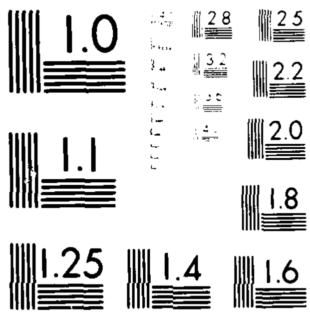
AD-A123 097 REUSE OF WASTE OIL AT ARMY INSTALLATIONS(U) 1/1
CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN
IL L C CHICOINE ET AL. SEP 82 CERL-TR-N-135
UNCLASSIFIED F/G 11/8 NL

END
DATE
FILMED
2-83
DTIC



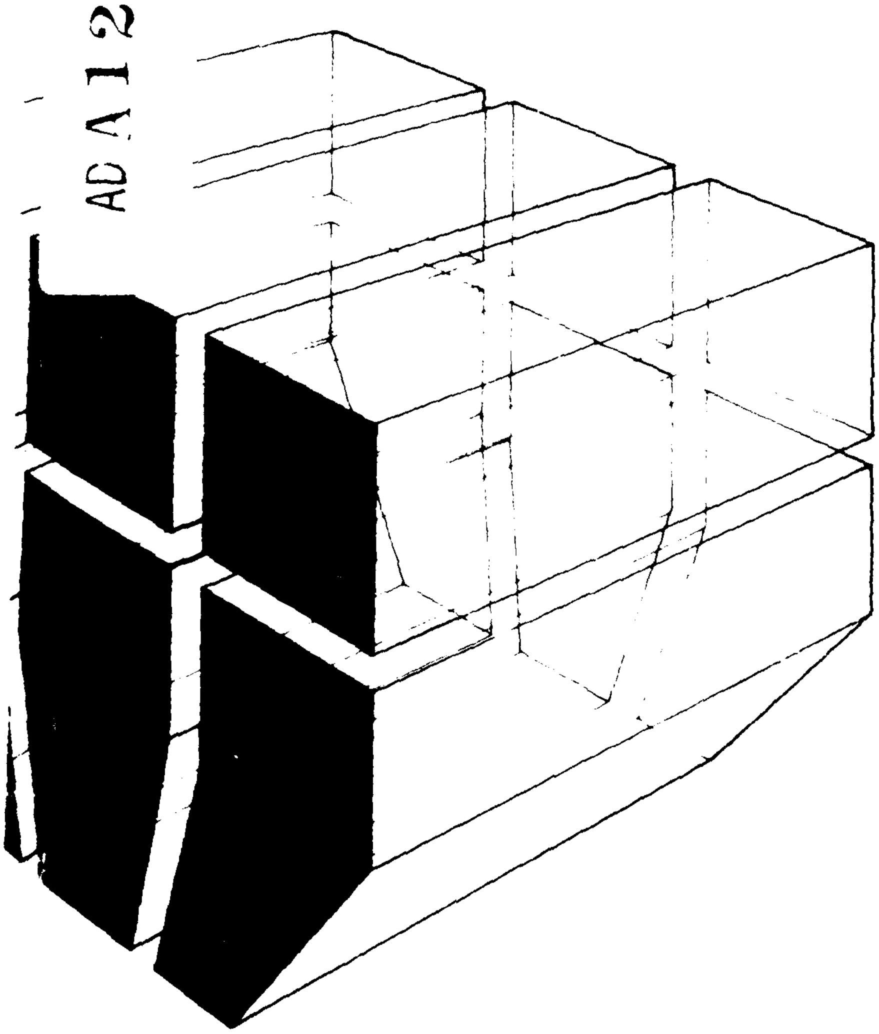
MICROCOPY RESOLUTION TEST CHART

construction
engineering
research
laboratory

United States Army
Corps of Engineers
Serving the Army
Serving the Nation

TECHNICAL REPORT N-135
September 1982
Hazardous/Toxic Waste Control

REUSE OF WASTE OIL AT ARMY INSTALLATIONS



by
L. C. Chicoine
G. L. Gerdes
B. A. Donahue

CERL

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: CERL-TR-N-135	2. GOVT ACCESSION NO.: [redacted]
3. RECIPIENT'S CATALOG NUMBER: AD-A123 097	
4. TITLE (and Subtitle): REUSE OF WASTE OIL AT ARMY INSTALLATIONS	5. TYPE OF REPORT & PERIOD COVERED: FINAL
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): L. C. Chicoine, G. L. Gerdes, B. A. Donahue	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY, P.O. BOX 4005, CHAMPAIGN, IL 61820	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 4A762720A896-A-032
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: September 1982
	13. NUMBER OF PAGES: 43
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

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

18. SUPPLEMENTARY NOTES

Copies are obtainable from the National Technical Information Service
Springfield, VA 22151

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

waste recycling
oil wastes

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

Typical Army installations produce large amounts of waste oil up to 250,000 gal annually. In response to the growing need for energy conservation, Army policy requires that these installations reuse oil whenever possible. The objective of this report is to analyze the economics of waste oil reuse, and to examine the environmental aspects of used oil management.

BLOCK 20. (CONTINUED)

Regulatory requirements dealing with waste oil reuse were reviewed, and personnel with Army agencies, the General Accounting Office, the Environmental Protection Agency, State agencies, and private industry were interviewed. Waste oil from three Army installations was analyzed.

Three options for reusing waste oil were assessed: selling the oil to a re-refinery, burning it as a boiler fuel, and recycling it in a closed loop agreement with a re-refiner. The closed loop recycling option appears to be most economical.

FOREWORD

This report was prepared for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Project 4A762720A896, "Environmental Quality for Construction and Operation of Military Facilities"; Task Area A, "Installation Environmental Management Strategy"; Work Unit 032, "Hazardous/Toxic Waste Control." The research was performed by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (CERL). Principal Investigator was Mr. B. A. Donahue. The OCE technical monitors were Mr. R. Newsome and Mr. F. Bizzoco. Dr. R. K. Jain is Chief of EN.

Special acknowledgement is given to Dr. R. Vogel, coordinator of the chemical analysis, and Mr. A. Miekowski, chemist, for their work in the oil characterization.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

		Page
	DD FORM 1473	1
	FOREWORD	3
	LIST OF TABLES AND FIGURES	5
1	INTRODUCTION	7
	Background	
	Objective	
	Approach	
	Mode of Technology Transfer	
2	REGULATIONS AFFECTING WASTE OIL REUSE	7
	Federal Water Pollution Control Act Amendments of 1972	
	PL 94-163	
	Resource Conservation and Recovery Act	
	Used Oil Recycling Act	
	DOD Policy	
3	CURRENT WASTE OIL MANAGEMENT	9
	Sources	
	Storage	
	Quantity	
	Quality	
	Is Army Waste Oil a Hazardous Waste?	
4	REUSE OPTIONS	15
	Current Policy	
	Re-Refining	
	Used Oil as a Fuel	
	Closed Loop Recycling	
	Economic Comparison	
	Pretreatment	
	Environmental Considerations	
5	CONCLUSIONS AND RECOMMENDATIONS	20
	REFERENCES	20
	APPENDIX A: Re-Refining Processes	23
	APPENDIX B: Waste Oil Re-Refiners and Processors	29
	APPENDIX C: Used Oil as a Boiler Fuel	33
	GLOSSARY	43
	METRIC CONVERSIONS	43
	DISTRIBUTION	

FIGURES

Number		Page
1	Conceptual Flow System Scheme for Waste Oil Disposal System	17
A1	Acid-Clay Process	24
A2	Vacuum Distillation of Crankcase Waste Oil	25
A3	Re-Refining by a Propane Extraction Process	28
C1	Charts for Determination of Firing Temperatures for Blending Fuels	34
C2	Relationship Between Higher Heating Value and Specific Gravity of Petroleum Oils at 60 F	36
C3	Storage Tank at Fort Benning	38
C4	Lead Emissions	40

TABLES

1	Characteristics of Various Types of Track-Laying Vehicles	10
2	Characteristics of Various Types of Wheeled Vehicles	11
3	Used Crankcase Oil Production Rates of Some Army Facilities	11
4	Estimated Waste Oil Generated Annually by Various Tactical Units	12
5	Characteristics of Used Oil	13
6	Lubricating Oil Additives and Contaminants Likely To Be Found in Used Motor Oils	14
7	CERL Army Waste Oil Analysis	15
8	Characteristics of a Used Oil Which May Be Combusted With Little or No Environmental Risk	18
A1	Properties of Used Lubricating Oil Processed by Vacuum Distillation	26
C1	Gravities, Densities, and Heats of Combustion of Fuel Oils	35
C2	Properties of Virgin Fuel Oil	39
C3	Particle Size Distribution of Lead and Other Major Contaminants in Emissions From Waste Oil Combustion	41
C4	Uncontrolled Emission Factors for Combustion	42

REUSE OF WASTE OIL AT ARMY INSTALLATIONS

1 INTRODUCTION

Background

Typical Army installations produce large amounts of waste oil—up to 250,000 gal annually. Recent emphasis on energy conservation and regulations concerning hazardous wastes have caused the Army to consider reusing its waste oil.[1] The Office of the Chief of Engineers (OCE) asked the U.S. Army Construction Engineering Research Laboratory (CERL) to assess waste oil handling and reuse for Directorate of Facility Engineers (DFAE) and Defense Property Disposal Office (DPDO) personnel.

Objective

The objectives of this research were: (1) to analyze the economics of waste oil reuse, and (2) to examine the environmental aspects of used oil management.

Approach

The state of the art of waste oil management was surveyed through a literature search and contacts with personnel at various Governmental and private agencies. Representatives from Army commands, Army installations, the General Accounting Office (GAO), the U.S. Environmental Protection Agency (EPA), State agencies, and re-refiners were interviewed. Waste oil samples from three installations were analyzed to see how the characteristics of Army waste oil affect reuse options (Chapters 2 and 3).

From this information, CERL assessed the three handling and reuse alternatives that are most appropriate for the Army: (1) selling the oil to a re-refinery, (3) burning it as a boiler fuel, and (3) recycling it in a closed loop agreement with a re-refiner (Chapter 4).

Mode of Technology Transfer

It is recommended that the information in this report impact on the Army Energy Plan and AR 200-1.

[1]*Army Energy Plan* (Headquarters, Department of the Army, 1978).

2 REGULATIONS AFFECTING WASTE OIL REUSE

Federal Water Pollution Control Act Amendments of 1972

One of the first and most important pieces of environmental legislation of the 1970s was the Federal Water Pollution Control Act Amendments of 1972. The purpose of this legislation was to reduce and eventually eliminate the discharge of pollutants into the nation's navigable waters. Discharging toxic pollutants in harmful amounts was prohibited immediately. One concern of Congress was the degradation of the environment cuased by the improper disposal of waste oil. The EPA was directed to conduct a study of:

1. The generation of used engine, machine, cooling and similar waste oil, including quantities, quality, present collection and disposal practices, and alternate uses.

2. The long-term, chronic biological effects of the disposal of waste oil.

3. The potential market for waste oils. The following issues were to be considered: the economic and legal factors relating to the sale of products made from such oils, the level of subsidy needed to encourage public and private nonprofit agencies to buy the products, and the possibility of Federal procurement of these products.

The result of this work was the EPA's *Waste Oil Study*.[2]

PL 94-163

To reduce energy demand and provide emergency conservation measures, the Congress passed the Energy Policy and Conservation Act (PL 94-163) in December 1975. The authors of this bill recognized used crankcase oil as a valuable, reusable resource and devoted a section of the law to policy on recycled oil. Section 383 of PL 94-163 was intended:

1. To encourage the recycling of used oil

2. To promote the use of recycled oil

[2]*Waste Oil Study–A Report to the Congress*, PB257693 (Environmental Protection Agency [EPA], April 1974).

3. To reduce consumption of new oil by promoting increased use of recycled oil.

4. To reduce environmental hazards and wasteful practices associated with the disposal of used oil.

In addition, PL 94-163 directed the National Bureau of Standards (NBS) to "develop test procedures to determine substantial equivalency of re-refined or otherwise processed used oils or blend of new and used oil for a particular end use." Test procedures developed by the Bureau for burner fuel were published in 1980.[3]

PL 94-163 also directed the Federal Trade Commission, after reviewing the Bureau's test procedures, to prescribe labeling standards for recycled oil containers. For containers of new oil, used oil, and recycled oil, the EPA was directed to establish labeling standards concerning the proper disposal of oil after use. Also, all Federal agencies were to revise policies to encourage procurement of recycled oil when available at competitive prices for the same use as new oil.

Finally, Federal agencies were to inform Federal, State, and private sector employees about the need to use recycled oil to conserve new oil and to prevent environmental hazards associated with improper oil disposal.

Resource Conservation and Recovery Act

In 1976, the Solid Waste Disposal Act (42 USC 3251) was amended by the Resource Conservation and Recovery Act (RCRA) PL 94-580. The revised law offers technical and financial assistance in developing facilities for and managing not only recovery of energy, but also safe disposal or recovery of discarded materials. The law also regulates the management of hazardous wastes. Section 3001 of RCRA requires the EPA to issue criteria for identifying hazardous wastes and for categorizing those subject to RCRA's subtitle (c). When characterizing a hazardous waste, the EPA must consider factors such as toxicity, persistence, degradability, potential for accumulation in tissue, flammability, and corrosiveness.

The hazardous waste regulations were issued in May 1980 (40 CFR Part 260), but used oil was not specifically mentioned, although it was in the proposed regulations. Nonetheless, CERL believes that used crankcase oil would qualify as a hazardous waste if it failed the toxicity test specified in the regulations.

Used Oil Recycling Act

The Used Oil Recycling Act of 1980 (PL 96-463) amended the Solid Waste Disposal Act to specifically include used oil. This law is described fully here because it is directly relevant to Army recycling policy.

Section 2 of the Act lists Congressional findings which reflect an increasingly favorable attitude toward used oil. Congress found that

1. Used oil is a valuable source of scarce energy and materials.

2. Technology exists to re-refine, reprocess, reclaim, and otherwise recycle used oil.

3. Used oil constitutes a threat to public health and the environment when reused or disposed of improperly. Therefore, it is in the national interest to recycle used oil in order to protect public health and the environment, and to conserve energy and materials.

Section 4 of the Act deals with labeling requirements for new and used oil containers. Part (c) effectively repeals the rule which requires used oil containers to bear a label indicating that the oil was made from used or recycled oil. It was thought that this notice implied that the product was inferior.

Section 5 (b) amends Section 4008 of the Solid Waste Disposal Act by adding a subsection providing financial assistance to States for oil recycling programs. To carry out the provisions of Section 5, Congress allocated $5 million each for fiscal years 1982 and 1983. None of the funds may be used for construction, land acquisition, or equipment.

Section 6 of PL 96-463 amends Section 4008 of the Solid Waste Disposal Act by authorizing the EPA to provide technical assistance to States which have to address economic and institutional problems with recycling used oil.

Section 7 amends subtitle (C) of the Solid Waste Disposal Act and directs the EPA to issue regulations on performance standards and other requirements necessary to protect public health and the environment from the hazards associated with recycled oil.

[3] D. A. Becker and J. J. Comeford, *Recycled Oil Program: Phase I Test Procedures for Recycled Oil Used as Burner Fuel*, Technical Note 1130 (National Bureau of Standards [NBS], August 1980).

Within 90 days after the enactment of PL 96-463 (or by 15 January 1981) the EPA was required by Section 8 to decide whether subsections 3001 (a) and (b) of the Solid Waste Disposal Act are applicable to used oil (i.e., is it a hazardous waste), and to report the decision and relevant data to Congress. The EPA was not to discourage the recycling and reuse of used oil when making this decision.

Finally, Section 9 requires the Administrator of the EPA, the Secretary of Energy, the Federal Trade Commission, and the Secretary of Commerce to study the environmental problems associated with the improper disposal or reuse of used oil, collection of used oil before recycling, supply and demand in the used oil industry, and energy savings associated with re-refining and recycling used oil.

DOD Policy

The Department of Defense (DOD) recognized the importance of proper management of waste oil before the Used Oil Recycling Act was passed. "Oil Recycling and Reuse Policy" is the subject of a 1979 DOD memorandum.[4] This document emphasizes re-refining waste oil and, if more economical, burning waste oil as a fuel.

A subsequent memorandum directs DOD to "establish a priority system to maximize the sale of used lube oil to re-refiners, reprocessors, brokers for re-refiners/reprocessors, and energy converters, and to purchase re-refined lube oil from industry through closed loop or stock, store, and issue systems."[5]

The most significant change in DOD regulations to promote the purchase of re-refined oil was the revision of MIL-L-46152, "Lubricating Oil, Internal Combustion Engine, Administrative Service," the specification qualifying engine lubricating oil for administrative service vehicles. The revision to MIL-L-46152A (23 January 1980) and then to MIL-L-46152B (26 January 1981) allows used oil as a feed stock. Previously, buying re-refined oil had been prohibited. MIL-L-2014, "Lubricating Oil, Internal Combustion Engine, Tactical Service," is also being changed to allow used oil as a feed stock.

3 CURRENT WASTE OIL MANAGEMENT

Sources

Waste oil at Army installations comes from the maintenance of tactical, support, and facility engineering vehicles. Crankcase oils, transmission oils, final drive oils, and hydraulic fluids are removed periodically from these vehicles at the maintenance facilities.

