasville, Pennsylvania	106
		Diamond Head Oil Refining Co., Kearny, New Jersey	190
		National Oil Recovery Corp., Bayonne, New Jersey	190
<u>MISSISSIPPI</u>			
Camp Shelby, Mississippi	54,000	Jackson Oil Products Co., Jackson, Mississippi	96
		Davis Oil Co., Tallahassee, Florida	347
		S&R Oil Co., Houston, Texas	419

Table 3 (continued)

LOCATIONS OF KEY MILITARY FACILITIES AND NEAREST RE-REFINERIES

Military Facility	Estimated Lube Oil Procurement Fiscal 1975 (gal)	Nearest Re-Refinery	Distance (Highway miles)
<u>NORTH CAROLINA</u>			
Fort Bragg, North Carolina	129,000	South Oil Co., Greensboro, North Carolina	83
		Seaboard Chemical Co., Doraville, Georgia	360
Marine Corps Air Station Cherry Point, North Carolina	53,000	South Oil Co., Greensboro, North Carolina	205
		Berks Assoc., Inc., Douglasville, Pennsylvania	452
		Seaboard Chemical Co., Doraville, Georgia	491
Camp LeJeune, North Carolina	128,000	South Oil Co., Greensboro, North Carolina	193
		Seaboard Chemical Co., Doraville, Georgia	460
<u>OKLAHOMA</u>			
Fort Sill	86,000	Double Eagle Refining Co., Oklahoma City, Okla.	83
		Capital Supply Co., Hurst, Texas	168
		Texas American Petrochemicals, Inc., Midlothian, Texas	168
		Cooks Oil Co., Boyd, Texas	168
Tinker A.F.B., Oklahoma	35,000	Double Eagle Refining Co., Oklahoma City, Okla.	0

Table 3 (continued)

LOCATIONS OF KEY MILITARY FACILITIES AND NEAREST RE-REFINERIES

Military Facility	Estimated lube Oil Procurement Fiscal 1975 (gal)	Nearest Re-Refinery	Distance (Highway miles)
TEXAS			
Fort Bliss, Texas	68,000	Capital Supply Co., Hurst, Texas	605
		Texas American Petrochemicals, Inc., Midlothian, Texas	605
		Cooks Oil Co., Boyd, Texas	605
		Double Eagle Refining Co., Oklahoma City, Okla.	682
Fort Hood, Texas	260,000	Capital Supply Co., Hurst, Texas	147
		Texas American Petrochemicals, Inc., Midlothian, Texas	147
		Cooks Oil Co., Boyd, Texas	147
		S&R Oil Co., Houston, Texas	195
VIRGINIA			
Fort Eustis, Virginia	48,000	South Oil Co., Greensboro, North Carolina	235
		Berks Assoc., Inc., Douglasville, Pennsylvania	296
Naval Ship Compound, Norfolk, Virginia	89,000	South Oil Co., Greensboro, North Carolina	230
		Berks Assoc., Inc., Douglasville, Pennsylvania	286

Table 3 (continued)

LOCATIONS OF KEY MILITARY FACILITIES AND NEAREST RE-REFINERIES

Military Facility	Estimated Lube Oil Procurement Fiscal 1975 (gal)	Nearest Re-Refinery	Distance (Highway miles)
WASHINGTON			
Fort Lewis, Washington	144,000	Nu-Way Oil Co., Portland, Oregon	113
		Ager & Davis Refining Co., Portland, Oregon	113
WISCONSIN			
Camp McCoy	54,000	Lubricants, Inc., West Allis, Wisconsin	166
		Gopher State Oil Co., Minneapolis, Minnesota	176
		Warden Oil Co., Minneapolis, Minnesota	176

TABLE 4

COMMERCIAL LUBE OIL RE-REFINERS

As of September 1974

California

A. Ray Banks
Bayside Oil Corp.
977 Bransten Road
San Carlos, California 94070
(415) 593-2944, 593-4848

Brian Fabian
Fabian Oil Refining Company
4200 Alameda Avenue
Oakland, California
(415) 532-5051

George Leach
Leach Oil Co., Inc.
625 E. Compton Blvd.
Compton, California 90220
(213) 323-0226

Howard Dudley
Motor Guard Lubricants Co.
4334 E. Washington Blvd.
Los Angeles, California 90023
(213) 269-3437, 268-6877

A.W. Talley
Talley Bros., Inc.
2007 Laura Avenue
Huntington Park, California 90255
(213) 587-1217

Roger E. Humphrey
Nelco Oil Refining Co.
1211 McKinley Avenue
National City, California 92050
(714) 474-7511

Florida

George Davis
Davis Oil Company
Box 1303
Tallahassee, Florida 32302
(904) 576-3116

Alan Venzer
Petroleum Products Co.
Box 336
Hallandale, Florida 33009
(305) 989-4000

John Schroter
Peak Oil Company
Route 3, Box 24
Tampa, Florida 33619
(813) 626-9116, 626-9153

Georgia

Jack and Bernard Blase
Seaboard Chemical Co., Inc.
Box 333
Doraville, Georgia 30340
(404) 451-6900

Illinois

B.R. Williams
Motor Oils Refining Co.
7601 W. 47th Street
Lyons, Illinois 60534
(312) 242-2306

TABLE 4 (continued)

Indiana

Andrew Carson
Westville Oil and Mfg., Inc.
Box 104
Westville, Indiana 46391
(219) 785-2534

Kansas

Richard O'Blasny
Coral Refining Company
765 Pawnee Avenue
Kansas City, Kansas 66105
(913) 281-5454

Michigan

Jack Epstein
Bernie Horton
Dearborn Refining Co.
3901 Wyoming Avenue
Dearborn, Michigan 48120
(313) 843-1700

Minnesota

C.H. Romness
Gopher State Oil Co.
2500 Delaware Street, S.E.
Minneapolis, Minnesota 55405
(612) 331-5936

Al Warden
Warden Oil Company
187 Humboldt Avenue, N.
Minneapolis, Minnesota 55405
(612) 374-1200

Mississippi

H.K. Robertson
Jackson Oil Products Co.
Box 5686
Jackson, Mississippi 39208
(601) 939-3131

New Jersey

Arthur Vash
Diamond Head Oil Refining Co.
1427 Harrison Turnpike
Kearny, New Jersey 07032
(201) 991-5800

Salfred Mazius
National Oil Recovery Corp
Box 338
Bayonne, New Jersey 07002
(201) 437-7300

New York

George T. Booth & Son, Inc.
76 Robinson Street
North Tonawanda, New York 14120
(716) 693-0861

North Carolina

Jerry Blaise
South Oil Company
Box 106
Greensboro, North Carolina 27402
(919) 375-5811

Ohio

Jac Fallenberg
Alan Gressel
Research Oil Refining Co.
3680 Valley Road
Cleveland, Ohio 44109
(216) 749-2777

Darryl Thomas
Keenan Oil Company
#1 Parkway Drive
Cincinnati, Ohio 45212
(513) 631-2900

TABLE 4 (continued)

Oklahoma

Cameron L. Kerran
Double Eagle Refining Co.
Box 11257
Oklahoma City, Oklahoma 73111
(405) Office: 232-0244
Plant: 232-6878

Oregon

A.L. Geary
Nu-Way Oil Company
7039 46th Avenue, N.E.
Portland, Oregon 97218
(503) 281-9375

T.M. Davis
Harold W. Ager, Jr.
Ager & Davis Refining Company
9901 - 33rd Avenue, N.E.
Portland, Oregon 97211
(513) 288-3584

Pennsylvania

Lester Schurr
Berks Associates, Inc.
Box 305
Douglasville, Pennsylvania 19518
(215) 385-3031

Tennessee

William M. Gurley
Gurley Oil Company
Box 2326
Memphis, Tennessee 38102
(901) 527-9940

Texas

R.A. Swasey
S & R Oil Company
Box 35516
Houston, Texas 77035
(713) 729-8740 - main office

Mr. Kildorf
Capital Supply Co.
Refining & Chemical Division
1401 West Hurst Blvd.
Hurst, Texas 76053
(817) 268-1129

Ed Fisher
Texas American Petrochemicals, Inc.
North 67
Midlothian, Texas
(214) 291-4400

Joe Gillespie
Cooks Oil Company
Boyd, Texas
(817) 433-2754

Utah

J.R. Mastelotto
Alco Refining Co.
133 No. First Street
Salt Lake City, Utah 84113
(801) 364-4214

Wisconsin

Dick Drexeler
Lubricants, Inc.
1910 South 73rd
W. Allis, Wisconsin 53214
(414) 541-1000

4.0 A CLOSED-CYCLE DEMONSTRATION: POLICIES AND PROCEDURES FOR IMPLEMENTATION

Once the participating facility and re-refiner have been selected, it is essential that policies and procedures for the design and conduct of the field test be clearly defined and agreed to by the key personnel. This chapter presents such a set of guidelines for implementation of the closed-cycle demonstration. These guidelines have been developed as a set of generic procedures and, for any particular situation, may require modification. The goal in preparing these guidelines is to provide a comprehensive set of procedures which, if followed closely, will insure the satisfaction of the re-refiner and the customer, facilitate smooth operation of the demonstration and, most importantly, provide adequate evidence to the user community of the quality of the oil being tested.

A thorough evaluation of the quality of an engine crankcase lubricating oil includes laboratory tests of the physical and chemical properties of the base stock, engine sequence tests of the performance properties of the lube oil-additive blend, and a field test of lube oil performance under actual service conditions. Specification MIL-L-46152 (Appendix B) provides information concerning laboratory and engine test requirements for lube oils which will be used in the demonstration. Details of all test procedures are provided in those publications of the American Society of Testing and Materials (ASTM) which are cited in Appendix B. There are only three commercial laboratories in the United States which have been approved by the Army Fuels and Lubricants Center for conducting the required laboratory and performance tests.(7) Thus one of these organizations must participate in the qualification of the re-refined product(s) used in the demonstration.

Unlike the laboratory and performance tests discussed in Appendix B, standardized field tests are not required for lube oil qualification. However, in view of the actual service conditions encountered, a properly designed field test can provide a more complete determination of the performance of a lubricant in day to day service. Since the vehicles which will be used in the field test will be similar to those operated by potential commercial users of re-refined products, a successful demonstration can be an important aid in reducing the barriers to use of re-refined oil in the commercial sector. It is the purpose of this chapter to establish policies and procedures for the closed-cycle demonstration including the design and conduct of the field test and guidelines for the accumulation and re-refining of used crankcase oils and the utilization of re-refined oils.

4.1 Design of the Field Test

4.1.1 Number of Vehicles

The design of a field test is constrained both by the need for obtaining results which are statistically significant and by the amount of money available for conducting the test. Ideally, a large number of vehicles of each class should

[illegible] factors upon the test pro-
gram. Such factors include excessively light or excessively heavy duty use, improper maintenance procedures, lost or incorrect test data, vehicle loss with to accident or theft, etc. In practice, a field test is usually designed to the expectation that the vehicle mortality rate will be 25 percent.

Although the use of a large number of vehicles is desirable, high costs restrict the number of vehicles used in a field test of a given lube oil. The major cost components include labor and vehicle operation (estimated at 10 cents per vehicle mile), engine purchase, overhaul, and inspections. As discussed in Section 4.1.3 (below), in order to determine lubricant performance all field test vehicles must be equipped with new or newly rebuilt engines. A new eight cylinder passenger car gasoline engine costs about $1000 while a new light duty diesel engine costs about $5000. In most test programs for every vehicle operated using the test oil a vehicle is operated using a reference oil whose performance properties are well established. Thus the cost of the evaluation rises twice as fast as the number of vehicles operated using the test oil. If two oils are being evaluated, then sets of three vehicles (one using each test oil and one using the reference oil) are required. If the same oil is tested in more than one type of service (e.g., gasoline passenger car and light duty diesel engines), separate sets of vehicles using the test and reference oils are required. Therefore, as a consequence of cost considerations, most field tests are designed with a minimum of four vehicles of the same type using each test oil. On the basis of a 25 percent mortality rate, this provides assurance that at least three sets of data will be obtained for each combination of lube [illegible] vehicle type [illegible] class of service.

[illegible] 2 [illegible] Vehicles

Lube oil procured under [illegible]
line engines in passenger car [illegible]ication MIL-L-46152 is [illegible]nded for use [illegible] gaso-
manufacturers warranties and [illegible] light to medium duty [illegible] operating [illegible]
in moderate duty. Since these a[illegible] super charged diese[illegible] [illegible]ines operated
commercial users of re-refined oil, [illegible]nes of equipment opera[illegible] by potential
cars, gasoline fueled trucks and lightly [illegible] be desirable to include [illegible]enger
the demonstration. However, as discussed in [illegible] 1.1, inclusion of three [illegible]harged diesel fueled trucks in
vehicle classes will require a minimum of twelve ve[illegible] for each test oil and
twelve vehicles for the reference oil. Thus a total of 24 [illegible] (8 passenger
cars, 8 gasoline fueled trucks and 8 diesel fueled trucks) [illegible]uired.
The cost of purchasing engines for these vehicles will probably [illegible].000.
Prior to commencement of the test, each engine must be disassemble[illegible]
and reassembled. Following completion of the test, each engine will have to [illegible]
disassembled, inspected, and (probably) rebuilt Thus the total cost for
engines, parts, labor and inspection could amount to more than $[illegible],000. A less
ambitious lube oil evaluation program might exclude the use of diesel engines,
but the impact of the test on the user community which includes operators of
vehicles equipped with diesel engines would be reduced.

Large additional costs will be incurred for qualification of the re-refined oil and for analyses of used crankcase oils. The cost of the five engine sequence tests required for qualification under Specification MIL-L-46152 is approximately $15,000. Since failure of one or more tests on the first try should be anticipated, the total cost of qualification could easily exceed $20,000. The quoted costs of the engine sequence tests required under MIL-L-46152 are summarized in Table 5.

Used oil analyses are much less costly than engine tests. A complete used oil analysis costs about $50 per sample. However, over the two year period of this demonstration (see Section 4.1.4 below) as many as 300 such analyses could be required. Hence the cost of used oil analyses could amount to $15,000.

4.1.3 Engine Inspections

4.1.3.1 Wear Measurements

Prior to commencement of the demonstration, the engines of all test vehicles must be inspected in order to ensure that any wear found at the end of the program is due solely to operation of the engine during the demonstration. For example, broken or missing piston rings, missing valve guides, etc., are frequently found during these inspections. Further, subtle differences in engine wear cannot be detected using manufacturers' tolerances for new parts. The same inspections must be made following completion of the test program. A comparison of the "before and after" measurements provides the data on engine wear which are used in evaluating the relative performance properties of the "test" and "control" lubricating oils.

The following measurements of key engine parts should be made prior to commencement and following completion of the test program:

1. The longitudinal and transverse bore of each cylinder.
2. The diameter of each camshaft lobe.
3. The height of each valve lifter.
4. The diameter of the valve guide for each intake and exhaust valve.
5. The weights of the top compression ring, second compression ring, and oil control ring on each piston.
6. The weights of each main bearing and each connecting rod bearing.
7. The diameter of each crankshaft journal.
8. The thickness of each piston ring.

Table 5

COSTS OF ENGINE SEQUENCE TESTS
REQUIRED UNDER SPECIFICATION MIL-L-46152*

Tests	Cost (dollars)
Oldsmobile Sequence II C	$ 2,350
Oldsmobile Sequence III C	3,600
Sequence V-C	3,925
CRC L-38	990
Caterpillar 1-H	3,675
Total Cost	$14,540

* Costs supplied by Automotive Research Associates

9. The gap between each piston ring and the piston.

10. The valve seat wear for each intake and exhaust valve seat. A reference valve, not used in the field test, is used for this purpose.

11. The tip wear and stem wear for each intake and exhaust valve.

4.1.3.2 Rust, Sludge and Varnish Ratings

Following completion of the test program all engines should be disassembled and inspected for rust, sludge and varnish formation, plugging of oil lines, scuffing and wear, etc. Engine disassembly must be accomplished in accordance with standard practices recommended by automobile manufacturers for engine maintenance and overhauls. Engine inspections shall include the following:

- Rust ratings for

  Valve lifters
  Rocker covers
  Pushrods
  Oil pan

- Sludge ratings for

  Rocker arm covers
  Valve decks
  Valve lifter chamber
  Valve chamber cover
  Timing gear cover
  Oil pan

- Varnish ratings for

  Rocker arm covers
  Valve chamber covers
  Timing gear cover
  Oil pan
  Piston skirts
  Cylinder walls
  Pushrods
  Valve lifter bodies

- Other ratings

  Percent oil screen filling
  Percent oil ring filling
  Piston land varnish
  Number of stuck rings

Other ratings (continued)

Number of sluggish rings
Number of stuck valve lifters
Number of scuffed or pitted lifters
Deposits on intake and exhaust valves:

a. underhead deposit
b. stem deposit
c. observation on seat condition

All ratings shall be conducted in accordance with procedures specified in the Coordinating Research Council (CRC) engine rating manuals.