Tactical vehicles provide most of the Army's used oil, as indicated by the crankcase and transmission capacities shown in Tables 1 and 2. Oil is changed about twice a year for tanks and other tracked vehicles, and once a year for armored personnel carriers. The oil in wheeled vehicles is changed twice a year, unless it is done according to mileage.[6]

Storage

Waste oil is stored in three places before it is finally disposed of: the container used to catch the oil when it is drained from a crankcase, a pod or underground storage tank to hold oil changes from one or more maintenance units, and central storage tanks serving the entire installation. The oil is usually hand-carried in its collection container from the motor pool to the maintenance unit's storage tank. Each unit's oil is usually picked up by a contractor and transferred to the central storage tank; however, at some installations the oil is hauled to the central storage area by the units. If the contractor collecting the oil from the units is also hauling the oil to a waste oil processing facility, then there probably will not be a central storage tank on the installation.

Quantity

The Defense General Supply Center reported that 3,329,842 gal of new crankcase oil were shipped to Army facilities between June 1979 and June 1980. Of this amount, 315,105 gal were to be used in administrative vehicles. These oils were required to meet

[4] "Oil Recycling and Reuse Policy," Memorandum for the Secretaries of the Military Departments, the Directors Defense Agencies (Assistant Secretary of Defense [Manpower, Reserve Affairs, and Logistics], June 4, 1979).

[5] "Defense Environmental Actions for 1981," Defense Environmental Quality Program Policy Memorandum No. 81-1 (Assistant Secretary of Defense [Manpower, Reserve Affairs, and Logistics], 12 January 1981).

[6] R. Fileccia, J. Benson, and J. Matherly, *In-Hardstand Tactical Vehicle Maintenance Facilities Concept Design and Preliminary Recommendations for Wastewater Treatment*, Interim Report N-67/ADA067985 (U.S. Army Construction Engineering Research Laboratory [CERL], 1979), pp 10, 11.

Table 1
Characteristics of Various Types of Track-Laying Vehicles

Designation	General Description	Crankcase Capacity, Qt	Transmission Capacity, Qt
M48A1	Tank, combat, 90 mm	72	92
M48A2/A2C	Tank, combat, 90 mm	64	92
M48A3	Tank, combat, 90 mm	48	76
M60/60A1	Tank, combat, 105 mm	48	76
M107	Gun, self-prop, 175 mm	26	57+
M110	Howitzer, self-prop, 8-in.	26	57+
M109	Howitzer, self-prop, 155 mm	28	52+
M108	Howitzer, self-prop, 155 mm	26	58+
M42/42A1	Gun, Anti-aircraft	44	44
M56	Gun, self-prop, 90 mm	11	15
M53	Gun, self-prop, 155 mm	104	96+
M55	Howitzer, self-prop, 8-in.	64	72+
M37	Howitzer, self-prop, 105 mm	16	30+
M52/52A1	Howitzer, self-prop, 105 mm	44	49
M44/44A1	Howitzer, self-prop, 155 mm	44	70
M84	Mortar, self-prop, 107 mm	22	45
53	Vehicle, combat engr, 165 mm	NA	688
M5-M5A4	Tractor, high speed	22	48
M8A1 - M8A2	Tractor, high speed	44	72
M6	Bulldozer, tank mounted	64	80+
M8	Bulldozer, tank mounted	72	92
M9	Bulldozer, tank mounted	48	76
M578	Recovery vehicle	26	NA
M88	Recovery vehicle	64	72
M113	Armored personnel carrier	10	16
M577-M577A1	Armored personnel carrier, command post	12 18	12

MIL-L-46152 specifications. In addition, 2,924,737 gal, shipped for use in tactical vehicles, had to qualify under MIL-L-2104.

The literature commonly assumes that 50 percent of the crankcase oil is lost during use, disposed of with the filter cartridge, or spilled.[7] If 50 percent of the Army's oil is indeed lost, then 1,600,000 gal of used oil is produced each year. Some Army facilities and their approximate rates of used oil production are listed in Table 3. Table 4 is an example of generation rates from the maintenance units at Fort Lewis, WA.[8]

[7] H. B. Kaufman, "EPA Activities in Waste Oil Management," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979), p 201.

[8] R. Fileccia, J. Benson, and J. Matherly, *In-Hardstand Tactical Vehicle Maintenance Facilities Concept Design and Preliminary Recommendations for Wastewater Treatment*, Interim Report N-67/ADA067985 (CERL, 1979).

Table 2
Characteristics of Various Types of Wheeled Vehicles

Designation	General Description	Crankcase Capacity Qt
M170	1/4 ton ambulance	5.5
M43 - M43B1	3/4-ton ambulance	5
M44,M45,M46, M46C,M58,M133, M207,M207C	2-1/2-ton truck chassis	9
M34,M36,M36C	2-1/2-ton truck chassis	18
M40,M40C,M61 M63,M63C,M139, M139C,M139D	5-ton cargo	9
M135,M211,M35 M54A2,M55	2-1/2 ton cargo truck	11
M125	10 ton cargo truck	22
M342	2-1/2-ton cargo, dump	10.5
M51	5-ton dump	22
M49,M49C	2-1/2-ton gasoline	9
M217,M217C	2-1/2-ton fuel servicing	9
M150,M222	2-1/2-ton water	9
M48,M221,M275	2-1/2-ton truck tractor	9
M52,M52A1	5-ton truck tractor	22
M123,M123C,M123D	10-ton truck tractor	22
M246	5-ton wrecker	22
M38,M38A1,M38A1C	1/4-ton utility	4
M151	1/4-ton utility	4
M108,M60	2-1/2-ton wrecker	9
M62,M62E1	5-ton wrecker	18
M512,M512C,M512D M512E,M512G	2-1/2-ton shop vans	9

Table 3
Used Crankcase Oil Production Rates of Some Army Facilities

Installation	Gal/Yr
Fort Hood, TX	256,596
Fort Polk, LA	255,364
Toelle Army Depot, UT	125,948
Stewart/Hunter AAF, TX	142,236
Red River Army Depot, TX	122,124
Anniston Army Depot, AL	118,000
Fort Bragg, NC	108,400
Fort Carson, CO	90,400

Quality

Before any oil recycling or reuse process is selected, the contaminants in the used oil must be identified and the contaminants' sources examined. Generally, contaminants are classified as metals, water, sediment, and ash. Table 5 gives the general characteristics of used oil; Table 6 lists typical additives and contaminants in used oil.

CERL conducted a limited characterization study to see if the Army's waste oil is similar to that discussed in the literature. Sampling was done at Fort Eustis, Fort Bragg, and Fort Benning; these installations were chosen because they are representative of the average producers of Army waste oil. All three installations have central storage tanks from which waste oil samples were taken. The results of CERL's analyses are shown in Table 7. Although time and funding restrictions prevented a more comprehensive analysis of the samples, the parameters considered most important for processing the oil or using it as boiler fuel were included.

Sources of Contaminants in Used Oil

Commercial basestocks contain only very small concentrations of metals, so these contaminants are introduced to oil as additives, or from wear, corrosion, or combustion.[9] Additives which usually constitute 20 percent, by volume, of high grade crankcase oils typically contain sodium, barium, calcium, zinc, and magnesium compounds.[10] Wear and corrosion processes contribute aluminum, copper, iron, silicon, and tin.[11] Combustion of leaded fuels in gasoline engines may cause the lead concentration in crankcase oils to increase by a factor of 10,000 to as much as 1.14 percent by weight.[12]

Of course, the metal profiles of gasoline engine and diesel engine crankcase oils differ; most significant is that used crankcase oil from diesel engines contains no

---

[9] T. D. Coyle and A. R. Siedle, "Metals in Oil: Occurrence and Significance for Reuse of Spent Automotive Lubricating Oils," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979), p 197.

[10] *Waste Oil Study: A Report to the Congress*, PB257693 (Environmental Protection Agency [EPA], April 1974), p 16.

[11] *Waste Oil Study*, p 16.

[12] Coyle and Siedle, p 23.

Table 4
Estimated Waste Oil Generated Annually by Various Tactical Units

Unit Designation	Vehicle Counts Track	Vehicle Counts Wheeled	Estimated Waste Oil Generated, Gal*
Cavalry Squadron	36	43	800
Artillery Battalion (BN) (inf div)	0-5	91-111	400-900
Air Defense Artillery BN	44	115	900
Military Police Group (GP)		54	100
Ordnance CO	2	46	400
Transportation CO		70-73	300-600
Adjutant General CO		29	100
Signal BN		160-222	600
Engineer BN	12-18	214-213	800-1700
Military Intelligence GP		21	100
Armored BN	94	78	3400
Mechanized Infantry BN	88	91	900
Medical GP	108		300
Infantry BN		116	300
Supply & Transport CO		123	600
Aviation BN		46	200

*Rounded to next highest 100 gal.

incremental lead from the combustion process.[13] This is an important consideration in the evaluation of reuse options discussed in Chapter 4. Additional metal contamination may occur during the collection, handling, and storage of the used oils. Table 5 lists some common metal contaminants and trace metals, and their concentration ranges in used oil.

During use, crankcase oil changes chemically and physically. Additives are consumed or undergo molecular change, and lead and wear metals accumulate as particulates. Organics are volatilized and inorganics are concentrated as oil losses occur.[14] Zinc dialkylidthiophosphate, an antiwear additive, is degraded to inorganic zinc-containing substances.[15] According to Coyle and Siedle, calcium dialkylnapthalene sulfonates are partially converted to inorganic calcium compounds and organic products. Magnesium and barium sulfonates may hydrolize to produce their respective hydroxides.[16]

Organic bromin... compounds are added to gasoline to scavenge lead as lead bromide. Coyle and Siedle suggest that some of the lead in oil from gasoline engines is present as lead dibromide. Lead is also thought to be present as lead salts and chlorides.[17]

[13] *Waste Oil Preliminary Report to the Congress* (Environmental Protection Agency, April 1973), as cited in T. D. Coyle and A. R. Siedle, "Metals in Oil: Occurrence and Significance for Reuse of Spent Automotive Lubricating Oils," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979), p 197.

[14] *Waste Oil Study*, p 12.

[15] C. Versino and C. DelSole, "Cromatagrafia S-Le Spettrofotometria IR di Oil Minerali Lubrificant," *La Rivista dei Combustibili*, Vol 26, No. 321 (1972); C. Versino, A. Bacchiorrini, and C. DelSole, "Spettrofotometria IR di un Olio Minerale Lubrificanti Esausto," *La Rivista dei Combustibili*, Vol 26, No. 421 (1972), as cited in Coyle and Siedle, p 203.

[16] Coyle and Siedle, p 203.

[17] Coyle and Siedle, p 200.

Finally, ferrous metal parts are worn to produce oxides Fe_2O_3 and Fe_3O_4.[18]

Although specific chemical and physical forms of metals in used oil are not entirely known, filtration and centrifugation have revealed small particles of lead, zinc, calcium, barium, magnesium, and iron.[19] As much as 50 percent of the lead present in used crankcase oil is believed to occur as fine suspended particles.[20]

Water contamination occurs as a product of fuel combustion, condensation, and seepage into storage tanks.[21] Water contamination varying from 0.2 to 33.8 percent by volume has been reported.[22] An analysis of the water in a contaminated oil sample may show large amounts of sodium, zinc, barium, calcium, iron, phosphorus, magnesium, boron, tin, and lead. This implies that the metals are present in ionic or salt-like forms. Consequently, simple separation of oil and water will remove some metals.[23]

Generally, factors such as length of drain intervals, extent of fuel leakage into the oil, engine operating conditions, and climate influence the rates of chemical and physical reactions in the oil, and therefore dictate the oil's metal profile.[24]

Analysis of used oil quality is important because the cost and effectiveness of recycling processes depend on the specific chemical forms of the metals.[25]

Contamination During Handling

The most serious contamination may occur after the oil has been drained from the crankcase. During CERL's sampling exercise, nearly all maintenance unit storage tanks were found to have been used as dumpsters. Oil filters, rags, cans, trash, and water were in these tanks. CERL also found significant concentrations of volatile liquids, probably solvents or fuels. In some tanks, up to 1 ft of water had accumulated. All of these contaminants make the oil less valuable for reuse as re-refining stock or boiler fuel.

Table 5
Characteristics of Used Oil

Property or Element	Used Oil
Viscosity (SUS* @ 40 C)	87 to 837
American Petroleum Institute (API) gravity (60 F)	19.1 to 31.3
Specific gravity	0.87 to 0.94
Water (% by volume)	0.2 to 33.8
BS & W** (% by volume)	0.1 to 42
Benzene insolubles (% by volume)	0.56 to 3.33
Gasoline (% by volume)	2.0 to 9.7
Flash point (C)	79 to 219
Heating value (Btu/lb)	13,570 to 19,300
Ash, sulfated (% by weight)	0.03 to 6.43
Carbon residue (% by weight)	1.82 to 4.43
Aluminum (ppm)	0.5 to 860
Barium (ppm)	9 to 3906
Cadmium (ppm)	4
Calcium (ppm)	211 to 3600
Chromium (ppm)	8 to 50
Copper (ppm)	4 to 348
Iron (ppm)	50 to 2401
Lead (ppm)	85 to 21,700
Magnesium (ppm)	10 to 1100
Phosphorus (ppm)	319 to 2000
Silicon (ppm)	10 to 875
Sodium (ppm)	16 to 300
Sulfur (% by weight)	0.17 to 1.09
Zinc (ppm)	260 to 3000

(Table derived from D. A. Becker and J. J. Comeford, *Recycled Oil Program, Phase 1: Test Procedures for Recycled Oil Used as a Burner Fuel*, Technical Note 1130 [National Bureau of Standards, 1980]; T. D. Coyle and A. R. Siedle, "Metals in Oil: Occurrence and Significance for Reuse of Spent Automotive Lubricating Oils," *Proceedings of a Workshop on Measurement and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 [NBS Special Publication 556, 1979].)

*SUS: Saybolt Universal Seconds

**BS & W: bottom settlings and water

[18]Coyle and Siedle, p 203.

[19]Coyle and Siedle, p 203.

[20]Coyle and Siedle, p 23.

[21]Coyle and Siedle, p 199.

[22]D. A. Becker and J. J. Comeford, *Recycled Oil Program Phase 1: Test Procedures for Recycled Oil Used as a Burner Fuel*, Technical Note 1130 (National Bureau of Standards, 1980), p 5.

[23]Coyle and Siedle, p 207.

[24]Coyle and Siedle, pp 193, 199.

[25]Coyle and Siedle, p 199.

Table 6
Lubricating Oil Additives and Contaminants Likely To Be Found in Used Motor Oils

(See H. A. Braier, "Metals in Oils," *Anal Chem.*, Vol 43, No. 185R [1971], and R. F. Terrell, *Anal Chem.*, Vol 149, No. 255R [1977], B. R. Williams, "Automotive Crankcase Drainings Used for Fuel," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil*, Gaithersburg, Maryland, National Bureau of Standards, 1976 [NBS Special Publication 488, 1977]; *Finnegan Spectra*, Vol 6, No. 2 [Sunnyvale, California, Finnegan Corp., 1976].)

Typical Additives	Primary Source and Type of Typical Contaminants
Antiwear: zinc organo-dithiophosphates, organic phosphorus compounds.	Gasoline: lead and lead compounds, halogens.
Corrosion inhibitors: sulfonates, amine phosphates; organic phosphites.	Additives: zinc and zinc compounds, phosphorus compounds, etc.
Detergents and dispersants: calcium, magnesium, barium, and zinc sulfonates, phosphonates, and phenates; alkenyl succinimides; acrylic polymers.	Combustion products: polynuclear aromatics, water, oxygenated compounds, sludge, varnish.
Viscosity index improvers: isobutylene polymers, acrylate polymers.	Fuel: volatile liquid.
Pour-point depressants: polymethacrylates, polyacrylamides.	Contamination: dirt, wear metals.
Antifoam agents: silicones, synthetic polymers.	Coolant leaks: water, ethylene glycol.
Antioxidants: zinc organo-dithiophosphates, hindered phenols, aromatic amines, sulfurized phenols.	

The solid trash problem could be corrected easily by putting screens over the inlet holes of the tanks. There would be fewer problems with water in the tanks if installations put spring closures on the tank lids and trained the troops in proper disposal methods. In addition, Fort Eustis personnel suggested putting the maintenance storage tanks on the outside of the compound enclosure. This would allow easy access for the contractor collecting the oil; additional piping would permit the tanks to be filled from inside the compound.

Is Army Waste Oil a Hazardous Waste?

A material is considered a hazardous waste if: (1) it is ignitible, corrosive, reactive, or toxic as defined in subpart c of 40 CFR Part 261, or (2) it is listed in subpart d of 40 CFR Part 261, the Hazardous Waste Regulations. A facility emitting over 1000 kg per month of hazardous waste is responsible for storing, transporting, and disposing of the waste according to the regulations in 40 CFR Parts 260-265.

Waste oil has not been officially listed as a hazardous waste in the Hazardous Waste Regulations. However, according to an EPA report, ". . .the following waste oils are hazardous wastes, and thus should be subject to the regulations prescribed under Sections 3002 through 3004 of RCRA: (1) Oil spilled to land, and oily debris generated from cleaning up spills to land or surface water; (2) used automotive oils; and, (3) used industrial oils." As to whether the Army's oil is "waste" or "used" oil, the EPA report states: "Used oil becomes a waste oil when it is contaminated with physical or chemical impurities resulting from use, such that the oil cannot be reused for its original purpose without first removing these impurities."[26] This definition suggests that oil becomes a waste when it is removed from the crankcase. In FY82, the EPA is scheduled to issue regulations dealing specifically with waste oil.

CERL's analyses of waste oil storage tank samples revealed that oil should be considered a hazardous

[26] *Report to Congress Listing of Waste Oil as a Hazardous Waste Pursuant to Section (8)(2), Public Law 96-463* (EPA, January 1981).

Table 7
CERL Army Waste Oil Analysis

	Fort Benning			Fort Bragg			Fort Eustis	
	Upper Sample	Middle Sample	Top Sample	Upper Sample	Middle Sample	Top Sample	Upper Sample	Middle Sample
Density (g/cc)	0.903	0.902	0.911	0.910	0.912	0.912	0.907	0.985
Specific gravity	0.890	0.884	0.895	0.892	0.892	0.892	0.901	0.989
Sulfur (%)	0.61	0.71	0.30	0.33	0.33	0.71	0.83	0.31
Heating value								
Btu/lb	19.000	19.000	15.700	15.100	16.100	18.700	18.800	7.800
Btu/gal	143.000	143.000	119.000	115.000	122.000	142.000	142.000	64.000
Bottom solids & Water (%)	0.41	0.50	2.0	6.6	7.6	0.2	0.2	6.5
Flash point (°C)	85	80	50	42	46	52	41	46
Viscosity (100°F) (cSt)	298	102	16	217	255	227	219	812
Lead (ppm)	480	310	10	70	220	80	80	20
Ash (%)	1.40	2.05	0.29	0.12	0.17	3.66	3.77	3.16
Polychlorinated biphenyl (PCB) (ppm)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

waste regardless of the new regulations. The ignitibility test for a hazardous waste is defined in 40 CFR Part 261.21. If a liquid has a flash point of less than 140°F (60°C), then it is ignitible and is a hazardous waste. All samples tested from Forts Bragg and Eustis, and at least one sample from Fort Benning, had flash points below 140°F. This test probably shows the presence of solvents or fuels. Improved management by segregating waste oils from other liquid wastes should alleviate problems with ignitibility.

Even if Army waste oil were classified a hazardous waste, it is not subject to the notification requirements of RCRA. Part 261.6 of the Hazardous Waste Regulations exempts wastes that are "being beneficially used or reused or legitimately recycled or reclaimed" from regulation under Parts 262 through 265, and from the notification requirements of Section 3010 of RCRA. However, this means that installations must be careful that all used oil is reused and none is disposed in another manner.

4 REUSE OPTIONS

Current Policy

The 4 June 1979 memorandum from the Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics) limits the options for disposing of used lubricating oil. The memorandum directs Defense agencies to sell as much oil as possible through DPDOs to re-refiners, and to burn the used oil as a fuel when re-refining is not economical. Disposal practices such as using the oil for weed, insect, and dust control, burning it in open pits, and dumping it into landfills or sewers are rejected as environmentally unacceptable.[27]

A GAO report to Congress recommends another option for recycling DOD's used oil. This report

[27] "Oil Recycling and Reuse Policy," Memorandum for the Secretaries of the Military Departments, the Directors Defense Agencies (Assistant Secretary of Defense [Manpower, Reserve Affairs, and Logistics], June 4, 1979).

proposes a "closed cycle" system in which a major Army installation provides used oil as a feed stock for a re-refiner and then buys back the processed oil.[28] The 12 January 1981 memorandum from the Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics) endorses this option.[29]

Re-Refining

Re-refineries buy bulk quantities of used oil at a wide range of prices, depending on factors such as the quality of the used oil, competition, and so on. Used oil is often brought to these companies by independent haulers who act as middlemen between the waste oil generator and the processors. Most Army installations are now selling their oil to these independent haulers. The amount paid to the installation varies across the country, ranging from less than \$.10 per gallon to more than \$.30 per gallon. After the waste oil has been reprocessed, it is sold as lubricating oil at \$1.50 to \$2.00 per gallon. Appendix A briefly describes various re-refining processes, and Appendix B lists reprocessing companies.

Used Oil as a Fuel

When economically feasible, used oil may be burned as a boiler fuel. Of course the costs of using this option for disposal depend on the boiler fuel system currently used at [illegible] tallation.

The three facilities CERL visited during the sampling survey were all using waste oil as a boiler fuel. As with these three boilers, conversion to waste oil burning is much more feasible if a liquid fuel system is already in use. Figure 1 is an example of a design for adding waste oil as a supplemental boiler fuel.

Impurities usually have to be pretreated before waste oil can be used as a fuel; the design in Figure 1 includes screens and filters. A system for eliminating and treating wastewater must also be provided. Suspended metals and other contaminants may cause air pollution problems. As Table 8 indicates, the Army's waste oil ranges from safe in all categories to unusable without air pollution controls on the boilers. Air pollution problems probably would result from particulate levels and lead emissions.

Table 8 lists EPA-recommended limits on the characteristics of waste oil used as a fuel. Appendix C is a detailed assessment of waste oil as a boiler fuel.

Closed Loop Recycling

The closed loop system is the most promising option for reusing waste oil. The Army is not now using this method, but the railroad and auto industries are having success with it, and it was used by the military during World War II. Closed loop recycling was not possible before January 1980 because MIL-L-46152, for administrative service vehicles, and MIL-L-2104, for tactical vehicles, did not allow used oils as a feed stock. However, the administrative vehicle specification has been amended (MIL-L-46152B), and the tactical vehicle specification will be amended by mid-1982 to allow used oil as feed stock. This change, along with the memoranda mentioned earlier, permits closed loop re-refining. All re-refiners contacted by CERL have stated that they are interested in closed loop agreements.

The major obstacle to the Army's using closed loop agreements extensively is the cost of qualifying an oil to meet MIL-L-46152 requirements. For a re-refiner's product to qualify under MIL-L-46152B, it must pass expensive engine sequence tests. Re-refiners have stated that the \$50,000 cost of the engine test has kept them from trying to qualify their oil. However, they said they would be interested if the cost of testing could be included in the closed loop agreement.

Economic Comparison

To determine which disposal method to use, the waste oil manager must assess the costs and benefits of each. The manager should consider several factors, which vary from installation to installation: current waste oil management, availability of large storage facilities, present boiler fuel system, proximity of re-refiners, and waste oil transportation costs. A manager would probably use the following method to analyze the options.

1. **Selling oil to private collector.**

\$Return = no. of gal of waste oil × \$/gal (going rate paid by collector).

2. **Using oil as a boiler fuel.**

\$Return = (\$ value of replaced fuel) − (\$ cost of handling, storage, filtering, and piping facility).

---

[28] *Ways the Department of Defense Can Improve Oil Recycling* (General Accounting Office, Report to Congress, September 28, 1977).

[29] "Defense Environmental Actions for 1981," Defense Environmental Quality Program Policy Memorandum No. 81-1 (Assistant Secretary of Defense [Manpower, Reserve Affairs, and Logistics], 12 January 1981).

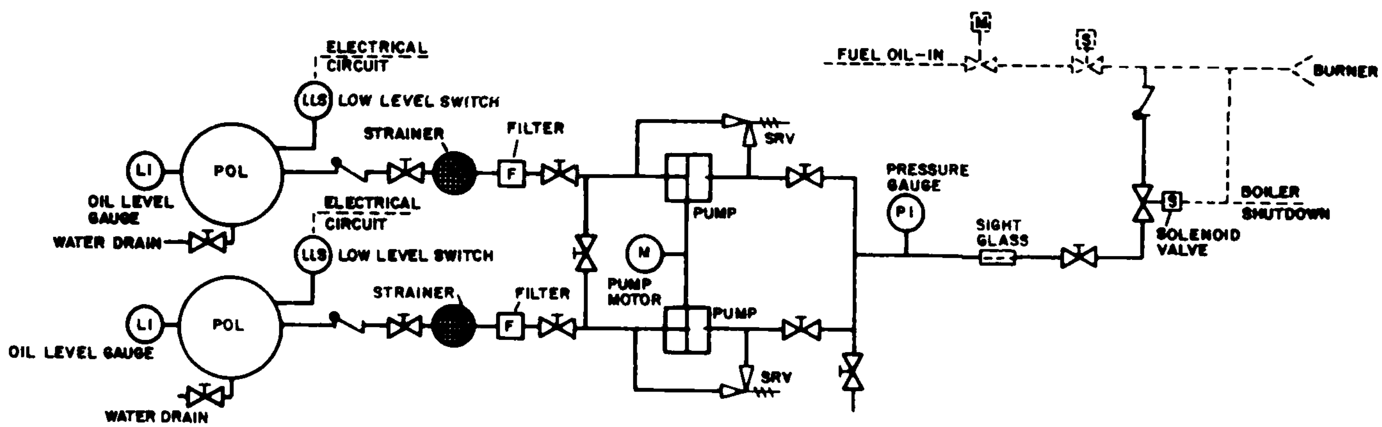


Figure 1. Conceptual flow system scheme for waste oil disposal system. (From P. L. Fink and J. W. Jackson, *Waste POL Disposal Through Energy Recovery* [Air Force Civil Engineering Center, June 1976].)

Table 8
Characteristics of a Used Oil Which May Be Combusted With Little or No Environmental Risk

Characteristic*	Comment*	CERL Analysis of Army Waste Oil
Total ash ≤ 0.37 (by weight)	Equivalent to 0.12 grams/SCF emission (0% excess air). Meets many state and local regs when burning 100% used oil.	0.12 to 3.77%
Lead content < 50 ppm	Meets almost all local ambient air quality standards when burning 100% used oil.	10 to 480 ppm
Chlorine < 0.4/(weight)	Normal for used oils indicating no contamination by chlorinated solvents.	Not analyzed
PCB < 50 ppm	Consistent with PCB criteria, 40 CFR Part 761.	Less than 1.0 ppm
BS&W < 1%	Indicator absence of substantial water and sediment which may contribute to emission or burning problems.	0.2 to 7.6
Flash point > 140°F (60°C)	Corresponding to hazardous waste classification under RCRA.	41 to 85°C
Sulfur: ≤ 0.2% (by weight) ≤ 0.5% (by weight)	Probably meets all State regs. Probably meets most State regs.	0.3 to 0.8%

*From *Used Oil Burned as a Fuel*, Vol 1, SW 892 (EPA, 1980), pp 1-7, 1-8.

3. **Entering into a closed loop purchase agreement.**

$Return = ($value of replaced new lubricating oil) − ($ cost of closed loop agreement, transportation to and from re-refining, and cost of re-refining oil).

Perhaps the best way to compare alternatives is to assume a hypothetical situation. Suppose an installation produces 100,000 gal of used oil per year. Assume major contamination has been eliminated by good management, and all of the oil can be shipped to a vacuum distillation re-refiner. Also assume that all maintenance units have storage tanks accessible to a contractor, and that administrative contracting costs are the same for all three options. All dollar figures are approximate norms derived from reported actual expenses.

1. **Sold to private collector.**

a. Costs: none.

b. Savings = $.15/gal × 100,000 gal = $15,000/year

Net Value = $.15/gal.

2. **Used as a boiler fuel.**

a. Costs: Retrofit at boiler and oil storage (assume 20-yr life) = $75,000 ($3750/yr).

Cost to transfer oil to boiler storage = $.10/gal × 100,000 gal = $10,000/yr.

Total costs = $13,750/yr.

b. Savings — 100,000 gal of used oil will replace about 85,000 gal of No. 4 fuel oil, due to differences in heating value.

85,000 gal × \$.90/gal = \$76,500/yr.

Net Value = 76,500 − 13,750 = \$62,750/yr. = \$.63/gal.

3. **Closed loop.**

Assume: 80 percent of volume is returned as new oil; re-refinery is 200 mi from installation.

a. Costs for transportation:

$$\frac{100{,}000 \text{ gal waste oil}}{6300 \text{ gal trip}} = 16 \text{ trips};$$

$$16 \text{ trips} \times \frac{200 \text{ mi}}{\text{trip}} \times \frac{\$1.20}{\text{mi}} = \$3840.$$

$$\frac{80{,}000 \text{ gal re-refined oil}}{6300 \text{ gal trip}} = 13 \text{ trips};$$

$$13 \text{ trips} \times \frac{200 \text{ mi}}{\text{trip}} \times \frac{\$1.20}{\text{mi}} = \$3120.$$

Transportation cost = \$6960.

b. Savings = (80,000 gal × \$3.10 gal for new oil purchase) − (80,000 × \$1.60/gal fee for re-refining service) = \$120,000/yr.

c. Net Value: \$120,000 − 7,000 = \$113,000/year = \$1.13/gal.

The above costs are for approximate comparison only and do not reflect all costs associated with the management of waste oil. The following expenses also should be accounted for: administrative costs of contracting, pretreatment costs of the waste oil to remove water and sludge, disposal costs for the water and sludge, possible increased maintenance at the boiler facility, and improvements to the present storage and collection facilities.

Pretreatment

The three installations CERL visited use pretreatment for their waste oil boiler fuel. All are similar to the system shown in Figure 1, but one important difference is that the installations have their two storage tanks in series, rather than in parallel, as shown in the figure. Oil is drawn from the upper part of the first tank and pumped into the second tank. This allows much of the water and heavy sediment to settle in the bottom of the first tank, where it can be drained off periodically. The characteristics of this water and sediment have not been determined; the pollution potential should be analyzed.

Interviews with boiler operators indicate that water contamination may be beneficial. The operators say that oil containing as much as 10 percent water will burn successfully in the boilers, and that water acts as a steam cleaner and may actually decrease maintenance on the inside of the boiler. Water's effect on combustion efficiency (zero BTU's/lb) and the quality of the stack emissions is not known, and should be determined.

Pretreating oil sold to re-refiners does not seem to be common, though it may be to the Army's advantage. Sludge and particulates in the feed oil to acid-clay re-refining increase the volume of waste sludges from the process, and thereby decrease the volume of the product oil. Though the contaminants may have less effect on vacuum distillation, the process' costs still must increase.

Pretreatment could be most important for closed loop recycle agreements. By decreasing the cost of re-refining by using pretreatment, the finished oil's cost to the Army will be lower. The best pre-treatment process still needs to be determined.

Environmental Considerations

The Army's first priority for improving waste oil management would probably be to remove solvents, waste fuels and sludges from the used oil. This should eliminate two immediate problems: handling the used oil as a hazardous waste and gaining approval of Army boilers as hazardous waste disposal facilities. However, solvents and sludges would then have to be dealt with. The most effective techniques for properly disposing of or reusing these wastes need to be determined.

In addition, waste oil managers should ensure the proper disposal of solid and liquid wastes coming from the pretreatment of the waste oil. The sediment and water drained from the bottom of storage tanks and filtration units contain emulsified oil and metals in solution or in suspension. To prevent these from entering groundwater or surface water, the wastewater should be collected and drained to a sanitary sewer, or preferably to an oil-water separation unit preceding the sanitary sewer. A characterization study should be done on this waste stream to determine to what extent it is a pollution hazard.

As mentioned previously, burning waste oil may cause air pollution problems if ambient air standards for lead or particulates are violated. The source of lead in waste oil is undoubtedly leaded gasoline, because new oil contains no lead additives. If waste oil is burned as a boiler fuel and lead becomes an air pollution problem, then the installation should consider restricting or prohibiting the use of leaded fuels in vehicles. Filtration alone may lower particulate levels enough. Pretreatment studies need to be done to decide how to make Army oil safe for use as a boiler fuel.

The problem of waste oil spillage can be addressed immediately. Oil is often spilled while being transferred from crankcase to storage tank or from storage tank to transporting vehicle. This oil is then washed away by storm water and may contaminate surface or groundwater supplies. To prevent this, storage tanks should be placed on a smooth, impervious surface with berming to contain spills and to allow drainage through an oil-water separator to a sanitary sewer.

5 CONCLUSIONS AND RECOMMENDATIONS

This report has evaluated the economic and environmental aspects of used oil management, emphasizing waste oil reuse. It is concluded that:

1. Closed loop agreements to re-refine the Army's waste oil appear to be the most economical option for disposal. However, the cost to qualify re-refined oil under MIL-L-46152B prevents most re-refiners from entering into these agreements. When deciding whether a closed loop purchase agreement with a re-refiner is practical, Army installations should consider including the cost of qualifying the oil for the military specification in the total cost of the contract.

2. Using waste oil as a boiler fuel is also a disposal option, but may cause air pollution problems because of contaminants in the oil. The effects of these contaminants on ambient air quality should be quantified to determine the usefulness of waste oil for boiler fuel.

3. Contaminants, especially trash, solvents and water, in the Army's waste oil can decrease its value for re-refining and for burning. Pretreatment of the oil may be required. The effect of such contaminants on the value of oil should be quantified.

4. Volatile organics found in samples of Army waste oil make this product a hazardous waste under the flammability criteria of the Hazardous Waste Regulations. The most likely source of this contamination is the dumping of waste solvents and fuels into waste oil storage tanks. Collection and storage should be managed so that used oil is not contaminated with solvents or fuels.

5. Water and solids drained from the bottom of waste oil storage tanks sometimes are allowed to run onto the ground and may pollute surface water and groundwater. Water and solids should be analyzed to determine their pollution potential. Wastewater should be collected and drained to a sanitary sewer.

6. Oil is frequently spilled on and around waste oil storage tanks. This oil could be carried away by storm water run-off and cause a pollution problem. Storage tanks should be placed on or buried under a non-absorbing surface with berming to contain oil spillage and direct run-off through an oil-water separator to a sanitary sewer.

7. Waste oil storage tanks at maintenance units are not always accessible to contract collectors, nor are they designed to prevent trash from being deposited in the tanks. Where possible, storage tanks should be placed outside maintenance unit compounds, with the tank inlet inside the compound. The inlets should have screening to keep trash out of the tanks.

CITED REFERENCES

Army Energy Plan (Headquarters, Department of the Army, 1978).

Beard, J. T., F. A. Lachetta, and L. U. Lillelcht, *Air Pollution Training Institute Course 427: Combustion Evaluation Student Manual*, EPA 450/2-80-063 (Environmental Protection Agency [EPA], February 1980).