4.1.4 Used Oil Analysis

4.1.4.1 Purpose of Used Oil Analysis

Physical and chemical tests of the properties of used engine oils provide valuable information concerning the level of contamination with undesirable solids and liquids and the extent of decomposition of the lube oil-additive blend. Contaminants include fuel combustion products, liquid fuel, wear particles (e.g., steel, copper, etc.), water and coolant additives. In a field test, a comparison of the levels of contaminants in the used oils provides information concerning the mechanical condition of the engine and the severity of service.

The decomposition which takes place in engine oils involves several chemical reactions including:

- Oxidation, which results in deposits and an increase in oil viscosity.
- Neutralization of alkaline additives by fuel-derived acids, which results in loss of wear protection.
- Cracking, in which long chain molecule additives are sheared into smaller ones.

Under normal conditions high quality lube oils break down slowly. Thus, during the field test, it is expected that used oil analyses should not reveal excessive levels of decomposition or contamination. However, if service conditions are overly severe, if the engine develops mechanical problems, or if the oil is unsuitable for the class of service, used oil analyses can reveal if continued operation without an oil change might result in engine damage. Hence a comparison of the analyses of the used oils being tested can provide information concerning the relative quality of the oils and the degree of uniformity of the mechanical condition and the operating conditions of the test vehicles.

4.1.4.2 Procedures for Used Oil Analysis

The engine in each test vehicle and each control vehicle should be fitted with a 1/8 inch pipe ball valve to facilitate removal of lube oil for used oil analysis. The valve can be installed at any convenient point downstream of the oil filter.

Used oil samples should be withdrawn at mileage intervals equal to one-half the normal oil change interval. The sampling procedure is as follows:

a. Four ounces of oil (or a volume greater than the "dead space" in the sampling tube) are withdrawn and discarded.

b. A four ounce sample of used oil is withdrawn into a sample bottle.

c. The label of each sample bottle should include the following information: vehicle identification, date, odometer miles, oil miles, and whether the sample is a drain sample or an interim sample (see below).

d. Eight ounces of fresh oil are added to the crankcase to replace the oil which was withdrawn. Such additions should not be entered as oil consumption.

Each sample of used oil should be subjected to the following tests:

a. Appearance and odor

b. Water (ASTM D 95)

c. Viscosity (ASTM D445)

d. Spectrochemical analysis

e. Flash point (ASTM D 92)

f. Fuel dilution (ASTM D 322)

g. Glycol test (ASTM D 2982)

h. Insolubles (ASTM D 893)

i. Alkaline reserve (ASTM D 2896)

At the end of each drain interval, the oil filter should be removed and replaced. The used filter should be cut open and residue contained on the walls of the filter removed. Spectrochemical analysis and insolubles determinations (ASTM D 893) should be made on this residue.

Used oil analyses should be conducted by an independent, certified laboratory. If any of the test results exceed by a wide margin the recommended operating limits shown in Table 6, the crankcase of the relevant engine should be promptly drained and refilled with fresh oil and an investigation made of the reasons for breakdown of the used oil.

If after a six month period the used oil analyses conducted at one-half the drain interval mileage reveal no adverse effects, such interim analyses should be discontinued. Used oil analyses should then be made only at the end of each drain interval.

4.2 Policies and Procedures for Waste Crankcase Oil Accumulation and Collection

1. All waste crankcase oils which are to be re-refined must be stored separately from all other wastes including other waste oil products such as fuel oil, synthetic lubricants, animal fats, etc. Sump tanks must be cleaned prior to storage of waste lube oils. If sump tanks are not available, waste lube oils should be stored in clean drums equipped with tight fitting covers. The Property Disposal personnel at the Facility will be responsible for providing the Re-refiner with waste oil in quantities sufficient to produce the required volume of re-refined oil.

2. In order to reduce the cost of re-refining, single viscosity waste crankcase oils should be stored separately from multiple viscosity waste crankcase oils. Viscosities must be clearly marked on the storage containers.

3. Records must be kept which contain the following information concerning accumulation of waste crankcase oils: Identification of vehicle from which crankcase oil was drained; vehicle mileage; date of oil draining; specification and viscosity of crankcase oil used in the vehicle; approximate volume of waste oil drained; identification of container in which waste oil was stored.

4. In order to assure uniformity of the waste oil properties and the additive response of the re-refined product, the Facility must agree for the duration of the demonstration to purchase all virgin crankcase oil used in the control vehicles from the same supplier.

5. Waste oils collected for re-refining should be characteristic of seasonal variations in dilution and severity of service. Thus at least four batches of waste crankcase oil should be re-refined annually.

6. The volume of waste crankcase oils accumulated must be sufficiently great to justify re-refining this oil as a single batch. The minimum volume shall be agreed to by the participating Facility and the Re-refiner.

Table 6

RECOMMENDED OPERATING LIMITS FOR USED ENGINE OIL TESTS

	Test Method[1]	Gasoline Engines	Automotive Diesel Engines
Basic Tests			
Appearance and Odor		No Numerical Limits	
Viscosity Increase at 100°F, %, Max.[2]	445	50	35
Viscosity Increase at 210°F, %, Max.[2]	2161	35	25
Viscosity Decrease at 100°F, %, Max.		25[3]	25[3]
Fuel Dilution, Vol %, Max.		5	5
Trace Metals, ppm, Max.			
Aluminum	Spectro-Chemical Analysis	40	40
Boron		—	—
Chromium		40	40
Copper		40	40
Iron		100	100
Lead		—	100
Silicon		20	20
Silver		—	—
Sodium		—	—
Tin		40	40
Zinc		—	—
Supplementary Tests			
Flash, Point, °F	92	[4]	[4]
Water, Vol %, Max.	95	0.2	0.2
Glycol Test	2982	Negative	Negative
Insolubles			
Pentane, Wt %, Max.	893	1.5	1.5
Benzene, Wt %, Max.	893	0.7	0.7
Oxidation Resins (Pentane-Benzene), Wt %, Max.	893	1.0	1.0
Coagulated Pentane, Wt %, Max.	893	—	—
Coagulated Benzene, Wt %, Max.	893	—	—
Alkaline Reserve			
Total Base Number	2896	—	2
pH	664	—	4

[1]Numbers refer to ASTM D _______ method.

[2]Limit based on SAE 30 viscosity oils (RR-SAE 40) under normal operation; limit can be varied for other viscosity number oils and special operation conditions.

[3]Fuel dilution will usually control.

[4]Should be measured and compared with fresh oil value when fuel dilution suspected.

7. The vehicle which collects the waste crankcase oil for shipment to the re-refinery must be empty of any other waste products such as sludge and other contaminants. The waste oil can be collected by the Re-refiner using his own vehicles or by a common carrier who has agreed to the procedures enumerated here.

8. Payment for waste oil collected shall be arranged as follows:

   (a) If a single tariff for waste oil collection, closed-cycle re-refining and crankcase oil delivery has been arranged, then no payment shall be made by either party.

   (b) If separate charges have been arranged, then the Re-refiner shall pay the Facility a fixed amount per gallon of waste oil collected. The size of this payment shall be agreed to by the re-refiner and the Facility Purchasing Agent.

   (c) If a common carrier is used for waste oil shipment, then the Re-refiner shall be responsible for payment of all transportation charges.

9. Records shall be maintained by the Facility which contain the following information:

   (a) Volume, specification and viscosity (when new) of waste crankcase oils collected.

   (b) Identification of the containers from which the oils was removed and/or the containers in which the oil was removed.

   (c) The payment (if any) made for collection of waste crankcase oil.

4.3 Policies and Procedures for Waste Crankcase Oil Re-Refining

1. All waste crankcase oils delivered to the re-refinery from the Facility shall be stored in sealed containers or covered tanks and kept separate from other waste crankcase oils. The Re-refiner shall keep records of the volume, specification and viscosity (when new), delivery dates, BS&W content, and flash point of all waste crankcase oils delivered from the Facility. If possible, waste oil delivery should be scheduled so that the waste oil may be fed directly into the dehydration unit.

2. Waste crankcase oils collected from the Facility shall be re-refined in a separate batch operation under conditions consistent with maintenance of product quality. The Re-refiner shall determine these conditions (temperatures, quantities of acid and clay, etc.) and shall assume responsibility for insuring that all re-refined oils produced meet the relevant limitations for physical and chemical properties (see below).

3. Re-refined base oils shall be stored in tanks empty of oils whose origin is other than the participating Facility. Samples of re-refined base oils shall be subjected to the following laboratory tests using standard ASTM test procedures:

   Viscosity @ 100°F

   Viscosity @ 210°F

   Pour Point, °F

   Flash Point, °F

   Gravity, API

   Neutralization Number

   Carbon Residue

   Phosphorus

   Chlorine

   Sulfur

   Nitrogen

   Sulfated Residue

   Fe, ppm

   Pb, ppm

   Ca, ppm

   Ba, ppm

   Zn, ppm

   Cr, ppm

   Al, ppm

   Cu, ppm

   Si, ppm

   Testing shall be performed by an independent, certified laboratory. All test results must be in compliance with limits established under existing Specification MIL-L-46152 (see Appendix B). Where necessary, bright stocks or other viscosity improvers shall be blended with re-refined base oil in order to raise the viscosity to the specified level.

4. Performance additives shall be blended with the re-refined base oils in accordance with procedures specified by the Systems Engineer. Blended oils shall be packaged in containers marked with the appropriate specification and viscosity as specified by the Purchasing Agent.

5. Samples of compounded oil shall be subjected to engine sequence tests as specified in MIL-L-46152. This testing shall be performed only on the first batch of re-refined oil produced in a closed-cycle demonstration.

The Systems Engineer shall review the results of the engine tests and recommend appropriate changes in the additive package. Once an oil passes all required engine sequence tests, no changes shall be made in the volume or type of additives or in any other step in the re-refining process, except as approved by the project Systems Engineer.

Engine sequence tests shall be conducted by a certified laboratory. The results of such tests, including color photographs of the engine parts, shall be submitted to the EPA Project Officer. The EPA Project Officer and the Systems Engineer will review the test results.

A complete set of laboratory and engine test results including engine parts will be presented to the Military Automotive Review Committee. Upon approval by this committee, the re-refined oil will be shipped to the Facility. Subsequent batches of re-refined oil produced during a demonstration project shall not require engine testing nor review of test results by the Military Automotive Review Committee.

6. Prior to shipment of re-refined oils to the Facility, Quality Assurance Personnel, assigned by the Department of Defense, shall inspect each batch of oil according to test procedures specified by the Department of Defense. The test results shall be forwarded to the Systems Engineer and EPA's Representative. The analyses must satisfy the requirements of the specification for which the oil was compounded. *Further, the levels of calcium, zinc, and other components must be consistent with those that would be obtained after blending the base oil with the recommended additive package. If the levels of these components are found to be inadequate, then the Quality Assurance Personnel shall reject the entire shipment of lube oil.* If any cause for rejection is found the Systems Engineer shall have responsibility for determining the sources and causes of any deficiencies. In cooperation with the Re-refiner, steps shall be taken to correct these deficiencies.

7. The Re-refiner shall be responsible for delivery of all re-refined lube oils ordered by the Facility.

8. All re-refined lube oils produced as a result of a demonstration which are not purchased by the Facility, shall be the exclusive property of the Re-refiner.

9. The Re-refiner shall present evidence of liability and property damage insurance coverage on all vehicles owned by him which are used to transport oil to and from the Facility.

10. The Re-refiner shall present evidence of liability insurance for damage to the engines of any demonstration vehicles that may result from inadequate performance of any lube oil provided by the Re-refiner. The amount of such coverage shall be agreed to by the Facility Purchasing Agent and the Re-refiner.

4.4 Policies and Procedures for Purchase and Utilization of Crankcase Oils

1. The Purchasing Agent at the Facility shall provide the Re-refiner with purchase orders for all crankcase oil used in the demonstration vehicles. These orders shall specify the following information: volumes of lube oil required by specification and viscosity, container sizes and delivery dates.

2. The prices paid for re-refined lube oils shall be agreed to in advance of the start of the demonstration program. Prices shall be competitive with those quoted by traditional suppliers of lube oil for the same quantities, container sizes and specifications. Unless other arrangements are made in advance, prices established at the start of the demonstration shall not be subject to escalation.

3. Selection of vehicles which will be used in the demonstration shall be based on the following criteria:

   (a) Three classes of vehicles - passenger cars, gasoline fueled light to medium duty trucks, and light duty diesel fueled trucks shall be included in the field test.

   (b) Within each vehicle class all units shall be of the same make and model and shall have the same size and design drive train.

   (c) Vehicles which are subjected to unusually severe or unusually light duty service, or which run odd routes (e.g., exclusively on dirt roads) or which are equipped with unusual accessories (e.g., four wheel drive, towing equipment, etc.) shall not be used in this demonstration.

   (d) In view of the limitations on cost, eight vehicles of each type listed in (1) above shall participate in the demonstration. Within each group four shall be operated using re-refined lubricating oil and four shall be operated using virgin lubricating oil exclusively. The re-refined oil shall be that oil provided solely for use during this demonstration. The virgin oil shall be that oil which is being used at the start of the field test in other vehicles of similar types to those specified in (a) above. Sufficient virgin oil of the same brand and formulation shall be kept in storage to supply the needs of twelve of the test vehicles throughout the field test.

4. Throughout the field test each test vehicle and each control vehicle within a given vehicle class (e.g., passenger car) shall use the same grade of fuel obtained from the same supplier. At no time during the field test shall the grade or supplier of fuel be changed.

5. Two identical record books shall be kept for each vehicle used in this demonstration. All data concerning maintenance, measurements, oil and fuel consumption, used oil analyses, etc., shall be entered into these record books. One copy of the book shall be kept in the vehicle; the other copy of the book shall be retained by the Maintenance Foreman.

6. Prior to initiation of the experiment, measurements shall be made of certain parts of the engines of all vehicles. The parts to be measured and the measurements to be made are listed in Section 4.1.3, above. If any parts are found to be worn or defective, these parts shall be replaced.

7. All new engines shall be "broken-in" using a virgin lubricating oil which meets Specification MIL-L-21260. During the break-in period (and in all subsequent periods) records shall be kept of fuel consumption, oil consumption, and miles per day driven in order to estimate severity of service and to forecast dates for oil inspections and oil changes. The break-in period shall be that recommended by the engine manufacturer. At the end of the break-in period, the oil in each engine shall be drained and replaced with either virgin or re-refined oil which meets Specification MIL-L-46152.

8. Used oil analyses shall be conducted as specified in Section 4.1.4.2, above.

9. Periodic maintenance shall be performed on all test vehicles. The maintenance shall include oil and oil filter removal and replacement. Maintenance intervals shall be the same as prescribed in normal operations. The Maintenance Foreman shall keep records of all repairs, including vehicle mileage, dates, type of maintenance and, where relevant, probable cause of damage. Records shall also be kept of the quantities, dates and vehicle mileage of any additions of motor fuel and of crankcase oil.

10. Duration of the Demonstration

    The closed-cycle demonstration shall continue for a period of at least one year. At the end of one year, inspections shall be made of the condition of the engine crankcase, valve stems, rocker arms and rocker covers. If, on the basis of these inspections and used oil analyses, sufficient differences in wear, rust, sludge and varnish formation between the engines of the control group and the test group are not evident, the engines shall be reassembled and the test program continued for a second year. Records of the results of these interim inspections shall be made a part of the general record of the demonstration.

    In order for the field test to produce meaningful results, participating vehicles should be driven as much as possible during the period of the demonstration. Thus the criteria for vehicle selection should include the expected annual mileage accumulation (see item 3, above).

11. Following completion of the test program, the engine parts inspected at the beginning of the demonstration shall be re-examined for wear. Measurements specified in Section 4.1.3, above, shall be made and compared with the values obtained previously. The Systems Engineer shall prepare a report

which contains all data relevant to the conduct of the demonstration including a statistical analysis of the measurements made on key engine parts and data on oil consumption and vehicle maintenance. On the basis of this analysis conclusions will be drawn as to the comparative performance of re-refined and virgin engine oils.

12. Following completion of the demonstration the Facility Oversight Officer, in cooperation with the other Facility Personnel, shall prepare a written report which summarizes their activities in the demonstration and contains the documentation specified earlier in these instructions. Copies of this report shall be sent to the EPA Project Officer, the Systems Engineer and the Re-refiner. This report shall be available within sixty days of completion of the demonstration.

4.5 Potential Problems in Implementing the Closed-Cycle Demonstration

As discussed in Chapter 2, implementation of a closed-cycle demonstration of the use of re-refined crankcase oil at a military facility will require modification of existing procurement procedures for lubricants. Authorization for such modification will probably have to come from the Office of the Assistant Secretary of Defense for Installations and Logistics (ASDI&L). In addition, since military specifications now prohibit the purchase of re-refined crankcase oils by government agencies, these specifications will require modification or revision to permit the use of re-refined oils which have passed all qualification tests. Further, procurement officials must be satisfied that restrictions on feedstock variation can be met through the use of a closed-cycle system and that the additive response of different batches of re-refined oil will be essentially the same.

While these problems must be resolved prior to commencement of any demonstration, additional difficulties may arise once authorization to proceed is granted. This section discusses a number of potential problems and proposes possible actions which can lead to their resolution.

Problem 1: Re-Refined Oil Fails to Pass One or More Engine Sequence Tests

Only a few sets of engine test data for re-refined oils exist; the results of these tests have not been encouraging. In 1974, the U.S. Army Mobility Equipment Research and Development Center conducted engine tests on two samples of re-refined oil. The tests conducted were those required under Specifications MIL-L-2104C and MIL-L-46152. Of the samples, one failed all engine tests by a wide margin. The other sample passed only one of the seven tests; performance on the other six tests was, however, significantly better than that of the other re-refined product.

At first examination, these results would appear to be discouraging. However, chemical analyses of the two test samples revealed that the first oil contained essentially no performance additives and the second oil contained about one-half the additive volume normally required to pass the engine tests. Thus the test results are certainly not surprising. In fact, failures for both these oils could have been predicted on the basis of the chemical analyses alone. For this reason the policies and procedures listed in Section 4.3 include a requirement for chemical analysis of samples of re-refined oil prior to acceptance of any shipment by a participating facility.

During the past year, several large petroleum companies have investigated the technical and economic feasibility for purchasing lube oil from re-refiners, compounding the oil to meet relevant performance specifications, and marketing the oil under their own label. In the course of these investigations, at least one company has run a series of engine tests on a re-refined base oil blended with a variety of additive packages. Results of these engine tests would be of value in selecting the proper types and volumes of additives for use in the demonstration program. Experience has shown that of the engine tests required under MIL-L-46152 the Caterpillar I-H test may be the most difficult to pass. This test measures the performance of engine lubricating oils under high temperature, medium supercharged conditions and is used for determining the effect of a lube oil on ring-sticking, wear, and the accumulation of engine deposits. A diesel fuel of low-sulfur content is used. The criteria for passing the I-H test are sufficiently stringent that many virgin lube oils fail the test several times. In some cases, it is necessary to experiment with a number of additive blends before the I-H test is passed. The test is further complicated by the fact that test results are sensitive to the sulfur content of the fuel, the operating temperature, etc. Hence additive packages need to be adjusted as these test parameters vary. During the past several years the severity of the I-H test has been increased by raising the engine operating temperature. As a result, some lube oil manufacturers may have been using additive blends which were not adequate to insure qualification under the new test conditions. Thus it is essential that the additive packages be selected on the basis of current engine test conditions.

Problem 2: Regulations Established Under the Mandatory Petroleum Allocation Program

Regulations established under the Mandatory Petroleum Allocation Program (10 CFR §211.01 _et seq._) require that the relationship between a supplier and a wholesale purchaser of petroleum products, including lube oils, be maintained for the duration of the Program. The relationship is that which existed during the calendar year 1972.

Specifically 10CFR §211.9 reads:

> §211.9 Supplier/purchaser relationships.
>
> (a) Supplier/wholesale purchaser relationship. * * *
>
> (2) * * *
>
> (ii) Unless otherwise provided in this Part or directed by FEA, the supplier/wholesale purchaser-consumer relationships defined by specific dates or base periods or otherwise imposed pursuant to this part shall be maintained for the duration of the Mandatory Petroleum Allocation Program and may not be revised or otherwise terminated except that any such relationship may be terminated by the mutual consent of both parties.
>
> (b) Supplier/end-user relationship. Each supplier of an allocated product shall, to the maximum extent practicable, supply all end-users which purchased that allocated product from that supplier as of January 15, 1974, and which are entitled to an allocation level under the provisions of Subparts D through K of this part.

The distinction between a wholesale purchaser-consumer and an end-user is made on the basis of volume of product purchased. Subpart K dealing with greases and lubricants contains the following definition at 10 CFR §211.202:

> "Wholesale purchaser-consumer" means any firm that is an ultimate consumer which, as part of its normal business practices, purchases or obtains an allocated product from a supplier and receives delivery of that product into storage substantially under the control of that firm at a fixed location and purchased or obtained more than 20,000 gallons of lubricants, 10,000 pounds of greases or 55,000 gallons of any other product subject to this subpart in any completed calendar year subsequent to 1971.

An "end-user" is an ultimate consumer of an allocated product other than a wholesale purchaser-consumer (10 CFR §211.51).

Thus, under the Mandatory Petroleum Allocation Program, wholesale purchaser-consumers must maintain their relationship with base period lube oil suppliers unless the consumers and the suppliers mutually agree to terminate their relationships. This requirement holds even if the wholesale purchaser-consumer is required to procure lube oils by soliciting competitive bids. FEA Ruling 1974-19, "Competitive Bids: Supplier/Purchaser Relationships" (39 FR 22133, June 20, 1974) provides that a wholesale purchaser-consumer must maintain his relationship with the base period supplier *even if the base period contract has expired and a lower bid has been made by another supplier.* Since it is likely that all military bases listed in Table 1 purchased more than 20,000 gallons of lubricants in any calendar year prior to 1971, any of these facilities will have to terminate its relationship with the lube oil supplier in order to participate in a closed-cycle demonstration. Although the Mandatory Petroleum Allocation Program will expire on August 31, 1975, there are indications that Congress will vote to extend it. Should the program be allowed to expire then the problem of maintenance of supplier-purchaser relationships will not be a problem.

Problem 3: Establishment of Criteria for a Successful Demonstration

A field test of the use of re-refined lube oils can be evaluated in several ways. In a qualitative sense, the test can be assumed to be successful if the frequency of engine maintenance and the consumption of lube oils do not increase significantly over that experienced when virgin lubricants were used. This demonstration of "customer satisfaction" may well be the single most important goal of the entire program.

However, the field test design described in Section 4.2 is much more quantitative in nature. Critical engine parts are examined at the beginning and at the end of the test period. A control group of vehicles, which will use a qualified virgin lube oil, is selected in order to obtain a base line with which test results can be compared. The test conditions (including temperature, humidity, fuel consumption (a measure of severity of service), mileage between oil changes and total mileage are closely monitored. The number and type of vehicles in each group are selected according to the requirements for statistically significant results.

If such a field test is carried out, the program might not be as quantitative as that described here. Firstly, the total cost of such a program could be prohibitive. Secondly, it may not be possible to locate facilities which operate sufficiently large numbers of heavy, medium, and light duty vehicles and which are located near a reputable re-refiner. Thirdly, it may not be possible to control the test conditions as closely as might be desirable. The monitoring of a control group of vehicles may also be impossible if an adequate number of vehicles and personnel are not available. Therefore, it is clear that a compromise will have to be made between a quantitative test design and the limitations imposed by the purpose of the experiment and the funding available.

Problem 4: Demonstrations Involving More Than One Facility

In order to provide a larger volume of waste oil and a greater number of test vehicles it may be necessary to involve more than one facility in a single demonstration. This would increase the number of candidate facility-re-refiner combinations listed in Table 3. However, a decision to conduct demonstrations of this type must be made with the understanding that the number of base personnel involved will be greatly increased thereby increasing the likelihood that problems in running the demonstration will arise. Additionally, each facility would have to follow identical procedures for waste oil accumulation and collection. If vehicle maintenance schedules were either different or out of phase at the facilities, these schedules would have to be revised. Similarly, lube oil purchase schedules might require modification. While none of these potential difficulties is insurmountable, their existence dictates that combined demonstrations be carefully planned and closely monitored by the key personnel involved.

Problem 5: One or More Test Vehicles Have Mechanical Breakdowns Due to Poor Manufacture or Design. These Breakdowns Are Attributed to the Use of Re-Refined Oil.

It is possible that the engines of one or more makes and models of vehicles owned by a facility may be so poorly designed and/or manufactured that mechanical problems will occur regardless of the quality of the lube oil used. Since proving the cause of engine failure, especially when the vehicle is operated under severe conditions, is likely to be a difficult task, it is essential that the vehicles selected for the demonstration exclude any makes or models whose service records have in the past been unsatisfactory.

Problem 6: A Facility Selected for Participation Has Already Contracted for Waste Oil Removal.

It is possible that one or more facilities where closed-cycle demonstrations are feasible has made a commitment to sell its waste oil to a collector or pay to have it removed. If these arrangements have been made under contract, then accumulation of the waste oil for use in re-refining may not be possible, depending on the contract provisions and the term of the agreement. One possible solution to this kind of problem is to have the re-refiner purchase the waste oil from the collector. Alternatively, the collector may agree to waive his rights to the waste oil in return for some form of compensation. In either case it is probable that the cost of the lube oil produced will be higher than would be normally expected. If the solution involves the handling of the waste oil by the collector, then an additional opportunity for feedstock contamination and other operational difficulties arises.

5.0 References

1. Waste oil study; report to the Congress. Washington, U.S. Environmental Protection Agency, Apr. 1974. 402 p.

2. Cukor, P., M.J. Keaton, and G. Wilcox (Teknekron, Inc., and the Institute of Public Administration.) A technical and economic study of waste oil recovery. pt.3. Economic, technical and institutional barriers to waste oil recovery. Environmental Protection Publications SW-90c.3. U.S. Environmental Protection Agency, 1974. 143 p. (Distributed by National Technical Information Service, Springfield, Va., as PB-237 620.)

3. Cukor, P.M., and T. Hall (Teknekron, Inc.). A technical and economic study of waste oil recovery. pt.4. Energy consumption in waste oil recovery. U.S. Environmental Protection Agency, 1976. (In press; to be distributed by National Technical Information Service, Springfield, Va.)

4. Oil contract bulletin; lubricating oils and insulating oil for the armed services and other departments of the Federal government. DSA 600-74-0100. Cameron Station, Alexandria, Va. Defense Fuel Supply Center, 1974 170 p.

5. Esso Research and Engineering Company. Research of oily wastes. Washington, U.S. Navy, Naval Supply Systems Command, 1973. 7 v.

6. Defense disposal manual (restructured). Cameron Station, Alexandria Va., Defense Supply Agency, 1974. 1 v. (various pagings).

7. These laboratories are: Southwest Research Institute, San Antonio, Texas; Autoresearch Laboratories, Chicago, Illinois; and Automotive Research Associates, San Antonio, Texas.

APPENDIX A

MILITARY SPECIFICATIONS MIL-L-2104C

FOR ENGINE CRANKCASE OILS

Preceding page blank

MIL-L-2104C
20 November 1970
SUPERSEDING
MIL-L-2104B
1 December 1964
MIL-L-45199B
28 June 1968

MILITARY SPECIFICATION

LUBRICATING OIL, INTERNAL COMBUSTION ENGINE, TACTICAL SERVICE

This specification is mandatory for use by all Departments and Agencies of the Department of Defense

1. SCOPE

1.1 Scope. This specification covers engine oils suitable for lubrication of reciprocating internal combustion engines of both spark-ignition and compression-ignition types used in tactical service (see 6.1).

1.2 Classification. The lubricating oils shall be of the following viscosity grades (see 6.2):

Viscosity Grade	Military Symbol
Grade 10	OE/HDO-10
Grade 30	OE/HDO-30
Grade 40	OE/HDO-40
Grade 50	OE/HDO-50

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-L-21260 - Lubricating Oil, Internal Combustion Engine, Preservative and Break-In.
MIL-L-46152 - Lubricating Oil, Internal Combustion Engine, Administrative Service.

STANDARDS

FEDERAL

/FSC 9150/

Preceding page blank

Fed. Test Method Std. 791 - Lubricants, Liquid Fuels and Related Products; Methods of Testing.

MILITARY

MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes.
MIL-STD-290 - Packaging, Packing and Marking of Petroleum and Related Products.

(Copies of specifications, standards, drawings and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM) TEST METHODS

D 92	Flash and Fire Points by Cleveland Open Cup
D 97	Pour Point
D 129	Sulfur in Petroleum Products by the Bomb Method
D 270	Sampling petroleum and Petroleum Products
D 287	API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D 445	Viscosity of Transparent and Opaque Liquids (Kinematic and Dynamic Viscosities)
D 524	Ramsbottom Carbon Residue of Petroleum Products
D 808	Chlorine in New and Used Petroleum Products (Bomb Method)
D 811	Chemical Analysis for Metals in New and Used Lubricating Oils
D 874	Sulfated Ash from Lubricating Oils and Additives
D 892	Foaming Characteristics of Lubricating Oils
D 1091	Phosphorus in Lubricating Oils and Additives
D 1317	Chlorine in New and Used Lubricants (Sodium Alcoholate Method)
D 1552	Sulfur in Petroleum Products (High Temperature Method)
D 2270	Calculating Viscosity Index from Kinematic Viscosity
D 2602	Apparent Viscosity of Motor Oils at Low Temperature Using the Cold Cranking Simulator

Engine Test Sequence IIB
Engine Test Sequence VC

(The ASTM test methods listed above are included in Part 17 or Part 18 of the Annual Book of ASTM Standards and are also available separately, except for Engine Test Sequences IIB and VC. Engine Test Sequence IIB is a part of ASTM Special Technical Publication STP 315-D. Engine Test Sequence VC will be included in ASTM Special Technical Publication STP 315-E, scheduled for publication after May 1971, and is currently available only as a preprint.

(Application for copies of all ASTM test methods except Engine Test Sequence VC should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

(Until publication of Special Technical Publication STP 315-E by ASTM, information concerning Engine Test Sequence VC may be obtained from U.S. Army Research and Development Center, Coating and Chemical Laboratory, AMXRD-CF, Aberdeen Proving Ground, Maryland 21005.)

Specifications and standards of technical societies are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.

3.1 <u>Qualification</u>. Engine lubricating oils furnished under this specification shall be products which are qualified for listing on the applicable Qualified Products List at the time set for opening of bids (see 4.5.1 and 6.4).

3.1.1 The qualifying activity (see 6.4) may waive complete qualification testing or may require only partial qualification testing of grade 40 oil if the supplier states in a written affidavit that the product has been formulated with base stocks, refining treatment, and additives the same as those used in the formulation of grade 30 and grade 50 oils qualified under this specification.

3.1.2 Each viscosity grade of oil which satisfies all the requirements of this specification shall be qualified for a period not exceeding four years from the date of its original qualification. The qualification period for each grade 40 oil qualified in accordance with 3.1.1 shall not exceed that of the grade 30 and grade 50 oils used in the qualification procedure. When the qualification period has expired, each product must be requalified if the supplier wishes to maintain the formulation as a qualified product and be eligible to bid on prospective products.

3.1.3 Whenever there is a change in the base stock, in the refining treatment or in the additives used in the formulation, requalification will be required. When proposed changes are minor and may not be expected to significantly affect performance, the qualifying activity may, at its discretion, waive complete requalification or may require only partial requalification in order to determine the significance and acceptability of the proposed changes.

3.1.4 The engine lubricating oil supplied under contract shall be identical, within permissible tolerances assigned by the qualifying activity for the properties listed in 3.4, to the product receiving qualification. The values resulting after the application of tolerances shall not exceed the maximum nor fall below the minimum limits specified herein (see table I and 3.3.1 through 3.3.6).

3.1.5 Pour-point depressant. No changes shall be made in either the type or concentration of the pour-point depressant after qualification testing and approval unless:

(a) The oil is retested for conformity to the stable pour point requirement (see table I).