Becker, D. A., and J. J. Comeford, *Recycled Oil Program Phase I Test Procedures for Recycled Oil Used as a Burner Fuel*, Technical Note 1130 (National Bureau of Standards, 1980).

Braier, H. A., "Metals in Oils," *Anal. Chem.*, Vol 43, No. 185R (1971).

Coyle, T. D., and A. R. Siedle, "Metals in Oil: Occurrence and Significance for Reuse of Spent Automotive Lubricating Oils," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979).

"Defense Environmental Actions for 1981," Defense Environmental Quality Program Policy Memorandum No. 81-1 (Assistant Secretary of Defense [Manpower, Reserve Affairs, and Logistics], 12 January 1981).

Fileccia, R., J. Benson, and J. Matherly, *In Hardstand Tactical Vehicle Maintenance Facilities Concept Design and Preliminary Recommendations for Wastewater Treatment*, Interim Report N-67/ADA067985 (U.S. Army Construction Engineering Research Laboratory [CERL], 1979).

Fink, P. L., and J. W. Jackson, *Waste POL Disposal Through Energy Recovery* (Air Force Civil Engineering Center, June 1976).

Finnegan Spectra, Vol 6, No. 2 (Sunnyvale, California: Finnegan Corp., 1976).

Fu, T. T., and R. S. Chapler, *Utilization of Navy-Generated Waste Oils as Boiler Fuel Economic Analysis and Laboratory Tests*, Technical Note N-1570 (Naval Construction Batallion Center, 1980).

Kaufman, H. B., "EPA Activities in Waste Oil Management," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979).

Mascetti, G. J., and H. M. White, *Utilization of Used Oils*, Final Report, U.S. Department of Energy Contract EY-76-C-03-1101-003/ATR7873841 (August 1978).

"Oil Recycling and Reuse Policy," Memorandum for the Secretaries of the Military Departments, the Directors Defense Agencies (Assistant Secretary of Defense [Manpower, Reserve Affairs, and Logistics], June 4, 1979).

Perkins, H. C., *Air Pollution* (McGraw Hill, Inc., 1974).

Report to Congress Listing of Waste Oil as a Hazardous Waste Pursuant to Section 8(2), Public Law 96-463 (EPA, January 1981).

Spawn, P. D., and P. F. Fennelly, "An Updated Look at the Fuel Potential of Waste Automotive Oil," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979).

Terrell, R. E., *Anal. Chem.*, Vol 149, No. 255R (1977).

Used Oil Burned as a Fuel, Vol 1, SW 892 (EPA, 1980).

Versino, C., and C. DelSole, "Cromatagrafia S-Le Spettrofotometria IR di Oil Minerali Lubrificant," *La Rivista dei Combustibili*, Vol 26, No. 321 (1972).

Versino, C., A. Bacchiorrini, and C. DelSole, "Spettrofotometria IR di un Olio Minerale Lubrificanti Esausto," *La Rivista dei Combustibili*, Vol 26, No. 421 (1972).

Waste Oil Preliminary Report to the Congress (EPA, April 1973).

Waste Oil Study A Report to the Congress, PB257693 (EPA, April 1974).

Ways the Department of Defense Can Improve Oil Recycling (General Accounting Office, Report to Congress, September 28, 1977).

Williams, B. R., "Automotive Crankcase Drainings Used for Fuel," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil*, Gaithersburg, Maryland, National Bureau of Standards, 1976 (NBS Special Publication 488, 1977).

UNCITED REFERENCES

Cutler, E. T., "Conserve Lube Oil: Re-refine," *Hydrocarbon Process*, Vol 86 (1976).

Hedtke, S. F., *The Effect of Waste Oil on Freshwater Aquatic Life*, PB257693 (EPA, April 1974).

Hess, L. Y., *Reprocessing and Disposal of Waste Petroleum Oils* (Noyes Data Corporation, Park Ridge, NJ, 1979).

Irwin, W. A., and K. Heimann, "Recent Federal and State Legislative Developments in Used Oil Recycling," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979).

Irwin, W. A., and R. A. Liroff, *Used Oil Law in the United States and Europe*, EPA-600/5-74-025 (EPA, July 1974).

Linnard, R. E., "PROP Re-refined Engine Oil Performance," *Proceedings of Joint Conference on Measurements and Standards for Recycled Oil Systems Performance and Durability*, Gaithersburg, Maryland, National Bureau of Standards, 1979 (NBS Special Publication 584).

Questions and Answers on Hazardous Waste Regulations, SW 853 (EPA, 1980).

A Technical and Economic Study of Waste Oil Recovery, Part I, PB237618 (U.S. Department of Commerce, October 1973).

A Technical and Economic Study of Waste Oil Recovery, Part III, PB237620 (U.S. Department of Commerce, October 1973).

Used Oil Recycling Kit (U.S. Department of Energy, February 1978).

Weinstein, Norman J., *Waste Oil Recycling and Disposal*, PB236148 (U.S. Department of Commerce, August 1974).

Whisman, M. L., J. W. Goetzinger, and F. O. Cotton, *Waste Lubricating Oil Research: Some Innovative Approaches to Reclaiming Used Oil* (U.S. Bureau of Mines, 1974).

APPENDIX A: RE-REFINING PROCESSES

Acid-Clay

Acid-clay is probably the most common re-refining process in the United States (Figure A1). A pretreatment step to remove debris and water usually precedes the process. After passing through grids and screens, free water is allowed to settle. The oil is then dehydrated at 300°F and atmospheric pressure. Before going to acid treatment, the oil is cooled to 100°F over 2 days.

The acid treatment is performed with 92 percent sulfuric acid in volumes of 4 to 6 percent of the reactor volume. The coagulation reaction occurs in 24 to 48 hours. The acid sludge which contains the contaminants and ash from the oil is drawn off and disposed of.

The clay treatment removes light fuel fractions, mercaptans, and color bodies from the oil. The process occurs at 500 to 600°F and takes 15 to 16 hours. The clay itself consists of activated clay and diatomaceous earth (200 to 250 mesh). About 0.4 lb of clay is required per gallon of oil.

The final step is a filtering process. The oil passes through a filter press at 250 to 300°F. It may be filtered more than once to achieve a desired quality. The finished oil is sent to storage, where additives may be introduced.[30]

A typical acid-clay process yields 45 to 75 percent of the feed oil, depending largely on operating conditions and feed composition. The product of an acid-clay process is a solvent neutral blending stock with a viscosity (Saybolt Universal Seconds [SUS], 210°F) of 55 to 58 seconds, corresponding to a Society of Automotive Engineers (SAE) 20-weight oil.[31] Diesel crankcase drainings as feed stock produce a heavier SAE 40-weight oil with a viscosity (SUS, 210°F) of 80 to 85 seconds.[32]

The major disadvantage of the process is disposing of the large volumes of acid sludge it generates. This sludge is produced at a volumetric rate of 1/10 of the oil feed rate; at least 1/10 of the incoming oil itself is contained in the sludge. Specifically, the sludge contains sulfuric acid, combustibles, lead, organometallics, sulfonates, and possibly some carcinogenic materials.[33] The fact that 30 to 50 percent of the sludge is soluble complicates the disposal dilemma. The sludge is combustible, but should not be burned because of the high concentration of sulfur oxides and very fine metal-containing particulates present.[34]

The spent clay is composed of polar compounds such as oxygen- and nitrogen-containing organics. The oil content is approximately 20 to 30 percent. Generally, the spent clay is not a disposal problem.[35]

Vacuum Distillation

Vacuum distillation presents no serious disposal problem (Figure A2). The process consists of three steps: pretreatment, distillation, and finishing. The pretreatment is a dehydration step. The oil is heated to 300°F at atmospheric pressure. The overhead is sent to a decantation process and the bottoms are mixed with caustic and naptha to break up oil-water emulsions and precipitate solids.

The distillation occurs at 700°F (371°C) with a vacuum of 27 in. of Hg (686 mm of Hg). The overhead goes to the plant fuel. The bottom may have an ash content as high as 10 to 25 percent, depending on the extent of pretreatment and feed stock characteristics. The bottoms are also higher in sulfur, nitrogen, oxygen and acidity than the feed stock. Finally, lead is concentrated in the bottoms, which may have a lead content of 5 to 15 percent.[36] The middle cut, or lube distillate, is sent to a finishing process (caustic clay treatment or hydrotreatment) and sold as lube oil. The properties of oil processed by vacuum distillation are listed in Table A1.

The distillation process is advantageous because more than one cut may be taken off the middle of the tower to produce several products with different viscosities. One can expect a 70 percent yield from a

---

[30] *Waste Oil Study: A Report to the Congress*, PB257693 (EPA, April 1974), pp 35–37.

[31] *Waste Oil Study*, p 40.

[32] G. J. Mascetti and H. M. White, *Utilization of Used Oils*, Final Report, U.S. Department of Energy Contract FY-76-C-03-1101-003/ATR7873841 (August 1978).

[33] *Waste Oil Study*, p 44.

[34] *Waste Oil Study*, pp 44–45.

[35] *Waste Oil Study*, p 45.

[36] *Waste Oil Study*, p 46.

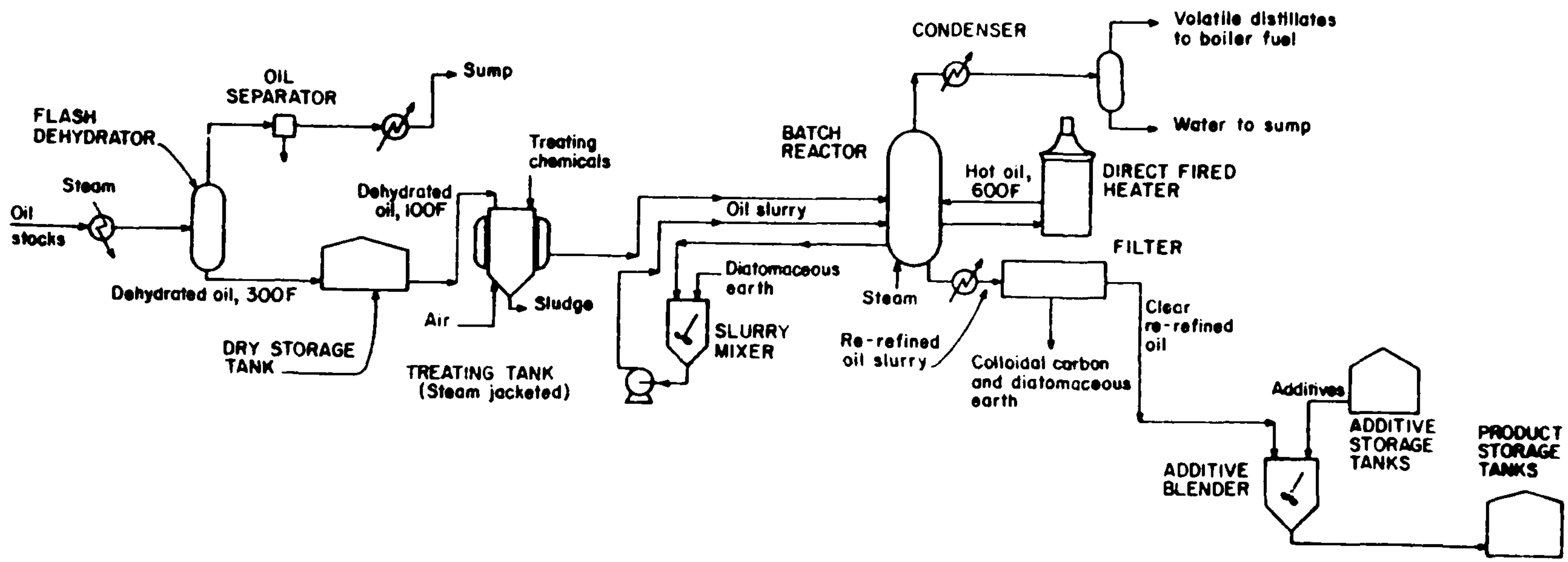


Figure A1. Acid-clay process. (From *A Technical and Economic Study of Waste Oil Recovery, Part III Economic, Technical and Institutional Barriers to Waste Oil Recovery*, PB23760 [EPA, October 1973].)

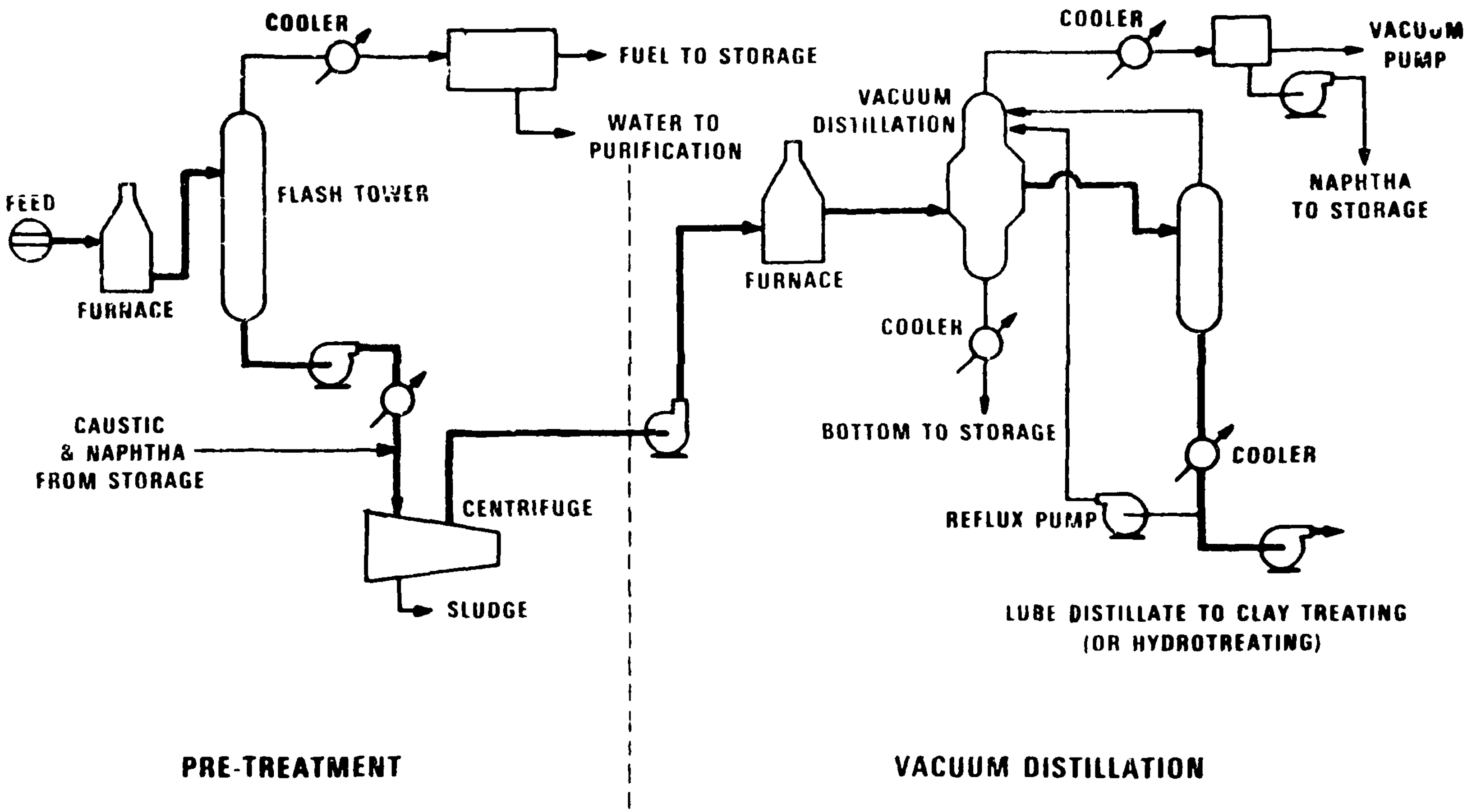


Figure A2. Vacuum distillation of crankcase waste oil. (From *Waste Oil Study: A Report to the Congress*, PB257693 [EPA, April 1974].)

Table A1

Properties of Used Lubricating Oil Processed by Vacuum Distillation

(From M. L. Whisman, J. W. Goetzinger, and F. O. Cotton, *Waste Lubricating Oil Research: Some Innovative Approaches to Reclaiming Used Oil* [U.S. Bureau of Mines, 1974], p 17.)

Property		New Oil	Used Oil	Processed Oil	Reformulated Oil
Sp gr, 60/60 F		0.878	0.897	0.869	0.881
Viscosity					
SUS, 100 F		280	265	149	265
SUS, 210 F		61.2	58.0	42.9	54.6
CCS*	poise	16.2	NA**	12.8	20.2
Viscosity index		178	165	90	137
Carbon residue		1.1	4.3	0	1.1
Sulfated ash	percent	1.13	2.82	nil	1.28
Flash point	F	355	220	375	365
Pour point	do	35	35	NA**	NA
Nitrogen	percent	0.021	0.091	0.025	0.087
Sulfur	do	0.30	0.32	0.14	0.32
Pentane insoluble	do	0.05	1.18	0.03	0.05
Antifreeze	ppm	NA	neg	NA	NA
Saponification No.		2.72	11.0	1.70	5.46
Gasoline dilution	percent	0.4	3.0	0	NA
Total acid No.		1.27	4.00	0.251	2.46
Total base No.		6.85	2.70	0.01	8.02
Falex wear		17	102	63	42
Corrosion (seawater)		Pass	Pass	Pass	Pass
Foam		Pass	Pass	NA	NA
Oxidation stability:					
Appearance		Light brown	NA	Dark brown	Brown
Acid No. increase		0.12	NA	4.48	0.13
Pentane insoluble increase		.6	NA	13.7	1.0
Viscosity (SUS,100°F) increase		0.02	NA	0.05	0.01
Metal concentration, ppm:					
Ba		162	150	0	22
Ca		3,430	3,600	0	1,850
Mg		20	47	0	600
Na		5	18	0	5
P		470	600	NA	NA
Zn		359	461	31	1,248
Al		1	14	0	NA
Cr		0	10	0	NA
Cu		<1	4	1	NA
Fe		1	149	0	NA
K		7	7	0	NA
Mn		<1	2	0	NA
Ni		0	2	0	NA
Pb		0	10,420	105	NA
Si		3	12	5	NA
Sn		0	10	0	NA
V		0	0	0	NA

Hydrocarbon Analysis: Property	New Oil	Used Oil	Processed Oil
Recovery, percent	100	100	[illegible]
Paraffins			
Recovered oil basis:			
Percent	80.3	80.0	84.[illegible]
Difference, percent	0	.37	4.61
Original oil basis:			
Percent	80.3	80.0	64.7
Difference, percent	0	.37	19.43
Monoaromatics			
Recovered oil basis:			
Percent	12	11.4	[illegible]
Difference, percent	0	5.79	14.88
Original oil basis:			
Percent	12.1	11.4	7.9
Difference, percent	0	5.79	34.71
Diaromatics			
Recovered oil basis:			
Percent	3.8	3.8	2.7
Difference, percent	0	0	28.95
Original oil basis:			
Percent	3.8	3.8	2.1
Difference, percent	0	0	44.74
Polyaromatic and polar			
Recovered oil basis:			
Percent	3.9	4.9	3.0
Difference, percent	0	+25.64	23.08
Original oil basis:			
Percent	3.9	4.9	2.3
Difference, percent	0	+25.64	41.03

*Cold-cranking simulator (apparent viscosity)
**Not available

vacuum distillation re-refining process, which is the most that can be attained with the acid-clay process. The product quality is comparable to that of the acid-clay process.[37]

Solvent Extraction and Clay Treatment

A propane extraction re-refining process is shown in Figure A3. The general treatment scheme is thermal dehydration, precipitation and solvent extraction, vacuum distillation, acid and clay treatment, and filtration.

Propane is used to selectively extract the base lube stock from additives and impurities. The propane-to-feed stock ratio must be 15 to 20:1 for a high quality product. The propane-oil mixture is removed from the extractor, and the propane is flashed from the oil and recycled. The residue at the unit bottom is a dark, asphaltic substance containing oxidized hydrocarbons and suspended solids.

The recovered lube oil next undergoes an acid-clay treatment similar to that described earlier. Because a significant amount of contamination has been removed, the acid and clay doses are only half of what would be used in an acid-clay re-refining process. The final step is filtration.[38]

The wastes from the process are the distillation bottoms, acid sludge, and spent clay. Even though the sludge and clay quantities are smaller than those from an acid-clay process, the disposal problem is significant because of the waste's characteristics. The color and color stability qualities of the product, however, are superior to that of an acid-clay process.[39]

Phillips Re-Refined Oil Process

The Phillips Petroleum Co. has developed the Phillips Re-Refined Oil Process (PROP). Phillips sells modular, skid-mounted PROP units that can treat 2, 5, and 10 million gallons per year, at costs of $1.8, $3.1, and $4.3 million, respectively.

The process begins by mixing diammonium phosphate (DAP) with heated oil to remove the metals. Metallic phosphates are formed and removed by filtration. Trace inorganics are then removed by mixing the oil with hydrogen, percolating it through a bed of clay, and passing it over a nickel molybdate catalyst. The treated oil is flashed, cooled, and put through a stripper to remove any remaining fuel.

The requirements for a 2 million gallon per year process are 900 lb/hr of 150 psi steam, 85 kW/hr of electricity, 300 gal/hr cooling water, and 0.85 million Btu/hr fuel. According to Philips, the process recovers 90 percent of the waste oil, containing less than 10 ppm metals.

Wastes from the process include the filter cake from the demetallization, which Philips says can be deposited in a sanitary landfill, and some wastewater which can be sent without pretreatment into a sanitary sewer.

Wastewater

Wastewater from re-refining operations originates as water separated from new drain oil, cooling water from heat exchangers, contaminated cooling water, water from condensed steam that contacts the oil, plant runoff water, and water from vent gas scrubbers.[40] The water can be expected to contain some metals as dissolved or suspended solids, as well as dissolved phenols and other organics, and suspended or emulsified oil.[41] Wastewater characteristics depend, of course, on the re-refining process and the feed stock.

Treatment facilities required at a re-refinery depend on cooling water and vacuum facilities, water contamination of the feed stock, runoff problems, land availability, regulations, and local sewage treatment plant availability.[42] Typically, acid-clay and distillation-clay plants are equipped with oil-water separators and neutralization facilities.[43]

Air Pollution

A properly operating re-refinery emits very few air pollutants; sources of these are vents from process and wastewater treatment units, and storage tanks. Emissions may be discharged to a furnace where combustible materials are burned. Any odors from a plant are probably due to esters and other organic compounds containing oxygen and nitrogen. Very low concentrations of organic sulfur compounds may be emitted. Acid-sludge processes may produce SO_2 and SO_3.[44]

---

[37] *Waste Oil Study*, p 37.

[38] *Waste Oil Study*, pp 40-42.

[39] *Waste Oil Study*, p 42.

[40] *Waste Oil Study*, p 46.

[41] *Waste Oil Study*, p 47.

[42] *Waste Oil Study*, p 39.

[43] *Waste Oil Study*, p 46.

[44] *Waste Oil Study*, p 47.

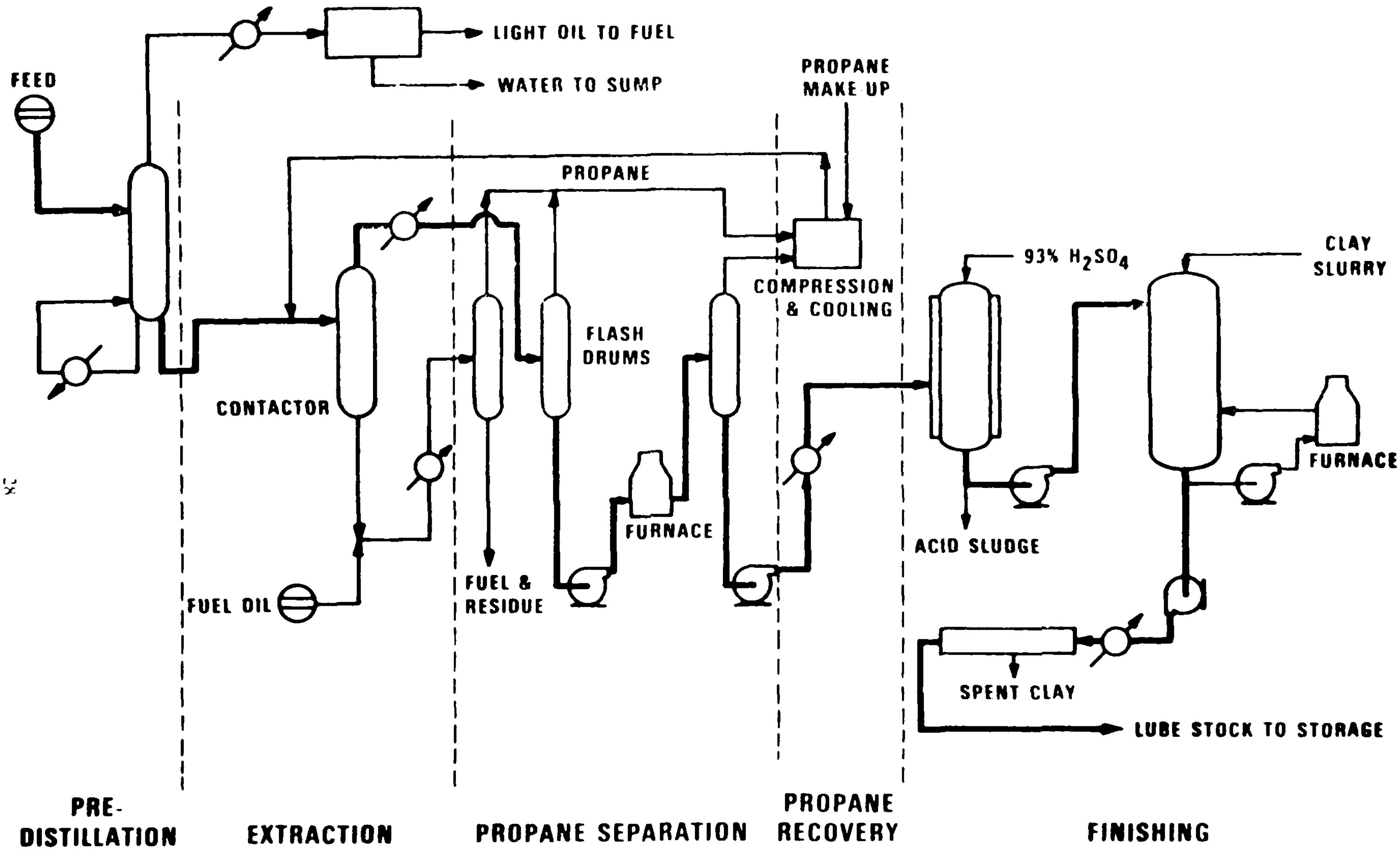


Figure A3. Re-refining by a propane extraction process. (From *Waste Oil Study: A Report to the Congress*, PB257693 [EPA, April 1974].)

APPENDIX B: WASTE OIL RE-REFINERS AND PROCESSORS

Arkansas

Henley Oil Company
P.O. Box 141
Norphlet, Arkansas 71759

Telephone: 501-546-2582
Contact: Charles W. Henley

California

Bayside Oil Corporation
977 Bransten Road
San Carlos, California 94070

Telephone: 415-593-2944
Contact: A. Ray Banks

Leach Oil Company, Inc.
625 East Compton Blvd.
Compton, California 90220

Telephone: 213-323-0116
Contact: George Leach

C. S. McAuley, Inc.
P.O. Box 219
Downey, California 90241

Telephone: 213-869-1179
Contact: C. S. McAuley

Motor Guard Lubricants Co.
4334 East Washington Blvd.
Los Angeles, California 90023
Telephone: 213-268-6877
Contact: H. B. Millard

Fabian Oil Refining Co.
4200 Alameda Avenue
Oakland, California 946[illegible]1

Telephone: 415-532-5051
Contact: Bryan Fabian

Talley Bros. Inc.
2007 Laura Avenue
Huntington Park, California 90255

Telephone: 213-587-1217
Contact: A. W. Talley

Nelco Oil Refining Company
1211 McKinley Avenue
National City, California 92050

Telephone: 714-474-7511
Contact: Otis F. Humphrey

Colorado

Williams Refining Company
5901 North Federal St.
Denver, Colorado 80221

Telephone: 303-433-2497
Contact: Lloyd Cunningham

Florida

Davis Oil Company
Box 1303, 1100 Orange Ave.
Tallahassee, Florida 32302

Telephone: 904-576-3116
Contact: George Davis

Peak Oil Company
Route 3, Box 24
Tampa, Florida 33619

Telephone: 813-626-9116
Contact: John Schroter

Petroleum Products Co.
Box 336, South Park Road
Pembroke Park
Hallendale, Florida 33009

Telephone: 305-989-4000
Contact: Sol Blair

Seaboard Oil Industries of Florida, Inc.
Box 6336
[illegible]ssonville, Florida

Telephone: 904-389-8845
Contact: Byron Cohen

Georgia

Seaboard Industries
Box 47333
5810 New Peachtree Road
Doraville, Georgia 30040

Telephone: 404-458-2241
Contact: Bryon Cohen

Illinois

Central Refining Company
2000 E. Madison
P.O. Box 3063
Springfield, Illinois 62703

Telephone: 217-525-2309
Contact: Martin Pierce

Estech Oil Company
7601 West 47th Street
McCook, Illinois 60525

Telephone: 312-242-2252
Contact: John O'Connell

Indiana

Westville Oil & Mfg. Inc.
Box 58 ?, State Road #2
Westville, Indiana 46391

Telephone: 219-785-2534
Contact: Andrew Carson

Kansas

Coral Refining Company
765 Pawnee Avenue
Kansas City, Kansas 66105

Telephone: 913-281-5454
Contact: Robert O'Blasny

Resource Technology, Inc.
809 S. 7th Street
P.O. Box 5187
Kansas City, Kansas 66119

Telephone: 913-621-0000
Contact: Timothy F. Sparks

Michigan

Dearborn Refining Company
3901 Wyoming Avenue
Dearborn, Michigan 48120

Telephone: 313-VI-3-1700
Contact: Jack W. Epstein, B. Horton

Minnesota

Warden Oil Company
187 Humboldt Avenue North
Minneapolis, Minnesota 55405

Telephone: 612-374-1200
Contact: A. L. Warden

Gopher State Oil Co.
2500 Delaware St., SE
Minneapolis, Minnesota 55405

Telephone: 612-331-5936
Contact: C. H. Romness

Mississippi

Jackson Oil Products Co.
Box 5685
Jackson, Mississippi 39208

Telephone: 601-939-3131
Contact: H. K. Robertson

Missouri

Midwest Oil Refining Co.
1900 Walton Road
St. Louis, Missouri 63114

Telephone: 314-427-2662
Contact: Glen Gettinger

Clayton Chemical Company
10 S. Brentwood Blvd.
Clayton, Missouri 63105

Telephone: 314-726-6320
Contact: Bud Haney

New Jersey

Diamond Head Oil Refining Co.
1427 Harrison Tnpk.
Kearney, New Jersey 07032

Telephone: 201-991-5800
Contact: Martin Morrison

National Oil Recovery Corp.
Box 338
Bayonne, New Jersey 07002

Telephone: 201-437-7300
Contact: Solfred Maizus

New York

George T. Booth & Son, Inc.
76 Robinson Street
North Tonawanda, New York 14120

Telephone: 716-693-0861
Contact: George T. Booth

Northeast Oil Company
327 Edward Drive
Fayetteville, New York

Telephone 315-454-4180
Contact R W Mahler

Newton Refining Corp.
37-80 Review Avenue
Long Island City, New York 11101

Telephone: 212-RA9-7660
Contact: R. W. Mahler

North Carolina

Seaboard Industries, Inc.
South Oil Division
Box 106, Old Burlington Road
Greensboro, North Carolina 27402

Telephone: 919-375-5811
Contact: Byron Cohen

Ohio

Research Oil Refining Company
3680 Valley Road
Cleveland, Ohio 44109

Telephone: 216-749-2777
Contact: Jac Fallenberg, Allan Gressel

Keenan Oil Company
#1 Parkway Drive
Cincinnati, Ohio 45212

Telephone: 513-631-2900
Contact: S. R. Passell

Oklahoma

Double Eagle Refining Co.
Box 11257
Oklahoma City, Oklahoma 73111

Telephone: 405-232-0244
plant: 405-232-6878
Contact: Frank Kerran, Cameron L. Kerran

Oregon

Nu-Way Oil Company
7039 NE 46th Avenue
Portland, Oregon 97218

Telephone: 503-281-9375
Contact: A. L. Geary

Ager & Davis Refining Co.
9901 NE 33rd Street
Portland, Oregon 97211

Telephone: 503-288-3584
Contact: Harold W. Ager, Jr.

Pennsylvania

Berks Associations, Inc.
Box 617
Pottstown, Pennsylvania 19464

Telephone: 215-385-3031
Contact: Lester Schurr

Petrocan Corporation
P.O. Box 547
Valley Forge, Pennsylvania 19481

Telephone: 215-383-5262
Contact: John Cunningham

Tennessee

Gurley Oil Company
Box 2326
Memphis, Tennessee 38102

Telephone: 901-527-9940
Contact: William M. Gurley

Texas

S&R Oil Company
Box 35516
Houston, Texas 77035

Telephone: 713-729-8740
Contact: R. A. Swasey

Capital Supply & Refining Co.
Box 597
1401 West Hurst Blvd.
Hurst, Texas 76053
Contact: Abel Theriot

Texas American Oil
300 Westwall, Suite 1012
Midland, Texas 79701

Telephone: 915-683-4811
Contact: William F. Judd

Utah

Alco Refining Company
133 North First West
Salt Lake City, Utah 84113

Contact: J. R. Mastelotto

Ekotek Lube, Inc.
P.O. Box 2106
Salt Lake City, Utah 84110

Telephone: 801-487-5984

Virginia

A. C. Oil Company
1500 North Quincy St.
Arlington, Virginia 22207

Contact: V. T. Worthington

Washington

QED Corporation
P.O. Box 1004
Renton, Washington 98055

Telephone: 206-271-1540
Contact: William S. Kemp

Wisconsin

Warden Refining Company
1910 South 73rd
W. Allis, Wisconsin 53214

Telephone: 414-541-1000
Contact: M. A. Warden

APPENDIX C: USED OIL AS A BOILER FUEL

Thousands of gallons of used crankcase oil are burned each year in Army boilers. Before an installation makes a commitment to such an oil disposal program, economic and environmental factors must be considered. Although using waste crankcase oil as a supplement or alternative to virgin fuel probably will reduce fuel costs, stack emissions of lead and other pollutants may increase significantly. The combustion performance of the boilers may be impaired. Maintenance may be needed more often because of rapid deposit buildup. Boiler parts may have to be replaced more frequently. Pretreatment of the used oil or boiler modification may eliminate some of the problems but will add to the capital expense of modifying the system. Finally, one must consider the availability (present and future) of used oil; fuel requirements, which are a function of heating season length; and current fuel prices and trends.