(b) The qualifying activity (see 6.4) is informed of the proposed change(s) and of the retesting of the stable pour point.

(c) The qualifying activity approves the proposed change(s) in writing.

3.2 Materials. The engine lubricating oils shall be petroleum products, synthetically prepared products or a combination of the two types of product compounded with such functional additives (detergents, dispersants, oxidation inhibitors, corrosion inhibitors, etc.) as are necessary to meet specified requirements. No re-refined constituent materials shall be used.

3.3 Physical and chemical requirements. The oils shall conform to the respective requirements specified in table I and 3.3.1 through 3.3.6.

Table I. Requirements

Property	Grade 10	Grade 30	Grade 40	Grade 50
Viscosity at 210°F. (99°C.), kinematic, centistokes				
min.	5.7	9.6	12.9	16.8
max.	< 7.5	< 12.9	< 16.8	< 22.7
Viscosity at 0°F. (-18°C.) 3/, apparent, centipoises				
min.	1200	--	--	--
max.	< 2400	--	--	--
Viscosity index (min.)	--	75	80	85
Pour point, °F. (max.)	-25	0	5	15
°C. (max.)	-32	-18	-15	- 9
Stable pour-point, °F. (max.)2/	-25	--	--	--
°C. (max.)	-32	--	--	--
Flash point, °F. (min.)	400	425	435	450
°C. (min.)	204	218	224	232
Gravity, API3/	X	X	X	X
Carbon residue3/	X	X	X	X
Phosphorus 3/	X	X	X	X
Chlorine 3/	X	X	X	X
Sulfur3/	X	X	X	X
Sulfated residue3/	X	X	X	X
Organo-metallic components3/	X	X	X	X

1/ Report measured, apparent viscosity at 0°F (-18°C) in centipoises for grade 10 oil.

2/ After being cooled below its pour point, the oil shall regain its homogeneity on standing at a temperature not more than 10° F (6° C) above the pour point.

3/ Values shall be reported ("x" indictes report).

3.3.1 Foaming. All grades of oil shall demonstrate the following foaming characteristics when they are tested in accordance with 4.6, table II.(ASTM D 892).

(a) Initial test at 75° ± 1° F (24° ± 0.5° C). Not more than 25 ml of foam shall remain immediately following the end of the 5-minute blowing period. No foam shall remain at the end of the 10-minute settling period.

(b) Intermediate test at 200° ± 1° F (93.5 ± 0.5° C). Not more than 150 ml of foam shall remain immediately following the end of the 5-minute blowing period. No foam shall remain at the end of the 10-minute settling period.

(c) Final test at 75° ± 1° F (24° ± 0.5° C). Not more than 25 ml of foam shall remain immediately following the end of the 5-minute blowing period. No foam shall remain at the end of the 10-minute settling period.

3.3.2 Stability and compatibility.

3.3.2.1 Stability. The oils shall show no evidence of separation or color change when they are tested in accordance with 4.6, table II (method 3470, Fed. Test Method Std. No. 791).

3.3.2.2 Compatibility. The oils shall be compatible with oils previously qualified under MIL-L-2104, MIL-L-46152, and MIL-L-21260. The oils shall show no evidence of separation when they are tested against selected reference oils in accordance with 4.6, table II (method 3470, Fed. Test Method Std. No. 791).

3.3.3 Moisture-corrosion characteristics. The oils shall prevent or minimize corrosion of ferrous-metal engine components in the presence of moisture induced by low-temperature operating conditions. Satisfactory performance in this respect shall be demonstrated when the oils are tested in accordance with 4.6, table II. (Engine Test Sequence IIB).

3.3.4 Low-temperature deposits. The oils shall minimize the formation of undesirable deposits associated with intermittent, light-duty, low-temperature operating conditions. Satisfactory performance in this respect shall be demonstrated when the oils are tested in accordance with 4.6, table II (Engine Test Sequence VC).

3.3.5 Bearing corrosion. The oils shall be noncorrosive to alloy bearings. Satisfactory performance in this respect shall be demonstrated when the oils are tested in accordance with 4.6, table II (method 3405, Fed. Test Method Std. No. 791).

3.3.6 Ring-sticking, wear, and accumulation of deposits. The oils shall prevent the sticking of piston rings and the clogging of oil channels, and shall minimize the wear of cylinders, rings and loaded engine components such as cam shaft lobes, cam followers, valve rocker arms, rocker arm shafts, and the oil pump and fuel injection pump drive gears. Satisfactory performance shall be demonstrated when the oils are tested in accordance with the appropriate methods listed in 4.6, table II (methods 340 and 341, Fed. Test Method Std. No. 791).

3.4 Other requirements and tolerances for quality conformance testing. The following physical and chemical properties shall be tested in accordance with the appropriate methods listed in 4.6 to insure that purchased products are of the same compositions as the respective qualification samples and to identify the products. No specific values or limits are assigned in qualification testing, except as otherwise specified in table I and in 3.3.1 through 3.3.6, but test results shall be reported for all properties listed. The qualifying activity (see 6.4) shall establish specific values and tolerances for subsequent quality conformance testing for these properties (see 6.3 and 6.4):

Viscosity
Viscosity index
Pour point
Flash point
Gravity, API
Carbon residue
Foaming
Phosphorus
Chlorine
Sulfur
Sulfated ash
Organo-metallic components

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Lot.

4.2.1 Bulk lot. An indefinite quantity of a homogeneous mixture of one grade of oil offered for acceptance in a single, isolated container; or manufactured in a single plant run (not exceeding 24 hours), through the same processing equipment, with no change in the ingredient materials.

4.2.2 Packaged lot. An indefinite number of 55 gallon drums or smaller unit containers of identical size and type, offered for acceptance, and filled with a homogeneous mixture of one grade of oil from a single, isolated container; or filled with a homogeneous mixture of one grade of oil manufactured in a single plant run (not exceeding 24 hours), through the same processing equipment, with no change in the ingredient materials.

4.3 Sampling.

4.3.1 Sampling of filled containers. Take a random sample of filled containers from each lot in accordance with MIL-STD-105 at inspection level II and acceptable quality level (AQL) = 2.5 percent defective.

4.3.2 Sampling for tests. Take samples from bulk or packaged lots for tests in accordance with ASTM Method D 270.

4.4 Inspection. Perform inspection in accordance with method 9601 of Fed. Test Method Std. No. 791.

4.4.1 Examination of filled containers. Examine samples taken in accordance with 4.3.1 for compliance with MIL-STD-290 with regard to fill, closure, sealing, leakage, packaging, packing, and marking requirements. Reject any container having one or more defects or under the required fill. If the number of defective or underfilled containers exceeds the acceptance number for the appropriate sampling plan of MIL-STD-105, reject the lot represented by the sample.

4.5 Classification of tests.

(a) Qualification tests.
(b) Quality conformance tests.

4.5.1 Qualification tests. Qualification tests consist of test for all of the requirements specified in section 3 and may be conducted in any plant or laboratory approved by the qualifying activity (see 6.4), unless otherwise specified in 4.6.1 through 4.6.2. Qualification tests shall be performed on each viscosity grade except as specified in 4.5.1.1 and 4.5.1.2.

4.5.1.1 The stable pour-point test (method 203, Fed. Test Method Std. 791) shall be required only on grade 10 oil.

4.5.1.2 Grade 40 oils may be qualified in accordance with 3.1.1.

4.5.2 Quality conformance tests. Tests for quality conformance of individual lots shall consist of tests for all of the requirements in section 3, except for the following (see table II):

Stable pour point
Stability and compatibility
Ring-sticking, wear, and accumulation of deposits
Low temperature deposits
Bearing corrosion
Moisture-corrosion characterisitcs

4.6 Test methods. Perform tests in accordance with table II and with 4.6.1 through 4.6.2 as applicable.

4.6.1 Stability and compatibility. Determine the stability and compatibility of the oils by the procedures for "Homogeneity" and "Miscibility" given in method 3470, Fed. Test Method Std. No. 791, as explained in 4.6.1.1 and 4.6.1.2. The procedures in 4.6.1.1 and 4.6.1.2 should be performed at the same time. This test shall be conducted only in a laboratory designated by the qualifying activity (see 6.4).

4.6.1.1 Stability. Determine the stability by subjecting an unmixed sample of oil to the prescribed cycle of temperature changes and examining the sample for conformance to the requirements of 3.3.2.1. Record the test results on a copy of the "Homogeneity and Miscibility Test" form in the column marked "None."

4.6.1.2 Compatibility. Determine the compatibility of the oil with other oils previously qualified under MIL-L-2104, MIL-L-21260 and MIL-L-46152, by subjecting separate mixtures of the oil with selected reference oils designated by the qualifying activity (see 6.4) to the prescribed cycle of temperature changes, then examining the mixtures for conformance to the requirements of 3.3.2.2. Record the test results on the same copy of the "Homogeneity and Miscibility Test" form (see 4.6.1.1) in the appropriate columns marked "1-30", "2-30", etc.

4.6.2 Stable pour point. The stable pour point test (method 203, Fed. Test Method Std. No. 791) shall be performed only in a laboratory designated by the qualifying activity (see 6.4).

Table II. Test Methods

Test	Test Method No. Fed. Std. 791	Test Method No. ASTM
Viscosity, kinematic		D 445
Viscosity, apparent		D 2602 1/
Viscosity index		D 2270
Pour point		D 97
Stable pour point	203 2/	
Flash point		D 92
Gravity, API		D 287
Carbon residue		D 524
Phosphorus		D 1091
Chlorine		D 808 or D 1317 3/
Sulfur		D 1552 or D 129 4/
Sulfated residue		D 874
Organo-metallic components		D 811 5/
Foaming		D 892
Stability and compatibility	3470 6/	
Moisture-corrosion characteristics		Sequence IIB 7/
Low temperature deposits		Sequence VC 8/
Bearing corrosion	3405	
Ring-sticking, wear, and accumulation of deposits:		
Medium-speed, supercharged, high-sulfur fuel	340	
High-speed, supercharged	341	

1/ Obtain the viscosity at 0°F. (-18°C.) by D 2602 for grade 10 oil.
2/ See 4.6.2.
3/ D 808 is the preferred method but D 1317 may be used as an alternate.
4/ D 1552 is the preferred method but D 129 may be used as an alternate.
5/ X-ray fluorescence or atomic absorption spectrochemical analysis methods that have been previously approved by the qualifying activity (see 6.4) may be used as alternates to D 811.
6/ Homogeneity and Miscibility Test. See 4.6.1 for clarifying instructions.
7/ Included in ASTM.
8/ Not yet published by ASTM. To be included in ASTM STP 315-E, when published (see 2.2).

5. PREPARATION FOR DELIVERY

5.1 Packaging, packing, and marking. Unless otherwise specified in the contract or purchase order (see 6.2), packaging, packing, and marking shall be in accordance with MIL-STD-290.

6. NOTES

6.1 Intended use. The lubricating oils covered by this specification are intended for the crankcase lubrication of reciprocating spark-ignition and compression-ignition engines used in all types of military tactical ground equipment and for the crankcase lubrication of high-speed, high-output, supercharged compression-ignition engines used in all ground equipment. The lubricants covered by this specification are intended for all conditions of service, as defined by appropriate Lubrication Orders, when ambient temperatures are above -20°F. (-29°C.).

6.2 Ordering data. Procurement documents should specify the following information:

(a) Title, number, and date of this specification.
(b) Grade of oil required (see 1.2).
(c) Quantity of oil required.
(d) Type and size of containers required (see 5.1).
(e) Level of packaging and level of packing required (see 5.1).

6.3 Other requirements and tolerances for quality conformance testing. Definite numerical values are not specified for certain of the physical and chemical properties listed in 3.4, and for which corresponding test methods are given in section 4. Values of some properties vary from one commercial brand of oil to another for the same grade These values are influenced by the source of the base stock, the identities and quantities of additives, etc. Definite numerical values are not always functionally important except, for some properties, within specified maximum and/or minimum limits. It is not possible (or necessary) to assign restrictive values in the specification before the testing of qualification samples. During qualification, test values will be determined which are characteristic of a particular product and which can serve thereafter to identify the product. Using the results of qualification testing, the qualifying activity (see 6.4) can set values, including permissible tolerances, for future quality conformance testing.

6.4 Qualification. With respect to products requiring qualification, awards will be made only for products which are at the time set for opening of bids, qualified for inclusion in the applicable qualified products list whether or not such products have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. The activity responsible for the qualified products list is the U.S. Army Aberdeen Research and Developement Center, Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland 21005, and information pertaining to qualification of products may be obtained from that activity.

6.5 Certain provisions of this specification are the subject of international standardization agreement (NATO STANAG 1135). When amendment, revision or cancellation of this specification is proposed which would affect or violate the international agreement concerned, the preparing activity will take appropriate reconciliation action through international standardization channels, including departmental standardization offices, if required.

Custodians:
Army - MR
Navy - SH
Air Force - 68

Review activities:
Army - ME, WC, AT
Navy - SA, SH, AS, YD
Air Force - 11, 68
DSA - PS

User activities:
Navy - MC

Preparing activity:
Army - MR

(Project No. 9150-0167)

☆ U. S. GOVERNMENT PRINTING OFFICE: 1971 - 433-697 6503

MILITARY SPECIFICATION

LUBRICATING OIL, INTERNAL COMBUSTION ENGINE, ADMINISTRATIVE SERVICE

This specification is mandatory for use by all Departments and Agencies of thd Department of Defense.

1. SCOPE

1.1 Scope. This specification covers engine oils suitable for lubrication of commercial-type vehicle reciprocating internal combustion engines of both spark-ignition and compression-ignition types used in administrative service (see 6.1).

1.2 Classification. The engine lubricants shall be of the following viscosity grades (see 6.2):

Viscosity grade

Grade 10W
Grade 30
Grade 10W-30
Grade 20W-40

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein.

SPECIFICATIONS

MILITARY
- MIL-L-2104 - Lubricating Oil, Internal Combustion Engine, Tactical Service
- MIL-L-21260 - Lubricating Oil, Internal Combustion Engine, Preservative and Break-In

FSC 9150

APPENDIX B

MILITARY SPECIFICATIONS MIL-L-46152

FOR ENGINE CRANKCASE OILS

Preceding page blank

MILITARY SPECIFICATION

LUBRICATING OIL, INTERNAL COMBUSTION ENGINE, ADMINISTRATIVE SERVICE

This specification is mandatory for use by all Departments and Agencies of thd Department of Defense.

1. SCOPE

1.1 Scope. This specification covers engine oils suitable for lubrication of commercial-type vehicle reciprocating internal combustion engines of both spark-ignition and compression-ignition types used in administrative service (see 6.1).

1.2 Classification. The engine lubricants shall be of the following viscosity grades (see 6.2):

Viscosity grade

Grade 10W
Grade 30
Grade 10W-30
Grade 20W-40

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein.

SPECIFICATIONS

MILITARY
MIL-L-2104 - Lubricating Oil, Internal Combustion Engine, Tactical Service
MIL-L-21260 - Lubricating Oil, Internal Combustion Engine, Preservative and Break-In

FSC 9150

STANDARDS

FEDERAL

Fed. Test Method Std. No. 791 - Lubricants, Liquid Fuels and Related Products; Methods of Testing

MILITARY

MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes

MIL-STD-290 - Packaging, Packing and Marking of Petroleum and Related Products

(Copies of specifications, standards, drawings and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated the issue in effect on date of invitation for bids or request for proposal shall apply:

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM) TEST METHODS

D 92 - Flash and Fire Points by Cleveland Open Cup
D 97 - Pour Point
D 129 - Sulfur in Petroleum Products by the Bomb Method
D 270 - Sampling Petroleum and Petroleum Products
D 287 - API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
D 445 - Viscosity of Transparent and Opaque Liquids (Kinematic and Dynamic Viscosities)
D 524 - Ramsbottom Carbon Residue of Petroleum Products
D 808 - Chlorine in New and Used Petroleum Products (Bomb Method)
D 811 - Chemical Analysis for Metals in New and Used Lubricating Oils
D 874 - Sulfated Ash from Lubricating Oils and Additives
D 892 - Foaming Characteristics of Lubricating Oils
D 1091 - Phosphorus in Lubricating Oils and Additives
D 1317 - Chlorine in New and Used Lubricants (Sodium Alcoholate Method)
D 1552 - Sulfur in Petroleum Products (High Temperature Method)
D 2270 - Calculating Viscosity Index from Kinematic Viscosity
D 2602 - Apparent Viscosity of Motor Oils at Low Temperature Using the Cold Cranking Simulator

Engine Test Sequence IIB
Engine Test Sequence IIIC
Engine Test Sequence VC

(The ASTM test methods listed above are included in Part 17 or Part 18 of the Annual Book of ASTM Standards and are also available separately, except for Engine Test Sequences IIB, IIIC, and VC. Engine Test Sequence IIB is a part of ASTM Special Technical Publication STP 315-D. Engine Test Sequences IIIC and VC will be included in ASTM Special Technical Publication STP 315-E, scheduled for publication after May 1971, and are currently available only as preprints.)