Air Pollution Legislation

The Clean Air Act of 1970, with amendments in 1974 and 1977, includes regulations which may affect the burning of used oil as a virgin fuel supplement or alternative. The National Ambient Air Quality Standard (NAAQS) (40 CFR Part 50) for lead is relevant because of the significant concentration of lead in automotive crankcase drainings. The NAAQS for total suspended particles is of concern since the higher ash content of used oil contributes to higher particulate emissions. Since the sulfur content of used oil is not significantly higher than that of virgin fuel oil, the SO_2 emissions from a boiler using recycled fuel will not be higher. Similarly, the NO_x emissions are approximately equal for recycled and virgin fuel.

Where air quality is better than the NAAQS, it is preserved by the Prevention of Significant Deterioration program. This may apply to some boilers modified to burn used oil and to some new boilers. Some modified boilers may not have to undergo the entire permit process.

The Nonattainment Provisions of NAAQS may affect new or modified sources that potentially will emit more than 100 ton/year of any regulated pollutant, or that lie in or affect a nonattainment region.

The New Source Performance Standards of NAAQS apply to new or modified generators with heat inputs greater than 250×10^6 Btu/hr. Army boilers though seldom this large, may be restricted by State and local regulations.

The Toxic Substance Control Act (PL 94-469) regulates used oil burning with respect to PCBs. See 40 CFR Part 761, May 31, 1979 for the most recent PCB regulations.[45]

Used Oil/Virgin Oil Blends

Generally, the values of properties of blends are linear with the proportion in each oil. The exceptions are viscosity and API gravity, important characteristics of a boiler fuel. Viscosity affects the flow rate of the fuel and the spray pattern from the nozzle.[46] The viscosity of a blend can be determined from a plot such as that in Figure C1. The desirable firing temperature for a given viscosity can then be obtained from Figure C1.

The API gravity of an oil (expressed as degrees API) is a function of the specific gravity and can be calculated by the following equation:

$$\text{degrees API} = \frac{141.5}{S\,(60°F)} - 131.5 \quad \text{[Eq C1]}$$

where S = specific gravity of the oil.

API gravity is also related to the heat of the burning oil. Table C1 lists densities and heats of combustion for a range of gravities. Figure C2 graphs the relationship between specific gravity, API gravity, and heating value.

Storage Considerations

The location and design of storage facilities are affected by several safety considerations, including the proximity of heavily traveled areas and compliance with local fire codes.[47] Generally, storage requirements are similar to those for residual fuels.[48] However,

---

[45] *Used Oil Burned as a Fuel*, Vol 1, SW 892 (EPA, 1980), pp 1-6 and 1-7.

[46] T. T. Fu and R. S. Chapler, *Utilization of Navy-Generated Waste Oils as Boiler Fuel Economic Analysis and Laboratory Tests*, Technical Note N-1570 (Naval Construction Batallion Center, 1980), p 14.

[47] P. L. Fink and J. W. Jackson, *Waste POL Disposal Through Energy Recovery* (Air Force Civil Engineering Center, June 1976), p 5.

[48] G. J. Mascetti and H. M. White, *Utilization of Used Oils*, Final Report, U.S. Department of Energy Contract EY-76-C-03-1101-003/ATR7873841 (August 1978), p 10-6.

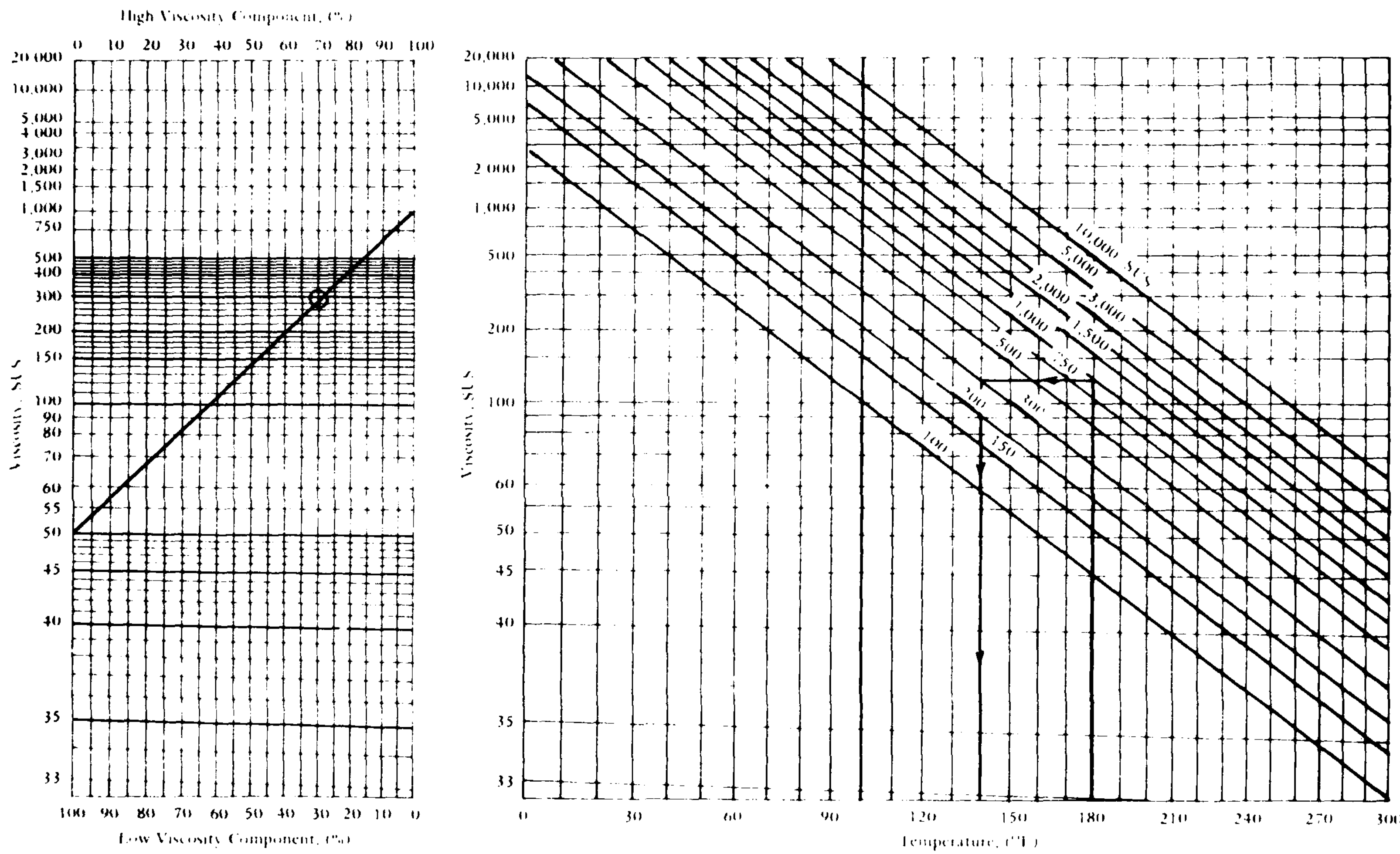


Figure C1. Charts for determination of firing temperatures for blending fuels. (From T. T. Fu and R. S. Chapler. *Utilization of Navy-Generated Waste Oils as Boiler Fuel Economic Analysis and Laboratory Tests.* Technical Note N-1570 [Naval Construction Battalion Center, 1980], p 44.)

Table C1
Gravities, Densities, and Heats of Combustion of Fuel Oils

(From G. J. Mascetti and H. M. White, *Utilization of Used Oils*, Final Report, U.S. Department of Energy Contract EY-76-C-03-1101-003/ATR7873841 [August 1978], p 10-3)

GRAVITY AT 60/60 F (16/16 C)		DENSITY, AT 60 F (16 C)	TOTAL HEAT OF COMBUSTION (At Constant Volume)			NET HEAT OF COMBUSTION (At Constant Pressure)		
DEG API	SPECIFIC GRAVITY	LB PER GAL	BTU PER LB	BTU PER GAL AT 60 F (16 C)	CAL PER G	BTU PER LB	BTU PER GAL AT 60 F (16 C)	CAL PER G
5	1.0366	8.643	18.250	157.700	10.140	17.290	149.400	9.610
6	1.0291	8.580	18.330	157.300	10.180	17.340	148.800	9.650
7	1.0217	8.518	18.390	156.600	10.210	17.390	148.100	9.670
8	1.0143	8.457	18.440	155.900	10.240	17.440	147.500	9.700
9	1.0071	8.397	18.490	155.300	10.270	17.490	146.900	9.720
10	1.0000	8.337	18.540	154.600	10.300	17.540	146.200	9.740
11	0.9930	8.279	18.590	153.900	10.330	17.580	145.600	9.770
12	0.9861	8.221	18.640	153.300	10.360	17.620	144.900	9.790
13	0.9792	8.164	18.690	152.600	10.390	17.670	144.200	9.810
14	0.9725	8.108	18.740	152.000	10.410	17.710	143.600	9.840
15	0.9659	8.053	18.790	151.300	10.440	17.750	142.900	9.860
16	0.9593	7.998	18.840	150.700	10.470	17.790	142.300	9.880
17	0.9529	7.944	18.890	150.000	10.490	17.820	141.600	9.900
18	0.9465	7.891	18.930	149.400	10.520	17.860	140.900	9.920
19	0.9402	7.839	18.980	148.800	10.540	17.900	140.300	9.940
20	0.9340	7.787	19.020	148.100	10.570	17.930	139.600	9.960
21	0.9279	7.736	19.060	147.500	10.590	17.960	139.000	9.980
22	0.9218	7.686	19.110	146.800	10.620	18.000	138.300	10.000
23	0.9159	7.636	19.150	146.200	10.640	18.030	137.700	10.020
24	0.9100	7.587	19.190	145.600	10.660	18.070	137.100	10.040
25	0.9042	7.538	19.230	145.000	10.680	18.100	136.400	10.050
26	0.8984	7.490	19.270	144.300	10.710	18.130	135.800	10.070
27	0.8927	7.443	19.310	143.700	10.730	18.160	135.200	10.090
28	0.8871	7.396	19.350	143.100	10.750	18.190	134.600	10.110
29	0.8816	7.350	19.380	142.500	10.770	18.220	133.900	10.120
30	0.8762	7.305	19.420	141.800	10.790	18.250	133.300	10.140
31	0.8708	7.260	19.450	141.200	10.810	18.280	132.700	10.150
32	0.8654	7.215	19.490	140.600	10.830	18.310	132.100	10.170
33	0.8602	7.171	19.520	140.000	10.850	18.330	131.500	10.180
34	0.8550	7.128	19.560	139.400	10.860	18.360	130.900	10.200
35	0.8498	7.085	19.590	138.800	10.880	18.390	130.300	10.210
36	0.8448	7.043	19.620	138.200	10.900	18.410	129.700	10.230
37	0.8398	7.001	19.650	137.600	10.920	18.430	129.100	10.240
38	0.8348	6.960	19.680	137.000	10.940	18.460	128.500	10.260
39	0.8299	6.920	19.720	136.400	10.950	18.480	127.900	10.270
40	0.8251	6.879	19.750	135.800	10.970	18.510	127.300	10.280
41	0.8203	6.839	19.780	135.200	10.990	18.530	126.700	10.300
42	0.8155	6.799	19.810	134.700	11.000	18.560	126.200	10.310
43	0.8109	6.760	19.830	134.100	11.020	18.580	125.600	10.320
44	0.8063	6.722	19.860	133.500	11.030	18.600	125.000	10.330
45	0.8017	6.684	19.890	132.900	11.050	18.620	124.400	10.340
46	0.7972	6.646	19.920	132.400	11.070	18.640	123.900	10.360
47	0.7927	6.609	19.940	131.900	11.080	18.660	123.300	10.370
48	0.7883	6.572	19.970	131.200	11.100	18.680	122.800	10.380
49	0.7839	6.536	20.000	130.700	11.110	18.700	122.200	10.390

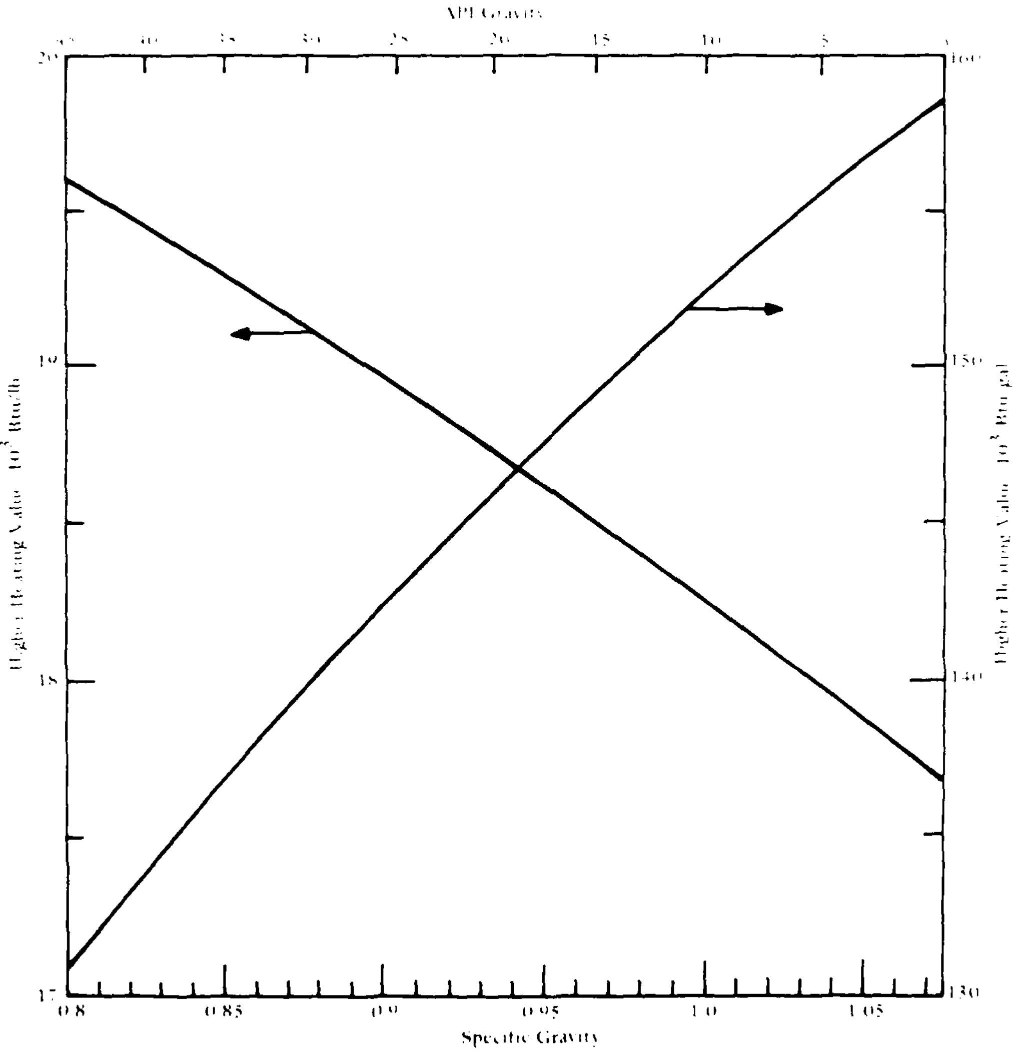


Figure C2. Relationship between higher heating value and specific gravity of petroleum oils at 60°F. (From T. T. Fu and R. S. Chapler, *Utilization of Navy-Generated Waste Oils as Boiler Fuel Economic Analysis and Laboratory Tests*, Technical Note N-1570 [Naval Construction Battalion Center, 1980], p 39.)

contamination of the used oil with readily combustible materials such as nonhalide solvents, glycols, and gasoline may raise the vapor pressure or alter the flash point of the mixture; therefore, special storage facilities may be needed.[49]

Drainage for gravity-settled sediment and water is an essential feature for used oil storage. Aboveground tanks should contain a drain valve, and subsurface tanks should have a suitable suction pump.[50] One of Fort Benning's two used oil storage tanks is shown in Figure C3.

The used oil-virgin oil blend must be mixed or agitated to prevent segregation of the oils over time because of density differences. Military Specification VV-F-815D, "Fuel Oil, Burner," requires either mechanical mixing or in-line blending of oil mixtures.

Boilers

A major consideration is the effect of used oil combustion on the boiler itself. Of course, used oil characteristics such as water and ash content, concentrations of various additives, and the degree of dilution with virgin oil determine the quality of oil actually entering the boiler (Table C2). Short-term burning of used oil probably does not significantly affect combustion efficiency or damage boiler equipment.

Some problems can be expected, though, as a result of long-term used oil combustion: clogging of pipes and nozzles, accelerated corrosion of pipes and tanks, and reduction of heat transfer efficiency. Sediment can clog transfer piping, and water may corrode tanks and pipes, as well as freeze fuel lines.[51] Oil additives may cause a fine lint buildup in barrels and nozzles, ash buildup in the fire box, and deposits on boiler tubes.[52]

Additives are available that can help solve these problems with burning used oil.

Emissions

Army boilers can be generally characterized as industrial-sized. That is, they have a capacity between 50×10^6 and 250×10^6 Btu/hr. Industrial-sized boilers usually burn residual fuel (or No. 4, 5, or 6 fuel oil) at a rate of 70 to 3500 gal/hr with 15 percent excess air.[53] Some are converted stoker-fired coal boilers. Others were constructed as oil-fired boilers. Few have modern air pollution control equipment. Many converted coal boilers have outdated, inefficient cyclones; some boilers have none. Oil-fired boilers usually do not have pollution control equipment. (Virgin fuel oil is a relatively clean-burning fuel.) Therefore, emissions from Army boilers burning used oil probably will be uncontrolled and should be carefully evaluated before a decision is made to fire used oil.