(Application for copies of all ASTM test methods except Engine Test Sequences IIIC and VC should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

(Until publication of Special Technical Publication STP 315-E by ASTM, information concerning Engine Test Sequences IIIC and VC may be obtained from U. S. Army Aberdeen Research and Development Center, Coating and Chemical Laboratory, AMXRD-CF, Aberdeen Proving Ground, Maryland 21005.)

Specifications and standards of technical societies are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.

3. REQUIREMENTS

3.1 Qualification. Engine lubricating oils furnished under this specification shall be products which are qualified for listing on the applicable qualified products list at the time set for opening of bids (see 4.5.1 and 6.4).

3.1.1 Each viscosity grade of oil which satisfies all the requirements of this specification shall be qualified for a period not to exceed four years from the date of its original qualification. When the qualification period has expired, each product must be requalified if the supplier wishes to maintain the formulation as a qualified product and be eligible to bid on prospective procurements.

3.1.2 Whenever there is a change in the base stock, in the refining treatment or in the additives used in the formulation, requalification will be required. When proposed changes are minor and may not be expected to significantly affect performance, the qualifying activity may, at its discretion, waive complete requalification or may require only partial requalification in order to determine the significance and acceptability of the proposed changes.

3.1.3 The engine lubricating oil supplied under contract shall be identical, within permissible tolerances assigned by the qualifying activity for the properties listed in 3.4, to the product receiving qualification. The values resulting after the application of tolerances shall not exceed the maximum nor fall below the minimum limits specified herein (see table I and 3.3.1 through 3.3.7).

3.1.4 Pour-point depressant: All grade oils. No changes shall be made in either the type or concentration of the pour-point depressant after qualification testing and approval unless:

a. The oil is retested for conformity to the stable pour point requirement (see table I).

b. The qualifying activity (see 6.4) is informed of the proposed change(s) and of the retesting of the stable pour point.

c. The qualifying activity approves the proposed change(s) in writing.

3.2 Materials. The engine lubricating oils shall be petroleum products, synthetically prepared products, or a combination of the two types of product compounded with such functional additives (detergents, dispersants, oxidation inhibitors, corrosion inhibitors, etc.) as are necessary to meet the specified requirements. No re-refined constituent materials shall be used.

3.3 Physical and chemical requirements. The oils shall conform to the respective requirements specified in table I and in 3.3.1 through 3.3.7.

Table I. Requirements

Property	Grade 10	Grade 30	Grade 10W-30	Grade 20W-40
Viscosity at 210°F (99°C)				
kinematic, centistokes				
min.	5.7	9.6	9.6	12.9
max.	< 7.5	< 12.9	< 12.9	< 16.8
Viscosity at 0°F (-18°C) 1/				
apparent, centipoises				
min.	1200	--	1200	2400
max.	< 2400	--	< 2400	< 9600
Viscosity index, min	--	75	--	--
Pour point, °F (max.)	-25	0	-25	-10
°C (max.)	-32	-18	-32	-23
Stable pour point, °F (max.) 2/	-25	--	-25	-10
°C (max.)	-32	--	-32	-23
Flash point, °F (min.)	400	425	400	415
°C (min.)	204	218	204	213
Gravity, API 3/	X	X	X	X
Carbon residue 3/	X	X	X	X
Phosphorus 3/	X	X	X	X
Chlorine 3/	X	X	X	X
Sulfur 3/	X	X	X	X
Sulfated residue 3/	X	X	X	X
Organo-metallic components 3/	X	X	X	X

1/ Report measured, apparent viscosity at 0°F (-18°C) in centipoises for grades 10, 10W-30, and 20W-40 oils.

2/ After being cooled below its pour point, the oil shall regain its homogenity on standing at a temperature not more than 10°F (6°C) above the pour point.

3/ Values shall be reported ("X" indicates report).

3.3.1 Foaming. All grades of oil shall demonstrate the following foaming characteristics when they are tested in accordance with 4.6, table II (ASTM D 892).

a. Initial test at 75° ± 1°F (24° ± 0.5°C). Not more than 25 ml of foam shall remain immediately following the end of the 5-minute blowing period. No foam shall remain at the end of the 10-minute settling period.

b. Intermediate test at 200° ± 1°F (93.5° ± 0.5°C). Not more than 150 ml of foam shall remain immediately following the end of the 5-minute blowing period. No foam shall remain at the end of the 10-minute settling period.

c. Final test at 75° ± 1°F (24° ± 0.5°C). Not more than 25 ml of foam shall remain immediately following the end of the 5-minute blowing period. No foam shall remain at the end of the 10-minute settling period.

3.3.2 Stability and compatibility.

3.3.2.1 Stability. The oils shall show no evidence of separation or color change when they are tested in accordance with 4.6, table II (Method 3470 of Fed. Test Method Std. No. 791).

3.3.2.2 Compatibility. The oils shall be compatible with oils previously qualified under MIL-L-2104, MIL-L-46152 and MIL-L-21260. The oils shall show no evidence of separation when they are tested against selected reference oils in accordance with 4.6, table II (Method 3470 of Fed. Test Method Std. No. 791).

3.3.3 Moisture-corrosion characteristics. The oils shall prevent or minimize corrosion of ferrous-metal engine components in the presence of moisture induced by low-temperature operating conditions. Satisfactory performance in this respect shall be demonstrated when the oils are tested in accordance with 4.6, table II (Engine Test Sequence IIB).

3.3.4 Low-temperature deposits. The oils shall minimize the formation of undesirable deposits associated with intermittent, light-duty, low-temperature operating conditions. Satisfactory performance in this respect shall be demonstrated when the oils are tested in accordance with 4.6, table II (Engine Test Sequence VC).

3.3.5 Oxidation characteristics. The oils shall resist thermal and chemical oxidation and prevent or minimize thickening and deposits associated with high-temperature operating conditions. Satisfactory performance in this respect shall be demonstrated when the oils are tested in accordance with 4.6, table II (Engine Test Sequence IIIC).

3.3.6 Ring-sticking, wear, and accumulation of deposits. The oils shall prevent the sticking of piston rings and the clogging of oil channels, and shall minimize the wear of cylinders, rings and loaded engine components such as cam shaft lobes, cam followers, valve rocker arms, rocker arm shafts, and the oil pump and fuel injection pump drive gears. Satisfactory performance shall be demonstrated when the oils are tested in accordance with 4.6, table II (Method 346 of Fed. Test Method Std. No. 791).

3.3.7 Bearing corrosion and shear stability.

3.3.7.1 Bearing corrosion. The oils shall be non-corrosive to alloy bearings. Satisfactory performance in this respect shall be demonstrated when the oils are tested in accordance with 4.6, table II (Method 3405 of Fed. Test Method Std. No. 791).

3.3.7.2 Shear stability. Grade 10W-30 and 20W-40 oils shall demonstrate shear stability by remaining within the respective viscosity ranges at 210°F (99°C), when tested in accordance with 4.6.3.

3.4 Other requirements and tolerances for quality conformance testing. The following physical and chemical properties shall be tested in accordance with the appropriate methods listed in 4.6 to insure that purchased products are of the same compositions as the respective qualification samples and to identify the products. No specific values or limits are assigned in qualification testing, except as otherwise specified in table 1 and in 3.3.1 through 3.3.7, but test results shall be reported for all properties listed. The qualifying activity (see 6.4) shall establish specific values and tolerances for subsequent quality conformance testing for these properties (see 6.3 and 6.4):

Viscosity
Viscosity index
Pour point
Flash point
Gravity, API
Carbon residue
Foaming
Phosphorus
Chlorine
Sulfur
Sulfated ash
Organo-metallic components

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Lot.

4.2.1 Bulk lot. An indefinite quantity of a homogeneous mixture of one grade of oil offered for acceptance in a single, isolated container; or manufactured in a single plant run (not exceeding 24 hours), through the same processing equipment, with no change in the ingredient materials.

4.2.2 Packaged lot. An indefinite number of 55 gallon drums or smaller unit containers of identical size and type, offered for acceptance, and filled with a homogeneous mixture of one grade of oil from a single, isolated container; or filled with a homogeneous mixture of one grade of oil, manufactured in a single plant run (not exceeding 24 hours), through the same processing equipment, with no change in the ingredient materials.

4.3 Sampling.

4.3.1 Sampling for the examination of filled containers. Take a random sample of filled containers from each lot in accordance with MIL-STD-105, at inspection level II and acceptable quality level (AQL) = 2.5 percent defective.

4.3.2 Sampling for tests. Take samples from bulk or packaged lots for tests in accordance with ASTM Method D 270.

4.4 Inspection. Perform inspection in accordance with Method 9601 of Fed. Test Method Std. No. 791.

4.4.1 Examination of filled containers. Examine samples taken in accordance with 4.3.1 for compliance with MIL-STD-290 with regard to fill, closure, sealing, leakage, packaging, packing, and marking requirements. Reject any container having one or more defects or under the required fill. If the number of defective or underfilled containers exceeds the acceptance number for the appropriate sampling plan of MIL-STD-105, reject the lot represented by the sample.

4.5 Classification of tests.

a. Qualification tests
b. Quality conformance tests

4.5.1 Qualification tests. Qualification tests consist of tests for all of the requirements specified in section 3 and may be conducted in any plant or laboratory approved by the qualifying activity (see 6.4) unless otherwise specified in 4.6.1 through 4.6.3. Qualification tests shall be performed on each viscosity grade except as specified in 4.5.1.1 and 4.5.1.2.

4.5.1.1 The stable pour-point test (Method 203 of Fed. Test Method Std. No. 791) shall be required only on grade 10W, 10W-30 and 20W-40 oils.

4.5.1.2 Shear stability shall be required for only grade 10W-30 and 20W-40 oils.

4.5.2 Quality conformance tests. Tests for quality conformance of individual lots shall consist of tests for all of the requirements in section 3, except for the following (see table II):

Stable pour point
Stability and compatibility
Ring-sticking, wear, and accumulation of deposits
Low-temperature deposits
Oxidation characteristics
Moisture-corrosion characteristics
Bearing corrosion and shear stability

4.6 Test methods. Perform tests in accordance with table II and with 4.6.1 through 4.6.3 as applicable.

4.6.1 Stability and compatibility. Determine the stability and compatibility of the oils by the procedures for "Homogeneity" and "Miscibility" given in Method 3470 of Fed. Test Method Std. No. 791, as explained in 4.6.1.1 and 4.6.1.2. The procedures in 4.6.1.1 and 4.6.1.2 should be performed at the same time. This test shall be conducted only in a laboratory designated by the qualifying activity (see 6.4).

4.6.1.1 Stability. Determine the stability by subjecting an unmixed sample of oil to the prescribed cycle of temperature changes, then examine the sample for conformance to the requirements of 3.3.2.1. Record the test results on a copy of the "Homogeneity and Miscibility Test" form in the column marked "None".

4.6.1.2 Compatibility. Determine the compatibility of the oil with other oils previously qualified under MIL-L-2104, MIL-L-21260, and MIL-L-46152 by subjecting separate mixtures of the oil with selected reference oils designated by the qualifying activity (see 6.4) to the prescribed cycle of temperature changes, then examine the mixtures for conformance to the requirements of 3.3.2.2. Record the test results on the same copy of the "Homogeneity and Miscibility Test" form (see 4.6.1.1) in the appropriate colums marked "1-30", "2-30", etc.

4.6.2 Stable pour point. The stable pour-point test shall be conducted only in a laboratory designated by the qualifying activity (see 6.4).

4.6.3 Shear stability. Determine the shear stability of grade 10W-30 and 20W-40 oils by the following method:

a. Weigh 25 grams of used oil, obtained at 10 hours of testing in accordance with Method 3405 of Fed. Test Method Std. No. 791, into a 50-ml three-necked round bottom flask equipped with a thermometer, gas inlet tube, stirrer, and distillation side arm.

b. Heat the sample at 248° ± 9° F (120° ± 5°C) in a vacuum of 100 mm of mercury with a nitrogen sparge for one hour.

c. Filter the stripped sample through a 0.1 micron Seitz filter pad.

d. Determine the kinematic viscosity at 210°F (99°C) of the filtered sample using ASTM Method D 445 for conformance to the requirements of 3.3.7.2.

Table II. Test methods

Test	Test Method No. Fed. Std. 791	Test Method No. ASTM
Viscosity, kinematic		D 445
Viscosity, apparent		D 2602 1/
Viscosity index		D 2270
Pour point		D 97
Stable pour point	203 2/	
Flash point		D 92
Gravity, API		D 287
Carbon residue		D 524
Phosphorus		D 1091
Chlorine		D 808 or D 1317 3/
Sulfur		D 1552 or D 129 4/
Sulfated residue		D 874
Organo-metallic components		D 811 5/
Foaming		D 892
Stability and compatibility	3470 6/	
Moisture-corrosion characteristics		Sequence IIB 7/
Low temperature deposits		Sequence VC 8/
Oxidation characteristics		Sequence IIIC 8/
Ring-sticking, wear, and accumulation of deposits	346	
Bearing corrosion and shear stability	3405 9/	

1/ Obtain the viscosity at 0°F (-18°C) by D 2602 for grade 10W, 10W-30 and 20W-40 oils.
2/ See 4.6.2
3/ D 808 is the preferred method but D 1317 may be used as an alternate.
4/ D 1552 is the preferred method but D 129 may be used as an alternate.
5/ X-ray fluorescence or atomic absorption spectrochemical analysis methods that have been previously approved by the qualifying activity (see 6.4) may be used as alternates to D 811.
6/ Homogeneity and miscibility test (see 4.6.1 for clarifying instructions.
7/ Included in ASTM STP 315-D.
8/ Not yet published by ASTM. To be included in ASTM STP 315-E, when published (see 2.2).
9/ See 4.6.3

5. PREPARATION FOR DELIVERY

5.1 Packaging, packing, and marking. Unless otherwise specified in the contract or purchase order (see 6.2), packaging, packing, and marking shall be in accordance with MIL-STD-290.

6. NOTES

6.1 Intended use. The lubricating oils covered by this specification are intended for the crankcase lubrication of commercial-type vehicles used for administrative (post, station, and camp) service typical of: (1) gasoline engines in passenger cars and light to medium duty trucks operating under manufacturer' warranties; and (2) lightly supercharged diesel engines operated in moderate duty. The lubricating oils covered by this specification are intended for use, as defined by vehicle manufacturer, when ambient temperatures are above -20°F (-29°C).

6.2 Ordering data. Procurement documents should specify the following information:

a. Title, number, and date of this specification.
b. Grade of oil required (see 1.2).
c. Quantity of oil required.
d. Type and size of containers required (see 5.1).
e. Level of packaging and level of packing required (see 5.1).

6.3 Other requirements and tolerances for quality conformance testing. Definite numerical values are not specified for certain of the physical and chemical properties listed in 3.4, and for which corresponding test methods are given in Section 4. Values of some properties vary from one commercial brand of oil to another for the same grade. These values are influenced by the source of the base stock, the identities and quantities of additives, etc. Definite numerical values are not always functionally important except, for some properties, within specified maximum and/or minimum limits. It is not possible (or necessary) to assign restrictive values in the specification before the testing of qualification samples. During qualification, test values will be determined which are characteristic of a particular product and which can serve thereafter to identify the product. Using the results of qualification testing, the qualifying activity (see 6.4) can set values, including permissible tolerances, for future quality conformance testing.

6.4 Qualification. With respect to products requiring qualification, awards will be made only for products which are at the time set for opening of bids, qualified for inclusion in the applicable Qualified Products List whether or not such products have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. The activity responsible for the Qualified Products List is the U.S. Army Aberdeen Research and Development Center, Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland 21005 and information pertaining to qualification of products may be obtained from that activity.