The number of pollutants emitted from a stack is a function of the characteristics of the oil and the combustion equipment itself. Pollutants of concern include lead and other heavy metals from the ash; sulfur, nitrogen, chlorine, and bromine originating from the ash and organic fractions. Also of concern are polynuclear aeromatics (PNAs) and polycyclic organic matter (POMs) from the combustion of fossil fuels. PCBs are not normally found in used oils, but if the used oil has been contaminated, burning it in an Army boiler would be not only harmful to the environment and the health of personnel, but also illegal. Other contaminants that affect emissions include gasoline, glycol antifreeze, pesticides, halides, and other solvents.[54]

Lead Emissions

Lead emissions from burning used oil are a function of the firing rate (liters per hour), lead concentration of the oil, and the percent of that lead which is emitted with the flue gas. Figure C4, data collected by the EPA from 1969 to 1978, shows an inverse relationship between lead emissions and the lead concentration in the total oil (used oil and virgin fuel).

---

[49] *Used Oil Burned as a Fuel*, Vol 1, SW 892 (EPA, 1980), p 4-7.

[50] P. L. Fink and J. W. Jackson, *Waste POL Disposal Through Energy Recovery* (Air Force Civil Engineering Center, June 1976), p 5.

[51] T. D. Coyle and A. R. Siedle, "Metals in Oil: Occurrence and Significance for Reuse of Spent Automotive Lubricating Oils," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979), p 199.

[52] T. T. Fu and R. S. Chapler, *Utilization of Navy-Generated Waste Oils as Boiler Fuel: Economic Analysis and Laboratory Tests*, Technical Note N-1570 (Naval Construction Batallion Center, 1980), pp 1-2.

[53] J. T. Beard, F. A. Lachetta, and L. U. Lilleleht, *Air Pollution Training Institute Course 427: Combustion Evaluation Student Manual*, EPA 450/2-80-063 (EPA, February 1980), p 8-2.

[54] *Used Oil Burned as a Fuel*, p 4-1.

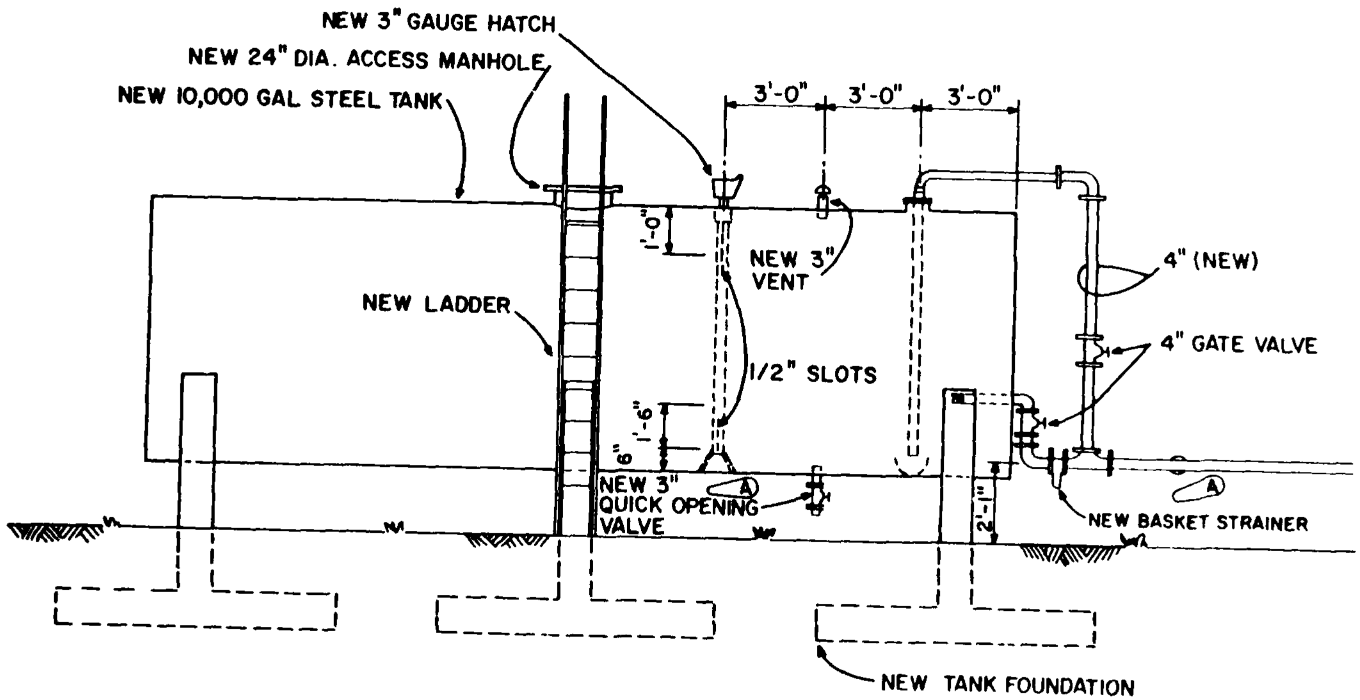


Figure C3. Storage tank at Fort Benning

Table C2
Properties of Virgin Fuel Oil (No. 2 Distillate and No. 6 Residual) and Used Oil (Automotive Crankcase Drainings)

(From G. J. Mascetti and H. M. White, *Utilization of Used Oils*, Final Report, U.S. Department of Energy Contract EY-76-C-03-1101-003/ATR7873841 [August 1978], p 10-4)

Property[a]	Composite Range Values		
	No. 2 Distillate	No. 6 Residual	Used Oil, Crank-case drainings
Gravity, deg API at 60°F	30.2 to 45.3	0.3 to 26.0	20.0 to 27.9
Specific Gravity	0.800 to 0.875	0.898 to 1.022	0.887 to 0.934
Density, lb/gal	6.68 to 7.30	7.5 to 8.5	7.40 to 7.78
Viscosity, SFS at 122°F	-	24 to 350	-
Viscosity, SUS at 100°F	32 to 40	-	37 to 837
Viscosity, Centistokes	1.8 to 4.1	7 to 750	17.3 to 180.6
Pour Point, °F	(-50) to 25	(-10) to 95	< (-40) to (-30)
Flash Point, °F	126 to 204	150 to 270	175 to 415
Heating Value, Btu/gal	130,900 to 141,800	146,100 to (>157,700)	105,555 to 143,360
Heating Value, Btu/lb	18,145 to 19,895	17,410 to (>20,480)	13,571 to 19,300
Neutralization Number, mg KOH/gm	-	-	4.0 to 14.3
Bottom Solids and Water, vol %	0.00 to (<0.1)	0.00 to 2.00	0.1 to 22.0
Sulfur, wt %	0.02 to 0.59	0.3 to 4.0	0.21 to 0.65
Ash, wt %	0.00 to 0.005	0.00 to 0.50	0.03 to 3.78
Silicon, ppm	-	8.2 to 164.0	10 to 875
Calcium, ppm	-	0.7 to 95.0	700 to 3,000
Sodium, ppm	-	1 to 480	16 to 300
Iron, ppm	-	10.5 to 230.0	50 to 2,000
Magnesium, ppm	-	0.4 to 27.9	10 to 1,108
Lead, ppm	-	1.7 to 4.1	800 to 11,200
Vanadium, ppm	-	1 to 380	3 to 39
Copper, ppm	-	0.5	5 to 348
Barium, ppm	-	-	10 to 2,000
Chromium, ppm	-	13.7	3 to 50
Nickel, ppm	-	3 to 118	3 to 30
Aluminum, ppm	-	0.5 to 219	10 to 800
Silver, ppm	-	0.3	1
Titanium, ppm	-	5.5	5 to 30
Molybdenum, ppm	-	2.3	2 to 3
Zinc, ppm	-	-	300 to 3,000
Phosphorus, ppm	-	-	500 to 2,000
Tin, ppm	-	-	5 to 112
Beryllium, ppm	-	-	6
Manganese, ppm	-	-	5 to 10
Cadmium, ppm	-	-	4
Strontium, ppm	-	-	10 to 30
Boron, ppm	-	-	3 to 20

[a]ppm (as the element) = 0.0001 wt %.

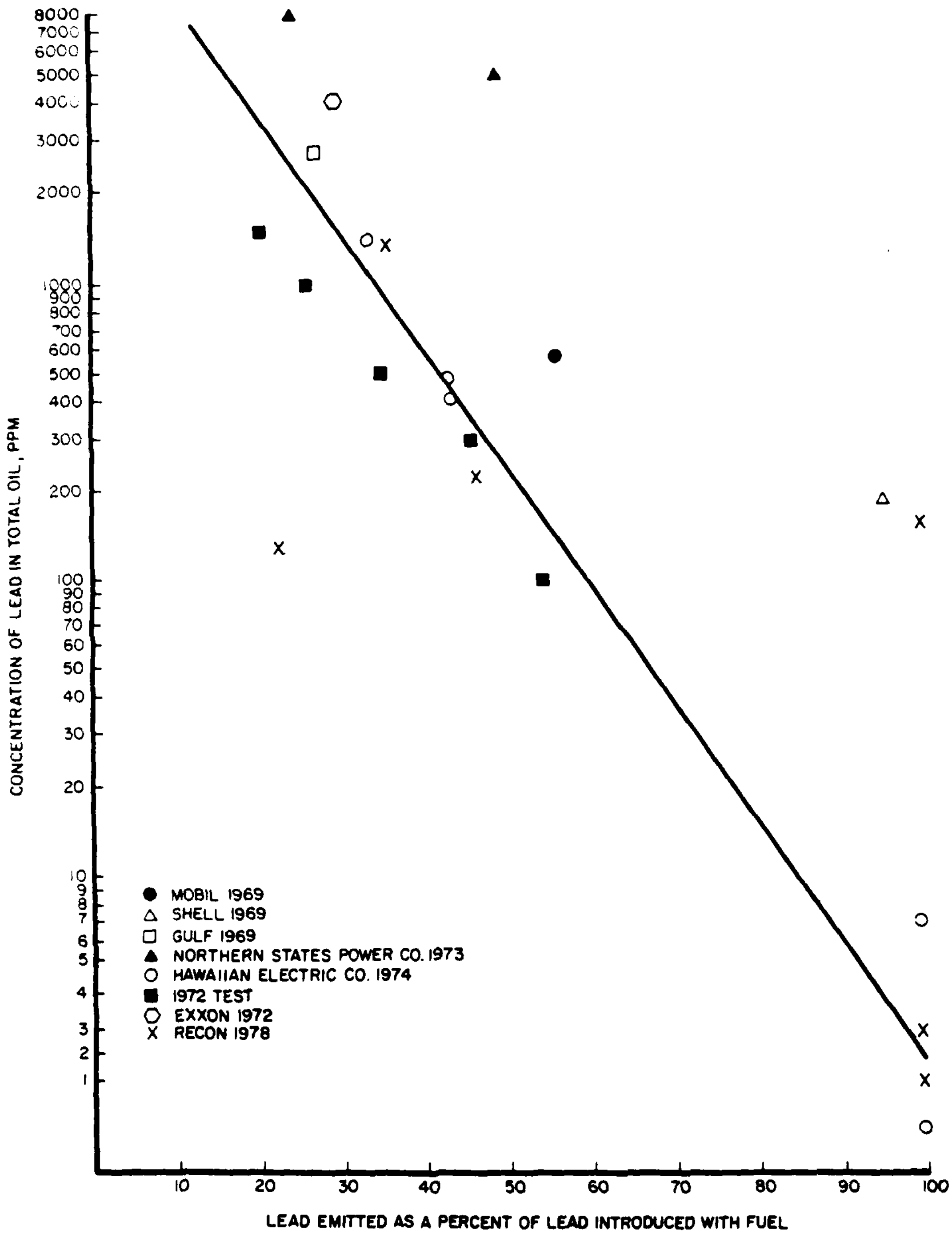


Figure C4. Lead emissions. (From *Used Oil Burned as a Fuel,* Vol 1, SW 892 [EPA, 1980].)

Table C3
Particle Size Distribution of Lead and Other Major Contaminants in Emissions from Waste Oil Combustion

(From G. J. Mascetti and H. M. White, *Utilization of Used Oils*, Final Report, U.S. Department of Energy Contract EY-76-C-03-1101-003/ATR7873841 [August 1978], p 10-15)

Particle Size	Weight Percent Lead	Calcium	Phosphorus	Zinc	Iron	Barium
< 1 micron	76 to 69	10 to 19	23 to 42	56 to 73	2.7 to 36	3.3 to 51
1 to 10 micron	16 to 21	71 to 74	49 to 66	23 to 39	51 to 80	40 to 79
> 10 micron	2.7 to 4.4	10 to 15	8.9 to 10	3.4 to 5.0	13 to 18	8.9 to 18

EPA tests show that from 20 to 100 percent of the lead entering a steam boiler can be expected to be emitted from the stack. Some lead is emitted as an aerosol or vapor, though most is associated with particulates.[55] Table C3 lists the particle size distribution of lead and other major contaminants in emissions from waste oil combustion. Knowing particulate size is important for considering environmental and health effects of pollutants. Smaller particles penetrate deep into the human respiratory tract, whereas larger particulates tend to be removed in the upper tract.[56] Also, if pollution equipment is to be installed, the particle size distribution is an important design parameter.

In one EPA test, 90 percent of the lead emitted was associated with particulates smaller than 1 micron. Nearly 75 percent of this lead was recovered from boiler tubes, and 25 percent was emitted directly into the atmosphere. Furnace deposits may be emitted to the atmosphere during soot blowing, or may be removed during furnace cleaning.[57]

Other Pollutants

SO_x emissions are a function of the sulfur content of the used oil. Since used crankcase oil usually has little sulfur, a blend of high sulfur residual oil and used oil can actually reduce SO_x emissions and corrosion of internal boiler surfaces.[58]

SO_x emissions will not be dealt with in this report because they are not specific to used oil combustion. Similarly, NO_x emissions are a function of combustion temperature and the nitrogen in the oil, rather than being related to oil contamination.[59]

In *Used Oil Burned as a Fuel*, the EPA combines air pollution and used oil composition criteria to characterize a used oil which may be burned with minimal environmental risk. The results are presented in Table 8. In the same publication, the EPA suggests uncontrolled emission factors for used oil and used oil-virgin oil blends. The emission factors are consistent with those previously published for the selected pollutants (Table C4).[60]

Modeling

Before building storage facilities and modifying boilers to burn oil, it might be useful to model the lead emissions that would result from burning used oil. The model could help in calculating the maximum lead concentration allowable in the oil. This maximum depends on the ambient lead concentration before the boiler emissions' contribution, and on the lead emitted as a function of lead concentration in the fuel. The amount of lead could be reduced, then, either by pretreatment or by reducing the ratio of used oil to virgin fuel. Waste oil managers may contact CERL for information about the modeling procedure.

Pretreatment

Pretreatment of the used oil can significantly improve oil quality, thereby reducing boiler damage

[55] *Used Oil Burned as a Fuel*, p 4-4.

[56] H. C. Perkins, *Air Pollution* (McGraw-Hill, Inc., 1974), p 336.

[57] *Used Oil Burned as a Fuel*, p 4-3.

[58] P. D. Spawn and P. F. Fennelly, "An Updated Look at the Fuel Potential of Waste Automotive Oil," *Proceedings of a Workshop on Measurements and Standards for Recycled Oil-II*, Gaithersburg, Maryland, National Bureau of Standards, 1977 (NBS Special Publication 556, 1979), p 51.

[59] J. T. Beard, F. A. Iachetta, and L. U. Lilleleht, *Air Pollution Training Institute Course 427, Student Manual*, EPA 450/2-80-063 (EPA, February 1980), p 8-3.

[60] *Used Oil Burned as a Fuel*, p 4-4.

Table C4
Uncontrolled Emission Factors for Combustion

(From *Used Oil Burned as a Fuel,* Vol 1, SW 892 [EPA, 1980])

Pollutant	Emission Factors, lb/10^3 gal EPA AP-42 (3)	Suggested for Used Oil*	Comments
Pb	Waste oil 0.0075(L)	0.0075(L)	L = ppm Pb in oil. Based on 100% emission at 7.5 lbs/gal oil density.
Pb	Virgin oils 0.0042(L) (residual, distillate)		Based on substantially less than 100% emissions. Ave L = 1.0 for residual oils, and 0.1 for distillate oils.
	Coal 1.6(l) lb/10^3 ton (bituminous, anthracite)	—	Based on 80% emissions.
Particulate	Waste oil 75(A)	75(A)	A = % ash in oil. Based on 100% equivalent emission at 7.5 lbs/gal oil density.
Particulate	Virgin oils #6 10(S) + 3 #5 10 #4 7 Ind./comm. dist. 2 Domestic dist. 2.5		S = % sulfur in oil. Note that used oil with approx. 0.13% ash would be equivalent to #5 fuel oil.
Other metals in particulate	Not included	0.0075(L)	L = ppm metal in oil.
SO_2	Residual oil 157(S) Distillate oil- 142(S)	150(S)	S = % sulfur in oil. Suggested factor for used oil based on 100% conversion of S to SO_2 for 7.5 lb/gal oil density.
SO_3	All virgin oils - 2S	2S	S = % sulfur in oil.
NO_x (total as NO_2)	Residual oils: Power plant tangential - 50 Power plant other - 105 Ind./comm. 22+400(N)2 Ind./comm. dist. 22 Domestic dist. -18	22	N = % nitrogen in oil. See AP-42 1.3 for further discussion of NO_x emissions.
Hydrocarbons (total, as CH_4)	All virgin oils - 1	1	RECON measurements ranged from 14 to 165 $\mu g/g$ fuel (113 avg) as compared to 1 lb/10^3 gal (approx. 133 $\mu g/g$) emission factor.
PNA's**	Not included	0.0075	Corresponds to 1 $\mu g/g$. Insufficient data to determine how PNA emissions for used oils compare to virgin oils.
HCl**	Not included	77(C) max.	C = % chlorine in oil.
HBr**	Not included	76(B) max.	B = % bromine in oil.
P (in particulate)	Not included	75(P) max.	P = % phosphorous in oil.
CO	5	5	CO emissions vary with combustion control on all fuels. No CO emission detected by Orsat analyses in RECON tests 1–4. Determinations by Kitagawa detector tube in runs 5–9 showed 10 to 100 ppm in the flue gas or an average of about 5 lb/10^3 gal.