Custodians:
Army - MR
Navy - SH
Air Force - 68

Preparing activity:
Army - MR

(Project No. 9150-0316)

Review activities:
Army - MI, WC, AT
Navy - SH, SA, AS, YD, MC
Air Force - 11, 68
DSA - PS

User activities:
Army - ME
Navy - OS

☆ U. S. GOVERNMENT PRINTING OFFICE: 1970 . 433-693/3060

A TECHNICAL AND ECONOMIC STUDY
OF WASTE OIL RECOVERY

PART VI   A Review of Re-refining Economics
by Peter M. Cukor

TABLE OF CONTENTS

79<

TABLE OF TABLES

80<

TABLE OF FIGURES

81<

1.0 INTRODUCTION AND SUMMARY

The purpose of this report is to update previously reported economic data for re-refining of waste crankcase oils and to provide some insight into the underlying causes of shifts in the profitability of recycling used lubricants. Previous research has described the forces which led to a sharp decrease in crankcase oil re-refining during the period 1960-1972[1]. During this interval, several interrelated factors contributed to an increase in the cost of re-refining:

- Costs of re-refining rose as a result of higher prices for feedstock, chemicals, labor and maintenance.
- The availability of top quality, major brand lube oils at discount prices resulted in a rapid increase in the number of user performed oil changes.
- Waste oil generation rose slowly in step with lube oil demand.
- Sources of waste oil available for recycling became more dispersed, thereby increasing collection costs.
- New performance additive formulations made crankcase oil re-refining more costly due to the higher volumes of acid required and the lower overall recovery of lube oil.

As has been discussed elsewhere[1], most re-refined lube oil is sold in bulk as non-detergent oil to independent jobbers. In view of the low quality image of re-refined oil, the jobbers are concerned mainly with price. Cheap, low quality virgin lubricants provide the alternative supply source for this market and the price of these oils sets a ceiling on the price that re-refiners can charge for their products. As shown in Figure 1, during the 1960's refinery prices for virgin lube oils remained steady at about 22¢ per gallon. Hence, re-refiners, faced with rising production costs, were unable to increase prices in order to preserve profitability. This cost/price squeeze was the major reason for a two-thirds reduction both in the number of re-refiners and in total annual production of re-refined oil which has occurred since 1960.

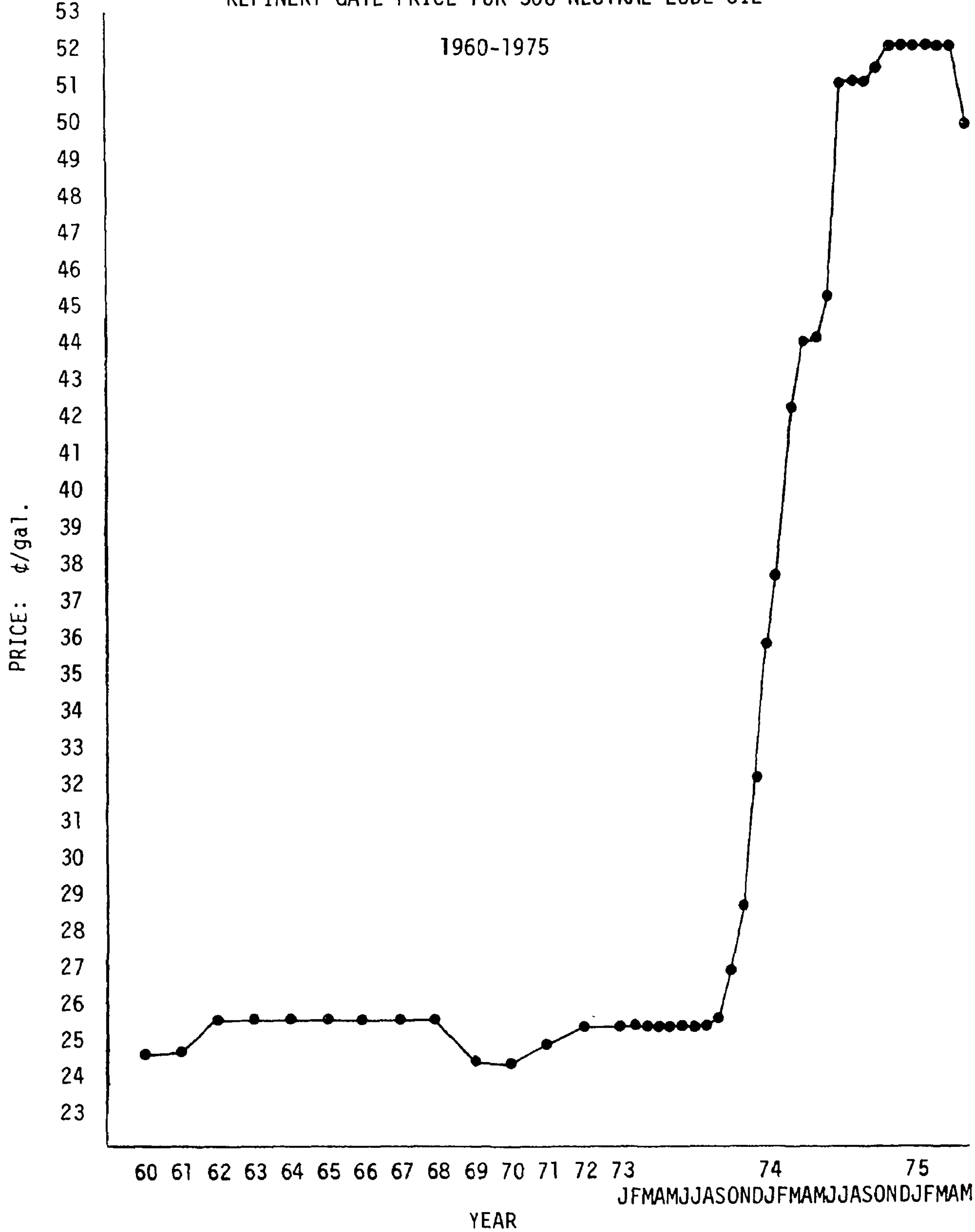
Since mid-1973, the re-refining industry has enjoyed a period of unprecedented profitability. A fourfold increase in crude oil prices coupled with declining production of virgin lube oils enabled re-refiners to raise prices sufficiently to increase profit margins from 1¢ per gallon in July, 1973 to more than 10¢ per gallon in July, 1974. By early 1975, however, softening demand for lube oils due to reduced economic activity resulted in a reduction of lube oil prices from the peak of about 53¢ per gallon registered in late 1974. By May of 1975, market prices for bulk sales of unblended re-refined oil fell to 50¢ per gallon. Continuing increases in production costs for re-refined products, especially as a result of competition from fuel markets for waste oil supplies, are now beginning to erode profit margins. The extent of this erosion will depend not only on future shifts in the relative prices of lube oil and fuel oil, but also on the prices re-refiners must pay for materials and labor.

82<

Figure 1

REFINERY GATE PRICE FOR 300 NEUTRAL LUBE OIL*

1960-1975



* *Platts Oil Price Handbook & Oilmanac*, McGraw Hill & Co., 1960-1974; and *Platts Oilgram*, January-May, 1975.

2.0 TRENDS IN LUBE OIL RE-REFINING

The response of the re-refining industry to the abrupt changes in the economics of waste oil collection, re-refining, and marketing which have occurred since mid-1973 is discussed in this section. A previous report provides more detailed background information on these three stages of waste oil recovery[1].

Much of the data and information presented in this report were collected during nineteen interviews conducted with re-refiners located in or near major metropolitan areas throughout the United States. Of these nineteen interviews, thirteen were conducted in mid-1973 and six were conducted in late 1974. Data collected in the second set of interviews were updated during telephone conversations in spring of 1975. Table 1 summarizes economic and operating data for the six companies interviewed in fall of 1974.

2.1 Waste Oil Collection

Prior to the Arab oil embargo and the sharp rise in crude oil prices, waste oil collectors charged about 3 cents per gallon for removal of used oil from service stations. A re-refiner could expect to receive waste oil at a delivered cost of about 3 to 4 cents per gallon. Many re-refiners purchased a significant portion of their waste oil from independent collectors.

Since the embargo, increasing volumes of waste oil have been directed to the fuel market where collectors can expect to receive as much as 15¢ per gallon depending on the season and geographical location. A recent survey of six re-refiners across the country revealed that the average delivered cost of waste oil rose from 3-4 cents per gallon in mid-1973 to 12-13 cents per gallon in early 1975. Further, waste oil availability at these prices was insufficient for plant operation at or near capacity. Re-refiners, processing crankcase oil only, are now operating at roughly 45 percent of capacity.

In response to the shift in waste oil availability, re-refiners have adopted two strategies. The first is to compete directly with waste oil collectors by purchasing tank trucks and scouring the local area for used oil supplies. A number of re-refiners have taken this approach in order to assure long term survival. However, since independent operators can collect waste oil at a lower cost than can re-refiners[1], a few re-refiners have purchased tank trucks and leased them to individuals on an annual basis. In this way, a re-refiner can avoid the high cost of salaries and maintenance he would incur if he operated his own trucks and still assure himself of an increased supply of feedstock.

The second strategy adopted by re-refiners to increase their supply of feedstock is to put greater emphasis on closed-cycle re-refining of waste oils provided by industrial and commercial clients. Under closed-cycle conditions, the waste oil is never available for any end use other than re-refining.

84<

Table 1

ECONOMIC AND OPERATING DATA FOR 6 RE-REFINING COMPANIES
FOR THE FISCAL YEAR 1973-1974

Company	Waste Oil Collected and Re-refined 1000 gal/yr		Delivered Cost of Waste Oil (Dry Basis)	Fraction of Capacity Utilized (%)	Cost of Re-refining (including feedstock but excluding taxes and administrative costs) ¢/gal of Product	Products Sold 1000 gal/yr	Principal Markets Served	Total Revenues $1000/yr
	Own Sources	Purchased from Independent Collectors						
1	4,400	600	12	48	29	3,000	5%: Bulk sales of unblended auto lube to jobbers at 50¢/gal; 20%: Sales of unblended auto lube in packages to distributors at 92¢/gal; 25%: Sales of blended auto lube in packages to distributors; 50%: Industrial oils sold directly to final users.	2,000
2	1,925	75	12	50	38	1,200	80%: Blended auto lube oil sold in drums to commercial accounts through distributors; 20%: Blended oil sold in quart cans to jobbers	1,500
3	10,600	3,400	12	87	35	10,000	90%: Industrial and railroad oils sold directly to final users; 10%: Sales of blended auto lube to commercial fleets	NA
4	2,400	1,600	13	42	32	2,480	50%: Bulk sales of unblended auto lube to jobbers at 40¢/gal; 30%: Sales of unblended auto lube in cases of quarts to jobbers at $1.04/gal; 15%: Sales of blended auto lube in drums to jobbers at $1.30/gal 5%: Sales of unblended auto lube in drums to jobbers at 60¢/gal	4,500
5	2,200	1,400	13	42	32	2,880	15%: Bulk sales of unblended auto lube to jobbers at 50¢/gal; 60%: Sales to wholesaler of unblended auto lube in cases of qts. at 90¢/gal; 25%: Sales to wholesaler of blended auto lube in cases of qts at $1.18/gal.	2,400
6	1,380	——	12	80	50	960	50%: Blended auto lube sold in drums to commercial accounts; 50%: Bulk sales of unblended auto lube to jobbers.	500

Further, oils recycled under such conditions compete with high quality virgin lubes and, therefore, command a much higher price than lube oils sold in bulk in wholesale markets. Additionally, closed-cycle re-refining provides clients with waste oil disposal services. In view of future regulations for solid waste management and hazardous waste disposal, closed-cycle re-refining of industrial oils is likely to increase significantly.

2.2 Crankcase Oil Re-Refining

Figure 2 presents a display of the important cost factors in the production of re-refined crankcase oil. By far the most important cost component in re-refining is the delivered cost of the waste oil feedstock. Based on interviews with six re-refiners, the average delivered cost of feedstock was 13 cents per gallon on a dry basis. Since bottom sediment and water (BS&W) typically amount to 15 percent of the waste oil volume, it is essential for re-refiners to monitor closely the quality of the waste oil they purchase. On the average, waste crankcase oil also contains about 3 volume percent fuel. The average yield of lube oil was reported to be about 75 percent based on dry waste oil feed. This corresponds to a 64 percent overall yield based on waste oil as received. The total cost of waste oil per gallon of finished product is 17¢ per gallon.

Since the cost of feedstock is about 50 percent of total re-refining costs, it is clear that the profitability of waste oil recovery is highly sensitive to changes in the cost of waste oil. For every cent increase in the delivered cost of waste oil, re-refining costs will rise by about 1.33 cents. An increase in fuel oil prices can be expected to result in a parallel increase in the cost to re-refiners of waste oil. If increases in waste oil costs are not compensated for by increases one-third greater in prices for re-refined products, then re-refiners will be unable to maintain recent profit margins.

2.2.1 Labor

Labor costs have risen sharply in recent years making it imperative for re-refiners to maintain production at maximum levels in order to minimize unit costs. For example, according to the Bureau of Labor Statistics, the annual average wage for refinery production workers rose more than 27 percent between 1970 and 1973. Although wages earned by workers in re-refineries are lower than wages earned by refinery workers, continued inflation has certainly resulted in further increases in labor costs.

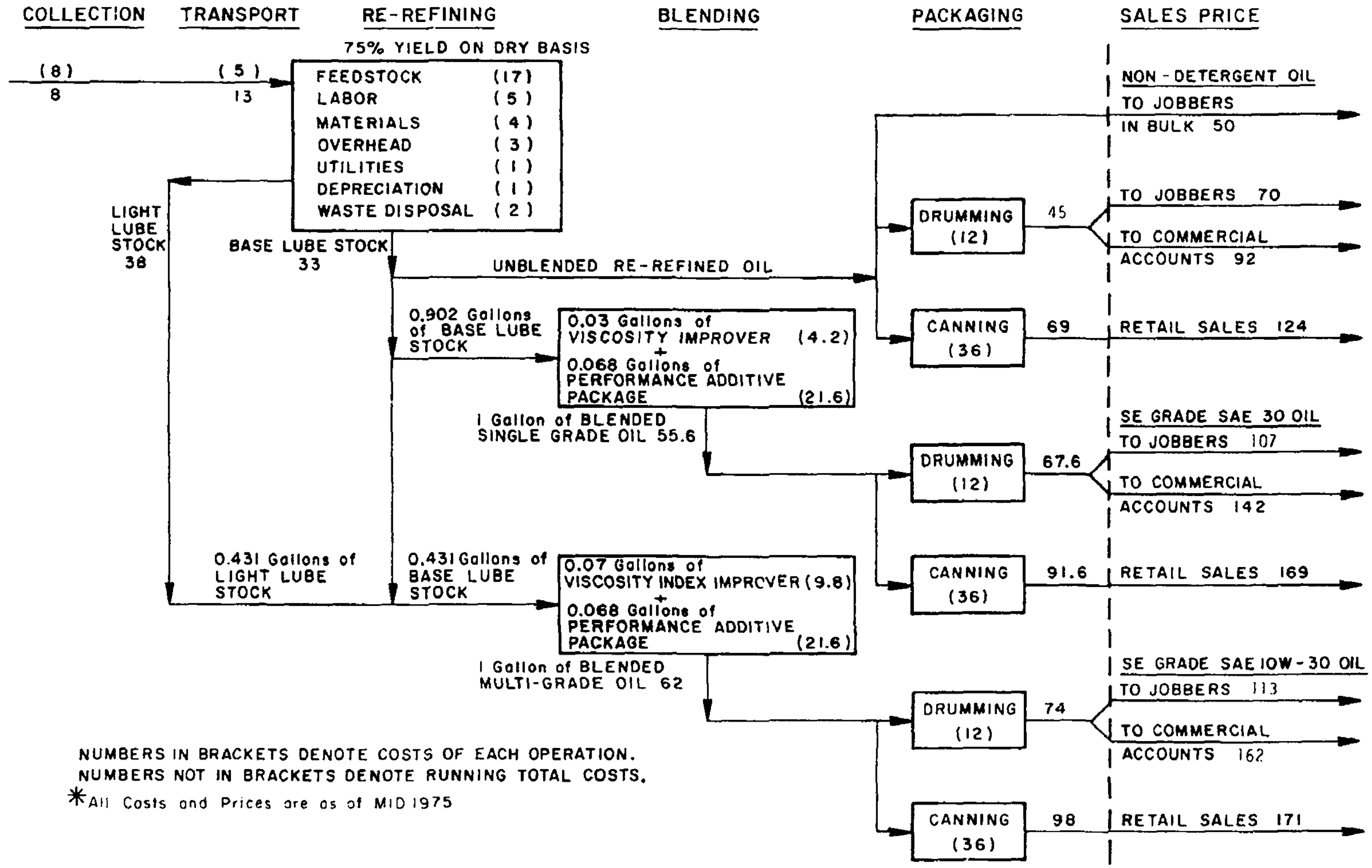
Re-refiners have attempted to reduce the combined impact of wage increases and reduced feedstock availability on profitability by diversification of their product mix. In addition to lube oil, a number of firms now produce fuel oil and industrial oils, frequently under closed-cycle conditions. In the case of fuel oil, re-refiners can accept contaminated feedstocks which are not suitable for lube oil recovery. In the case of industrial oils, closed-cycle operations effectively eliminate competition from independent collectors who sell to fuel marketers.

86<

Figure 2

SUMMARY OF RE-REFINING ECONOMICS*

(All Costs Expressed In Cents Per Gallon Of Oil)



NUMBERS IN BRACKETS DENOTE COSTS OF EACH OPERATION.
NUMBERS NOT IN BRACKETS DENOTE RUNNING TOTAL COSTS.

*All Costs and Prices are as of MID 1975

A TECHNICAL AND ECONOMIC STUDY OF WASTE OIL RECOVERY

Principal Investigator: Dr. P.M. Cukor
EPA Contract No. 68-01-2904, Performed for:
Laurence B. McEwen, Jr. and
Dr. John H. Skinner, Deputy Director
Resource Recovery Division
Office of Solid Waste Management Programs
U.S. Environmental Protection Agency

TEKNEKRON, INC.
BERKELEY, CALIFORNIA

2.2.2 Materials

Increases in price for sulfuric acid and clay are important contributors to the recent increases in re-refining costs. Current price data indicate that sulfuric acid (H_2SO_4), at $50 per ton, contributes about 2.7 cents to the cost of producing a gallon of re-refined oil. Clay, at $82 per ton, contributes 1.6 cents to the cost of producing a gallon of re-refined oil. Typical quantities of acid (66° Baumé) and clay required per gallon of finished oil are 1.06 lbs H_2SO_4 and 0.4 lbs of clay.

2.2.3 Waste Disposal

Several years ago disposal costs for acid sludge and spent clay were a very small contribution to total re-refining costs. Together, the cost of disposal of these materials amounted to less than one cent per gallon of finished oil. Recently, however, increasingly stringent state regulations for solid waste disposal and hazardous waste management have, in some instances, forced re-refiners to abandon traditional dumping sites in favor of geologically insulated landfills. Since such landfills are, in most cases, more distant from the plant than formerly acceptable disposal sites, sludge transportation costs have escalated sharply.

For example, one large re-refiner was dumping acid sludge in a sanitary landfill where the soil was a porous sand. Local water pollution control officials ordered the re-refiner to locate an alternative disposal site within two weeks. After two weeks time, the company was unable to locate a suitable site and as a result was forced to cease operations. Another month passed before the firm was able to locate a candidate disposal site and provide the local water pollution control office with core drillings which indicated that the site was geologically insulated. The new landfill is eighty miles distant from the plant.

For this company, the total cost of waste disposal is now about 3 cents per gallon of finished oil. Formerly, the cost of acid sludge and clay disposal amounted to less than 0.8 cents per gallon of finished oil.

The effect of solid waste disposal regulations on the cost of acid sludge disposal has not been uniform throughout the country. However, re-refiners are acutely aware of the impact of new disposal regulations on their businesses.

As an alternative to the disposal of acid sludge, a group of re-refining companies developed a limestone neutralization process. However, the cost of this alternative is estimated at between 8 and 10 cents per gallon of lube oil produced. Further, leaching of heavy metals, especially lead, may still be a problem for neutralized sludges. The critical choice for re-refiners forced to seek new disposal sites involves a tradeoff between the cost of sludge transport and disposal at distant sites which are geologically insulated and the cost of sludge treatment and disposal at nearby less insulated landfills.

88<

2.3 Blending and Compounding

2.3.1 Viscosity Improvers

Re-refined oils vary somewhat in viscosity depending on feedstock properties and processing conditions. Generally the finished product has a viscosity of between 55 and 58 Saybolt Universal Seconds (SUS) at 210°F. This is equivalent to the viscosity of an SAE 20 weight oil. In order to raise the viscosity to that of a 30 weight or 40 weight oil, a small percentage of a heavy virgin oil or brightstock may be added. Brightstocks frequently used have viscosities of 150 and 165 SUS at 210°F. A rough rule of thumb is that the viscosity, at 210°F of a 20 weight lubricating oil, will increase by 1 SUS for every 3 percent of brightstock added. Brightstocks are purchased by re-refiners from major oil companies for about 64¢ per gallon. If it is desired to raise the viscosity of a re-refined oil from 55 SUS (SAE 20) to 61 SUS (SAE 30), then 18 percent brightstock must be added at a cost of 11.5¢ per gallon of oil produced. Since brightstocks are virgin oils, a federal excise tax of 6¢ per gallon must be paid on brightstocks used in blending.

Alternatively, chemical additives such as polyisobutylene may be blended to increase viscosity. Polysiobutylene has the added advantage of raising the viscosity index as well as the viscosity of the oil with which it is blended. One supplier of such additives quotes a price for viscosity improver of $1.40 per gallon f.o.b. Los Angeles. For the same base stock mentioned above, only 3.0 percent of a polyisobutylene compound must be blended to raise the viscosity to 61 SUS at 210°F. This would cost 4.2¢ per gallon of product[†]. No excise tax is levied on the blended material in this case.

2.3.2 Performance Package

Once the viscosity of a re-refined oil has been adjusted to the desired value, further blending with specialized additives is required to produce a high performance product which meets automobile manufacturers' specifications for engine oils for use in new cars.

One important supplier of engine oil additives manufactures a general purpose motor oil performance additive which when blended with a 30 weight non-detergent base oil produces an oil which meets all the specifications required for an API SE rating and meets automobile manufacturers warranty requirements for 1975 model vehicles. This performance additive sells for $3.17 per gallon f.o.b. Los Angeles, California[††]. 6.8 percent by volume of this performance

---

† Due to supply shortages during 1974 and early 1975, many re-refiners were unable to purchase polyisobutylene.

†† No excise tax is levied on performance additives.

additive is required to produce an SE grade oil. The cost of this blending is about 21.6¢ per gallon of product. Hence the total cost to produce an SE grade oil from crankcase drainings is about 55.6¢ per gallon. Table 2 gives details of this calculation.

2.3.3 Multi-Grade Oils

Multi-grade oils are produced by combining a viscosity index improver with a blend of lube oil stocks and the performance additive. As shown in Figure 2, 10W-30 (a popular multi-viscosity oil) can be made by mixing a viscosity index improver and a performance additive package with a blend of equal volumes of re-refined base lube stock (viscosity 56 SUS at 210°F) and re-refined light lube stock (viscosity 40 SUS at 210°F). (A re-refined light lube stock costs more to produce than a re-refined base stock because additional distillation and acid/clay treating steps are required.) The resulting mixture should have a viscosity at 0°F equal to that of a 10 weight oil (6,000-12,000 SUS) and a viscosity at 210°F equal to that of 30 weight oil (58-70 SUS). Thus, multi-grade lube oils have the advantages of a light weight (SAE 10W) oil at low temperatures and a heavier weight (SAE 30) oil at high temperatures. Such oils are commonly recommended by automobile manufacturers for use in modern vehicle engines. While the cost of producing multi-grade oils is higher than that for single-grade and non-detergent oils, profit margins on such sales are very attractive (see Figure 2).

2.4 Marketing

2.4.1 Wholesale and Retail Markets

Historically, most of the oil produced by U.S. re-refiners was sold as non-detergent oil in bulk lots of several thousands of gallons to independent jobbers. Jobbers act as middle men between re-refiners (and other producers of lubricants, fuels and automobile accessories) and marketing outlets such as automotive supply stores, garages, discount houses, service stations, etc. Thus a jobber may have a number of sources of lube oil supply and will buy from those sources which offer the lowest price. Jobbers may also blend and/or package lube oils for major oil companies and distribute these products to local markets. Major brand lube oils are normally sold by jobbers under the label of the producing company. Lube oils produced by re-refiners may be sold under a variety of brand names.

Re-refined oils sold by jobbers compete with cheap, low quality virgin lubes as customers seeking a quality product generally select their purchases on the basis of identification with nationally advertised major brands. Even in discount stores, a recent marketing study indicated that brand name and quality level (as indicated by the service classification printed on the container label) are far more important factors in purchase decisions than price[2].

90<

Table 2

BLENDING COSTS FOR RE-REFINED OILS

(Single Viscosity)

Operation	Percent Additive Blended	Cost, ¢/Gal of Blended Oil
Viscosity Improvement from 55 SUS to 61 SUS at 210°F	3.0	4.2
Performance package to meet SE specifications	6.8	21.6

Summary

Product	Gallons	Cost, ¢/Gal of Blended Oil
Re-refined base stock	0.902	29.8
Viscosity improver	.030	4.2
Performance package	.068	21.6
SE grade oil	1.00	55.6

91<

Since U.S. re-refiners are small businessmen who spend little or no money on advertising, brand identification has played essentially no role in the marketing of re-refined oils. Since a lube oil purchaser is generally not able to evaluate independently the quality of the lube oil he buys, he must depend on the integrity of the manufacturing company for protection. Although use of poor quality lubricants can lead to costly engine repair bills, the use of a label designating an oil as suitable for a given class of service is wholly the responsibility of the producer of that particular brand of oil. There is no independent organization which monitors lube oil quality. Consumers do, therefore, place a considerable amount of trust in the quality control procedures exercised by lube oil manufacturers.

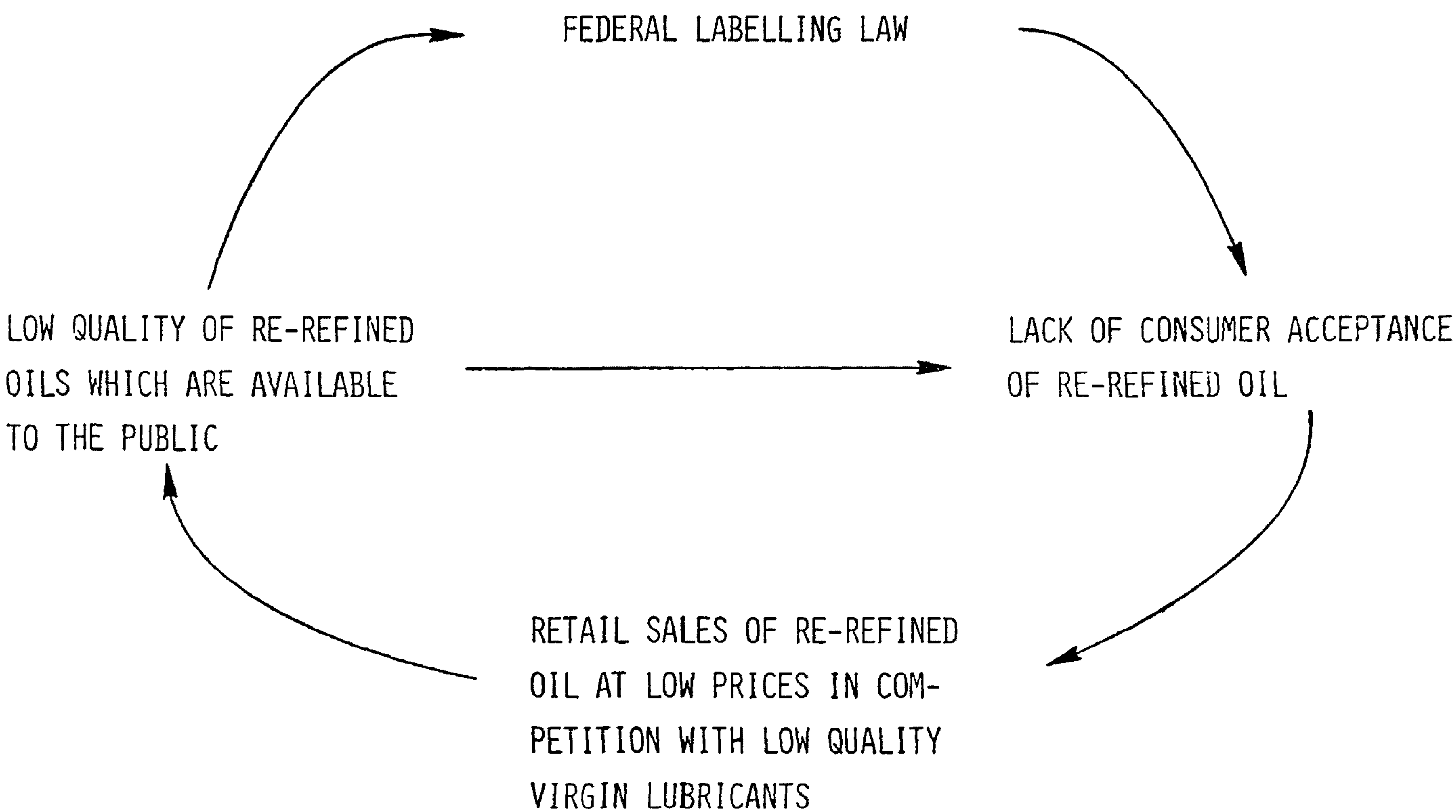
In view of this situation, it is not difficult to understand why re-refined oil sold in retail markets has failed to gain acceptance among quality conscious customers and must therefore compete with low quality lubricants. Regardless of the actual performance of re-refined products, the re-refining industry has never enjoyed a reputation for producing high quality lube oils. Rather, this business has a history of opportunists and men of questionable integrity whose operations have served to discredit those re-refiners who do produce high quality products. Partially as a result of this situation, in 1958 the Federal Trade Commission ruled that oils sold in interstate commerce which are in whole or part composed of previously used oils must be labelled as "manufactured from previously used oils." Hence, regardless of the quality of re-refined lubricants, the FTC ruling has cast a stigma on these oils since, to the customer, the word "used" frequently implies a product of inferior quality. As a result, most individuals who knowingly buy re-refined oils in retail markets are concerned with obtaining the cheapest oil available. Hence high quality re-refined oils which have been blended with additives are rarely, if ever, sold in retail outlets because the price of such oils is too high relative to that of the competing low quality, non-detergent virgin lubes.

These barriers to public acceptance of re-refined oils are illustrated in Figure 3. This diagram shows how the considerations discussed above build upon one another and reinforce the public's negative attitude towards re-refined oil. Both the failure of the re-refining industry to regulate the quality of its products and the Federal labelling law have served to foster a poor public image for recycled lube oil. Thus re-refined oil has become acceptable only to customers who are highly price conscious. High quality re-refined oils are not price competitive with low quality, non-detergent virgin lubes and thus are not available in most retail markets. As a result, only low quality, non-detergent re-refined oil is marketed. Under these conditions, public confidence in the quality of recycled oils can never be increased because high quality recycled oils are not readily available to the public. Further, because of the inherent trust which a purchaser places in the manufacturer of lube oil, it is unlikely that the small and relatively obscure firms that produce re-refined oils could be successful in retail marketing of high quality recycled oils in competition with equivalent lubes produced by nationally known petroleum companies.

92<

Figure 3

Barriers to Public Acceptance of Re-Refined Oil



93<

Although the re-refining industry has not earned the confidence of quality conscious lube oil consumers, the marketing efforts of producers of virgin lubricants have traditionally relied heavily on public confidence gained through familiarity with established brand names and many years of acceptable product performance. For example:

> *When your car is worth caring for,*
> *Penzoil is worth asking for;* and
>
> *You can trust your car to the man*
> *who wears the star*

are advertising slogans which typify the strategy of large oil companies in marketing of lube oils to retail customers. Thus if those firms which now market high quality virgin lube oils were to include top quality re-refined oils in their product lines, it is highly probable that such oils would gain public acceptance over a relatively short period of time. However, it is unlikely that a producer of virgin lube oils would consider purchasing base stocks from a re-refiner unless lower cost virgin lubes of equivalent quality were not available elsewhere. During late 1973 and early 1974 (see Section 2.5 below) an acute shortage of virgin lube oils did develop and several major oil companies did actively explore the possibility of supplementing lubricant supplies by purchasing re-refined oil. Recent increases in lube oil supply in the face of falling demand have, however, had a dampening effect on these activities.

Since most re-refining companies sell the bulk of their production as unblended base stock to independent jobbers, and since re-refined oil sold by jobbers competes with cheap, low quality virgin lubes, the price of these relatively inexpensive virgin oils acts as a ceiling for the price of most re-refined oil. Thus those firms which sell primarily to jobbers can be vulnerable to sharp swings in profitability depending on the product demand and the available supply of those grades of virgin lube oil with which re-refined oils must compete. During periods when lube oil demand is high relative to supply, available volumes of virgin lube oils are directed first to the high quality, high price markets. These include retail outlets such as service stations and automobile garages, and commercial accounts such as trucking companies, taxi fleets, etc. As a result, customers who normally pay a lower price, such as large industries, discount stores, and other bulk consumers may find themselves without a supplier. Further, since the higher quality oils (those blended with specialized chemical additives) are the products whose sales yield the greatest profits, the available volume of lower quality (unblended, non-detergent) lube oils is sharply reduced. This low quality market, which consists principally of non-dealership garages, independent service stations and discount stores, is the major outlet for re-refined oils. Reduced competition from producers of virgin lubes permits re-refiners to realize higher profit margins during such periods of tight virgin oil supply. Conversely, as new productive capacity for virgin lube oils comes on stream and/or demand falls, some of the available production will be directed to the low quality market served by re-refiners. Competition will increase resulting in lower profit margins. For example, as late as the summer of 1973, the bulk of all sales of lube oil by re-refiners was made at a

94<

profit of only about 1¢ per gallon. Since then, the price of lube oil in the same markets has risen relative to production costs so that today a profit margin of 10¢ to 15¢ per gallon on sales of unblended re-refined oil is not uncommon. It should be clear that the existence of such attractive profit margins will attract a portion of the future production from virgin lube oil plants and thus reduce the profit margin available to re-refiners. In an inflationary period, the inability to control production costs in the face of increasing competition from suppliers of virgin lube oils could result in a recurrence of the cost/price squeeze which forced many re-refiners out of business in the late 1960's and early 1970's.

2.4.2 Commercial/Industrial Markets

The commercial/industrial lube oil market consists of both "on highway" and "off highway" users. On highway users include truck, taxi, and bus fleets and motor pools. Off highway users include railroads and farms, where engine lubricants are required, and manufacturing and mining industries where cutting oils, hydraulic fluids, transformer oils, grinding oils, etc., are used. In the commercial/industrial market the emphasis is on quality and hence re-refined lube oils must compete with high grade lubricants produced by the major oil companies. Although profit margins are not as large as in the high quality retail automotive market, barriers to the use of re-refined oils are not as great. Several re-refiners have for many years been able to sell most of their production to commercial and industrial clients. These firms are among the most profitable in the re-refining industry.

Since mid-1973, sales of re-refined oil to commercial and industrial users have expanded significantly. While it is not possible to specify the actual volumes consumed nationwide, all the re-refiners interviewed for this study emphasized the success of their marketing efforts in this sector. An acute shortage of virgin lube oils which occurred in late 1973 and early 1974 forced a number of industries and businesses to turn to re-refiners for lube oil supplies. Successful use of re-refined oils by these clients has provided an important marketing tool for re-refiners in further expanding their commercial and industrial business. As discussed in a previous report, a re-refiner's success in penetrating this market has been traditionally based upon long term, close working relationships with the clients as well as a competitive lube oil price[1]. From these relationships the client develops a trust in the integrity of the re-refiner and the quality of the re-refiner's product. During the past 18 months a shortage of virgin lube oils provided re-refiners with an opportunity to secure many new customers over a relatively brief period of time. However, the present oversupply of lube oils is certain to result in a return of stiff competition for re-refiners from producers of virgin lubricants (see Section 2.5.4, below).

95<

2.5 Price and Availability of Virgin Lube Oils

Three major factors have affected the profitability of re-refining since mid-1973:

- A sharp rise in the price of fuel oil
- Increases in the costs of labor, materials and chemicals
- A sharp rise in the price of virgin lube oil

The first two factors were discussed in Sections 2.1 and 2.2 above. This section focuses on the price and availability of virgin lube oils and the effect of these variables on the future of the re-refining industry.

2.5.1 Price of Virgin Lube Oil

As shown in Figure 1, since the fall of 1973, refinery gate prices for virgin lube oils have more than doubled. This has permitted re-refiners to raise the price of re-refined base stock by about the same percentage. Thus while in 1973 profit margins on bulk sales of re-refined lube oil were only a few cents per gallon, by mid-1975 margins as large as 17¢ per gallon could be realized. Margins on sales of blended products to commercial and retail customers also rose sharply, but the percentage increase was much less than in the case of the wholesale market.

Although the steep rise in the price of virgin lube oil was mainly attributable to the increase in crude oil prices, strong demand, and artificial shortages created by the oil embargo and price controls also contributed to the escalation in lube oil prices. In fact, for a period during early 1974, when lube oil prices were controlled at the pre-embargo level, refiners found it profitable to crack lube feedstocks (light, medium and heavy vacuum gas oils) to produce gasoline and other fuels which were not subject to price controls. As a result the supply of virgin lube oils became increasingly tight. A number of petroleum companies halted marketing activities, recalled salesmen from the field, and placed customers on allocation according to 1972 purchases. Articles appeared in the trade press which forecast a long term shortage of industrial lube oils [3,4]. The situation was thought to be especially critical in view of the closure of older lube oil refineries due to shortages of special types of crude oils and the excessive cost of compliance with environmental and health and safety regulations. The shortage of virgin lubricants provided re-refiners with an important opportunity to expand sales in the high profit commercial/industrial market. Municipalities, vehicle fleets, and industries which traditionally obtained lube oils from major oil companies and independent compounders were forced to seek supplies from re-refiners. Re-refiners who have been able to provide the required products and assurance of quality to such customers have been able to increase the profitability of

96<

their operations. For example, as late as fall of 1973, one of the re-refiners interviewed in this study sold about 95 percent of his production as non-detergent oil to a local jobber. As discussed above, at that time the profitability of such sales was about one cent per gallon. In early 1974 the local city government solicited bids for lube oil supply and received only one response – the re-refiner's. After considerable discussions relating to quality control procedures, the city accepted the re-refiner's bid. Since obtaining the contract with the city the re-refiner has been able to make substantial progress in increasing the fraction of his production which is sold as blended oil to quality conscious commercial and industrial customers. By early 1975 less than half of the firm's production was being sold in the bulk wholesale market.

2.5.2 Future Lube Oil Supply and Demand - Impact on the Re-Refining Industry

Although during the past 18 months the re-refining industry has enjoyed a period of unprecedented profitability, it is unlikely that these profit levels can be maintained over the longer term. By the end of 1974 decreasing demand for lube oils coupled with additions to refining capacity resulted in large additions to lube oil stocks. Table 3 summarizes Bureau of Mines data for domestic lube oil production and demand for the period 1965-1974. From 1965-1971 domestic manufacturing capacity plus imports satisfied the domestic and export demand. Excesses or deficiencies in supply in any year were reflected in adjustments to inventory. In 1972 and 1973 sizeable inventory reductions were required to satisfy domestic demand. Toward the end of 1973 the belief was widespread in the petroleum industry that there would be a severe shortage of base lubricating oils in future years.

However, in 1974, due to reduced economic activity and curtailments in vehicular use, domestic demand for lube oils fell by about 4.2 percent while production rose by 1.8 percent. Although imports were lower than in 1973 this decrease was not sufficient to compensate for a greater decrease in lube oil exports. As a result inventories rose by about 3.2 million barrels. Thus while only a year ago lube oil stocks were at an all time low and lubricants were in short supply, at present a surplus situation exists due to record production levels and declining demand.

A recent study by Sun Oil Company provides projections of lube oil demand and derived supply to 1985[5]. These projections, shown in Table 4, indicate that in 1975 domestic lubricant demand is expected to fall by 5 percent to 53.7 million barrels. Following a recovery in demand of 0.9 percent in 1976 and 1.3 percent in 1977, annual demand growth is expected to range between 1.2 and 2.0 percent between 1977 and 1980. Between 1980 and 1985 the minimum and maximum annual increases should be about 1.4 and 1.9 percent.

Table 3

LUBE OIL SUPPLY AND DEMAND 1965-1974

(Volume in Thousands of Barrels)

Year	Manufactured In the U.S.	Imported Into U.S.	Total U.S. Supply	Exported From U.S.	Adjustment To Inventory	Derived Domestic Demand
1965	62,925	29	62,954	16,592	- 758	47,120
1966	65,407	32	65,439	17,112	- 622	48,949
1967	64,870	40	64,910	18,695	+2092	44,123
1968	65,684	33	65,717	18,001	- 751	48,467
1969	65,080	163	65,243	16,396	+ 65	48,782
1970	66,183	224	66,407	16,090	+ 624	49,693
1971	65,473	10	65,483	15,825	+ 337	49,321
1972	65,349	669	66,018	14,983	-1778	52,813
1973	68,742	2032	70,774	12,822	-1065	59,037
1974 est	70,000	1800	71,800	12,100	+3200	56,500

Table 4

PROJECTED TOTAL DEMAND AND DERIVED SUPPLY NECESSARY TO SATISFY DEMAND

(Millions of Barrels)

Year	Needed Mfg'ed in the U.S.	Imported Into U.S.	Total U.S. Supply	Export From U.S.	Adj. to Invt.	Total U.S. Demand
1973	68.7	2.0	70.7	12.8	-1.1	59.0
1974	70.0	1.8	71.8	12.1	+3.2	56.5
1975	63.7	2.0	65.7	12.0	0	53.7
1976	64.2	2.0	66.2	12.0	0	54.2
1977	65.0	1.9	66.9	12.0	0	54.9
1978 Lo	67.1	1.8	68.9	12.0	0	56.9
1980 Hi	68.5	1.8	70.3	12.0	0	58.3
1985 Lo	69.1	1.5	70.6	10.0	0	61.6
1985 Hi	71.6	1.5	73.1	10.0	0	63.1

2.5.3 Supply of Lubricating Base Oils

As shown in Figure 4, during the period 1961-1972 lube oil manufacturing capacity in the U.S. exhibited a strong upward growth. The 5 percent decrease in capacity which occurred in 1973, a year in which lube oil demand rose by nearly 12 percent, did cause concern in the petroleum industry over the possibility of long term shortages of lubricants. However, the year 1973 was an anomaly. Since then, finished lube capacity has risen by about 8.5 percent.

Using recent production data from Table 4 and production capacities from Figure 4 it is possible to calculate the fraction of lube oil manufacturing capacity utilized in a given year. In both 1973 and 1974 the ratio of production to capacity was about 91 percent. If this level of production were to be maintained throughout 1975 nearly 74.4 million barrels of lubricants would be produced. Yet demand including net exports is forecast to be only 63.1 million barrels. Hence an 11.3 million barrel surplus would have to be absorbed. Although it is certain that production levels will be curtailed in order to prevent such a large overproduction, this example does serve to illustrate the oversupply and overcapacity situation which presently exists.

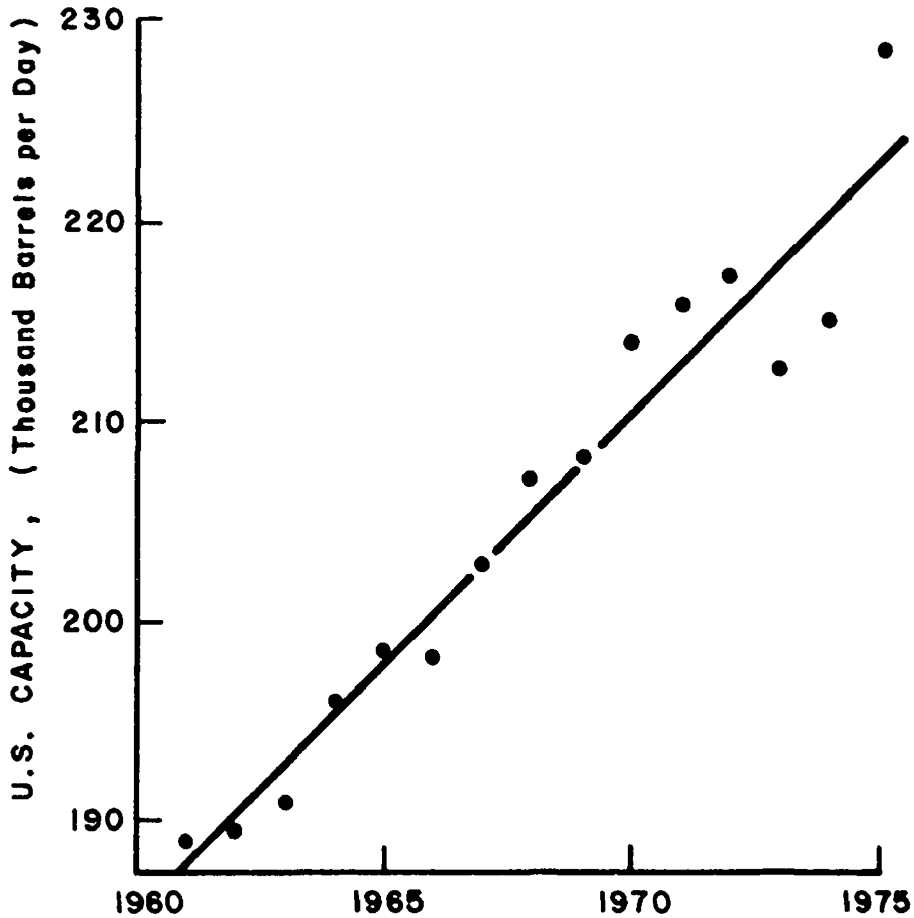
As discussed above, based on operation of 91 percent of current capacity, domestic lube oil plants can produce 74.4 million barrels per year. According to the forecasts in Table 4 even if production capacity were to fall to 70 million barrels, this would still be sufficient to satisfy demand through 1980 without any reduction in inventories. After 1980 the forecast indicates that new capacity will be required.

2.5.4 Implications for the Re-Refining Industry

The supply/demand forecasts discussed above indicate that, at least over the next five years, re-refiners will face increasing competition for lube oil markets. The absence of competition from producers of virgin lubes which occurred in late 1973 and early 1974 is unlikely to be repeated unless crude oil supplies are restricted, price controls are reimposed and economic activity accelerates rapidly. Since these events are unlikely to occur again simultaneously, re-refiners will find it increasingly difficult to increase their share of the high quality commercial/industrial market. Further, increased availability of virgin lube oils will tend to cause a weakening in prices in all markets, especially the low quality bulk market. Future increases in crude oil prices may not result in greater margins on sales of re-refined products unless increases in the delivered cost of waste oil per unit of production are less than increases in the price of lube oil. In view of the Government's policy to achieve energy independence, the petroleum industry will be under considerable pressure to load increases in product prices on industrial fuels and gasoline. Should this take place, re-refiners may be unable to increase their prices to compensate for increases in the delivered cost of waste oil. In the absence of restrictions on the use of waste oil as a fuel, rising feedstock costs combined with continued inflation in the cost of labor and materials and competition from cheap virgin lubes will present a difficult challenge to the re-refining industry.

Figure 4

U.S. FINISHED LUBE CAPACITY



101<

3.0 References

1. Cukor, P., M.J. Keaton, and G. Wilcox (Teknekron, Inc., and the Institute of Public Administration.) A technical and economic study of waste oil recovery. pt.3. Economic, technical and institutional barriers to waste oil recovery. Environmental Protection Publication SW-90c.3, U.S. Environmental Protection Agency, 1974. 143 p. (Distributed by National Technical Information Service, Springfield, Va., as PB-237 620.)

2. Cukor, P., M.J. Keaton, and G. Wilcox (Teknekron, Inc., and the Institute of Public Administration). A technical and economic study of waste oil recovery. pt.2. An investigation of dispersed sources of used crankcase oils. Environmental Protection Publication SW-90c.2. U.S. Environmental Protection Agency, 1974. 63 p. (Distributed by National Technical Information Service, Springfield, Va., as PB-237 619.)

3. Lube pinch looms for industrial users. Oil & Gas Journal, 71(45):45, Nov. 5, 1973.

4. Twomey, D. W. The changing lubricants market. Presented at National Fuels and Lubricants Meeting, Houston, Sept. 12-14, 1973. 12 p.

5. Helms, J. L. The outlook for lubricants. Presented at 73rd Annual Meeting, National Petroleum Refiners Association, Miami, Fla., Mar. 31-Apr. 2, 1974. 31 p.

μσr305