*And for used oil/virgin oil mixture.
**Suggested for these pollutants.

over an extended time. The treatment may be as simple as screening to remove large foreign objects and sediment. The most common treatment is settling to remove water and sediment. More sophisticated reprocessing consists of centrifugation, filtration, atmospheric or vacuum distillation, or chemical treatment.[61]

GLOSSARY

additive: A chemical added to improve oil.

aniline number (or point): Temperature (°C) at which mixtures of petroleum and aniline become miscible. The value is a measure of sludge solvent power. A low aniline number indicates high solvent power.

asphalt: A solid hydrocarbon found as a natural deposit. When subjected to distillation to remove light fractions, crude oil of high asphaltic content leaves asphalt as a residue. Asphalt is dark brown or black and is a solid at normal temperatures.

BS&W: Abbreviation for bottom solids and water. Found in petroleum crudes, undistilled fuels and used oils.

flash point: Maximum temperature at which oil can be stored and handled without serious fire hazard.

lubricating oil: That fraction of the crude oil which is sold to reduce friction in any industrial or mechanical application. This term includes re-refined oil.

neutralization number: The number of milligrams of potassium hydroxide needed to neutralize 1.0 g of an oil sample.

pour point: Primary indication of the lowest temperature at which an oil can be stored and still flow under very low forces.

reclaiming or reprocessing: Physical treatment with or without chemical treatment to prepare fuels from used oils.

recycled oil: Any used oil which is reused for any purpose. This includes oil which is re-refined, reclaimed, burned, or reprocessed.

re-refined oil: Used oil from which the physical and chemical contaminants acquired through use have been removed by a re-refining process.

Saybolt Universal Viscosity: Time (in seconds) it takes to run 60 mL of a fluid through a standard size orifice. Usually reported at 100°F, 150°F, or 210°F.

Saybolt Furol Viscosity: Same as Saybolt Universal Viscosity, except the orifice through which the fluid passes is larger; 62 seconds. Saybolt Furol Seconds (SFS) = 600 seconds SUS.

used oil: Any oil which has been refined from crude oil and used, and which has therefore been physically or chemically contaminated.

virgin oil: Oil products manufactured from previously unused petroleum products.

viscosity: Measure of a fluid's resistance to shear or angular deformation. Indicates relative ease of flow.

viscosity index: An empirical measure of the effect of temperature on the viscosity of oils. A low index indicates a large change with temperature.

METRIC CONVERSIONS

1 gal = 3.785 L

°C = 5/9 (°F-32)

1 lb = 0.37 kg

1 psi = 6.895 X 10^3 Pa

1 Btu = 0.293 W

1 ton = 0.9 MT

1 mi = 1.6 km

1 in. = 25.4 mm

---

[61] *Used Oil Burned as a Fuel*, Vol 1, SW 892 (EPA, 1980), pp 2-6, 2-7.

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-CCP
ATTN: DAEN-CW
ATTN: DAEN-CWE
ATTN: DAEN-CWM-R
ATTN: DAEN-CWO
ATTN: DAEN-CWP
ATTN: DAEN-MP
ATTN: DAEN-MPC
ATTN: DAEN-MPE
ATTN: DAEN-MPO
ATTN: DAEN-MPR-A
ATTN: DAEN-RD
ATTN: DAEN-RDC
ATTN: DAEN-RDM
ATTN: DAEN-RM
ATTN: DAEN-ZC
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM

FESA, ATTN: Library 22060

FESA, ATTN: DET III 79906

US Army Engineer Districts
ATTN: Library
Alaska 99501
Al Batin 09616
Albuquerque 87103
Baltimore 21203
Buffalo 14207
Charleston 29402
Chicago 60604
Detroit 48231
Far East 96301
Fort Worth 76102
Galveston 77550
Huntington 25721
Jacksonville 32232
Japan 96343
Kansas City 64106
Little Rock 72203
Los Angeles 90053
Louisville 40201
Memphis 38103
Mobile 36628
Nashville 37202
New Orleans 70160
New York 10007
Norfolk 23510
Omaha 68102
Philadelphia 19106
Pittsburgh 15222
Portland 97208
Riyadh 09038
Rock Island 61201
Sacramento 95814
San Francisco 94105
Savannah 31402
Seattle 98124
St. Louis 63101
St. Paul 55101
Tulsa 74102
Vicksburg 39180
Walla Walla 99362
Wilmington 28401

US Army Engineer Divisions
ATTN: Library
Europe 09757
Huntsville 35807
Lower Mississippi Valley 39180
Middle East 09038
Middle East (Rear) 22601
Missouri River 68101
New England 02154
North Atlantic 10007
North Central 60605
North Pacific 97208
Ohio River 45201
Pacific Ocean 96858
South Atlantic 30303
South Pacific 94111
Southwestern 75202

Army Europe
HQ, 7th Army Training Command 09114
ATTN: AETTG-DEH (5)
HQ, 7th Army ODCS/Engr. 09403
ATTN: AEAEN-EH (4)
V. Corps 09079
ATTN: AETVDEH (5)
VII. Corps 09154
ATTN: AETSDEH (5)
21st Support Command 09325
ATTN: AEREH (5)
Berlin 09742
ATTN: AEBA-EN (2)
Southern European Task Force 09168
ATTN: AESE-ENG (3)
Installation Support Activity 09403
ATTN: AEUES-RP

8th USA, Korea
ATTN: EAFE (8) 96301
ATTN: EAFE-Y 96358
ATTN: EAFE-ID 96224
ATTN: EAFE-4M 96208
ATTN: EAFE-H 96271
ATTN: EAFE-P 96259
ATTN: EAFE-T 96212

ROK/US Combined Forces Command 96301
ATTN: EUSA-HHC-CFC/Engr

USA Japan (USARJ)
Ch, FE Div, AJEN-FE 96343
Fac Engr (Honshu) 96343
Fac Engr (Okinawa) 96331

Rocky Mt. Area

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

Western Area Office, CE
Vandenberg AFB, CA 93437

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10996
ATTN: Facilities Engineer
ATTN: Dept of Geography & Computer Science
ATTN: DSCPER/MAEN-A

Engr. Studies Center 20315
ATTN: Library

AMMRC, ATTN: DRXMR-WE 02172

USA ARRCOM 61299
ATTN: DRCIS-RI-I
ATTN: DRSAR-IS

DARCOM - Dir., Inst., & Svcs.
ATTN: Facilities Engineer
ARRADCOM 07801
Aberdeen Proving Ground 21005
Army Matls. and Mechanics Res. Ctr.
Corpus Christi Army Depot 78419
Harry Diamond Laboratories 20783
Dugway Proving Ground 84022
Jefferson Proving Ground 47250
Fort Monmouth 07703
Letterkenny Army Depot 17201
Natick R&D Ctr. 01760
New Cumberland Army Depot 17070
Pueblo Army Depot 81001
Red River Army Depot 75501
Redstone Arsenal 35809
Rock Island Arsenal 61299
Savanna Army Depot 61074
Sharpe Army Depot 95331
Seneca Army Depot 14541
Tobyhanna Army Depot 18466
Tooele Army Depot 84074
Watervliet Arsenal 12189
Yuma Proving Ground 85364
White Sands Missile Range 88002

DLA ATTN: DLA-WI 22314

FORSCOM
FORSCOM Engineer, ATTN: AFEN-FE
ATTN: Facilities Engineer
Fort Buchanan 00934
Fort Bragg 28307
Fort Campbell 42223
Fort Carson 80913
Fort Devens 01433
Fort Drum 13601
Fort Hood 76544
Fort Indiantown Gap 17003
Fort Irwin 92311
Fort Sam Houston 78234
Fort Lewis 98433
Fort McCoy 54656
Fort McPherson 30330
Fort George G. Meade 20755
Fort Ord 93941
Fort Polk 71459
Fort Richardson 99505
Fort Riley 66442
Presidio of San Francisco 94129
Fort Sheridan 60037
Fort Stewart 31313
Fort Wainwright 99703
Vancouver Bks. 98660

HSC
ATTN: HSLO-F 78234
ATTN: Facilities Engineer
Fitzsimons AMC 80240
Walter Reed AMC 20012

INSCOM - Ch, Instl. Div.
ATTN: Facilities Engineer
Arlington Hall Station (2) 22212
Vint Hill Farms Station 22186

MDW
ATTN: Facilities Engineer
Cameron Station 22314
Fort Lesley J. McNair 20319
Fort Myer 22211

MTMC
ATTN: MTMC-SA 20315
ATTN: Facilities Engineer
Oakland Army Base 94626
Bayonne MOT 07002
Sunny Point MOT 28461

NARADCOM, ATTN: DRDNA-F 01760

TARCOM, Fac. Div. 48090

TRADOC
HQ, TRADOC, ATTN: ATEN-FE
ATTN: Facilities Engineer
Fort Belvoir 22060
Fort Benning 31905
Fort Bliss 79916
Carlisle Barracks 17013
Fort Chaffee 72902
Fort Dix 08640
Fort Eustis 23604
Fort Gordon 30905
Fort Hamilton 11252
Fort Benjamin Harrison 46216
Fort Jackson 29207
Fort Knox 40121
Fort Leavenworth 66027
Fort Lee 23801
Fort McClellan 36205
Fort Monroe 23651
Fort Rucker 36362
Fort Sill 73503
Fort Leonard Wood 65473

TSARCOM, ATTN: STSAS-F 63120

USACC
ATTN: Facilities Engineer
Fort Huachuca 85613
Fort Ritchie 21719

WESTCOM
ATTN: Facilities Engineer
Fort Shafter 96858

SHAPE 09055
ATTN: Survivability Section, CCB-OPS
Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

Fort Belvoir, VA 22060
ATTN: ATZA-DTE-EM
ATTN: ATZA-DTE-SW
ATTN: ATZA-FE
ATTN: Engr. Library
ATTN: Canadian Liaison Office
ATTN: IWR Library

Cold Regions Research Engineering Lab
ATTN: Library

ETL, ATTN: Library 22060

Waterways Experiment Station 39180
ATTN: Library

HQ, XVIII Airborne Corps and 28307
Ft. Bragg
ATTN: AFZA-FE-EE

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

Norton AFB 92409
ATTN: AFRCE-MX/DEE

Tyndall AFB, FL 32403
AFESC/Engineering & Service Lab

NAFEC
ATTN: RDT&E Liaison Office
Atlantic Division 23511
Chesapeake Division 20374
Southern Division 29411
Pacific Division 96860
Northern Division 19112
Western Division 94066
ATTN: Sr. Tech. FAC-03T 22332
ATTN: Asst. CDR R&D, FAC-03 22332

NCEL 93041
ATTN: Library (Code L08A)

Defense Technical Info. Center 22314
ATTN: DDA (12)

Engineering Societies Library 10017
New York, NY

National Guard Bureau 20310
Installation Division

US Government Printing Office 22304
Receiving Section/Depository Copies (2)

ENE Team Distribution

Chief of Engineers
ATTN: DAEN-MPO-B
ATTN: DAEN-MPO-U
ATTN: DAEN-MPR
ATTN: DAEN-MPZ-A

US Army Engineer district
New York 10007
ATTN: Chief, NANEN-E
ATTN: Chief, Design Br.
Pittsburgh 15222
ATTN: Chief, Engr Div
Philadelphia 19106
ATTN: Chief, NAPEN-E
Norfolk 23510
ATTN: Chief, NAOEN-D
Huntington 25721
ATTN: Chief, ORHED-H
Wilmington 28401
ATTN: Chief, SAWEN-PM
ATTN: Chief, SAWEN-E
Charleston 29402
ATTN: Chief, Engr Div
Savannah 31402
ATTN: Chief, SASAS-L
Jacksonville 32232
ATTN: Env Res Br
Mobile 36128
ATTN: Chief, SAMEN-C
Vicksburg 39180
ATTN: Chief, Engr Div
Louisville 40201
ATTN: Chief, Engr Div
St. Paul 55101
ATTN: Chief, ED-H
Chicago 60604
ATTN: Chief, NCCCO-R
ATTN: Chief, NCCED-H
ATTN: Chief, NCCPD-ER
ATTN: Chief, NCCPE-PES
St. Louis 63101
ATTN: Chief, ED-B
ATTN: Chief, ED-D
Kansas City 64106
ATTN: Chief, Engr Div
Omaha 68102
ATTN: Chief, Engr Div
Little Rock 72203
ATTN: Chief, Engr Div
Tulsa 94102
ATTN: Chief, Engr Div
Fort Worth 76102
ATTN: Chief, SWFED-D
ATTN: Chief, SWFED-MA/MR
Galveston 77550
ATTN: Chief, SWGAS-L
ATTN: Chief, SWGCO-M
Los Angeles 90053
ATTN: Chief, SPLED-E
San Francisco 94105
ATTN: Chief, Engr div
Sacramento 95814
ATTN: Chief, SPKED-D
Far East 96301
ATTN: Chief, Engr Div
Seattle 98124
ATTN: Chief, NPSEN-FM
ATTN: Chief, EN-DB-SE
ATTN: Chief, NPSEN-PL-WC
ATTN: Chief, NPSEN-PL-ER
Walla Walla 99362
ATTN: [illegible], Engr Div
Alaska 99[illegible]
ATTN: Chief, NPASA-R

US Army Engineer Division
New England 02154
ATTN: Chief, NEDED-E
North Atlantic 10007
ATTN: Chief, NADEN-T
Middle East (Rear) 22601
ATTN: Chief, MEDED-T
South Atlantic 30303
ATTN: Chief, SADEN-Te

US Army Engineer Division
Huntsville 35807
ATTN: Chief, HNDED-CS
ATTN: Chief, HNDED-ME
ATTN: Chief, HNDED-SR
Lower Mississippi Valley 39180
ATTN: Chief, PD-R
Ohio River 45201
ATTN: Chief, Engr Div
North Central 60605
ATTN: Chief, Engr Planning Br
Missouri River 68101
ATTN: Chief, MRDED-T
Southwestern 75202
ATTN: Chief, SWDED-TH
South Pacific 94111
ATTN: Chief, SPDED-TG
ATTN: Laboratory
Pacific Ocean 96858
ATTN: Chief, Engr Div
ATTN: Chief, PODED-MP
ATTN: Chief, PODED-P

5th US Army 78234
ATTN: AFKB-LG-E

6th US Army 94129
ATTN: AFKC-EN

7th US Army 09407
ATTN: AETTM-HRD-EHD

US Army Foreign Science & Tech Center
ATTN: Charlottesville, VA 22901
ATTN: Far East Office 96328

USA ARRADCOM
ATTN: DRDAR-LCA-OK

West Point, NY 10996
ATTN: Dept of Mechanics
ATTN: Library

Ft. Belvoir, VA 22060
ATTN: Learning Resources Center
ATTN: ATSE-TD-TL (2)
ATTN: British Liaison Officer (5)

Ft. Clayton Canal Zone 34004
ATTN: DFAE

Ft. A. P. Hill 24502
ATTN: FE

Ft. Leavenworth, KS 66027
ATTN: ATZLCA-SA

Ft. Lee, VA 23801
ATTN: DRXMC-D (2)

Ft. McPherson, GA 30330
ATTN: AFEN-CD

Ft. Monroe, VA 23651
ATTN: ATEN-AD (3)
ATTN: ATEN-FE-E
ATTN: ATEN-FE-U

Aberdeen Proving Ground, MD 21005
ATTN: AMXHE
ATTN: HSE-EW

Naval Facilities Engr Command 22332
ATTN: Code 04

US Naval Oceanographic Office 39522
ATTN: Library

Naval Training Equipment Center 32813
ATTN: Technical Library

Port Hueneme, CA 93043
ATTN: Morell Library

Bolling AFB, DC 20332
AF/LEEEU

WASH DC 20330
AF/RDXT

Little Rock AFB
ATTN: 314/DEEE

Patrick AFB, FL 32925
ATTN: XRQ

Tinker AFB, OK 73145
2854 ABG/DEEE

Tyndall AFB, FL 32403
AFESC/PRT

Bldg Research Advisory Board 20418

Dept of Transportation
Tallahassee, FL 32304

Dept of Transportation Library 20590

Transportation Research Board 20418

Airports and Construction Services Dir
Ottawa, Ontario, Canada K1A 0N8

Division of Building Research
Ottawa, Ontario, Canada K1A 0R6

National Defense Headquarters
Ottawa, Ontario, Canada K1A 0K[illegible]

[illegible], John [illegible]
[illegible] waste [illegible] at Army installations [illegible]
[illegible] Champaign, Il [illegible] Construction Engineering Research Laboratory [illegible]
[illegible] from NTIS [illegible]
[illegible] Technical Report [illegible]

[illegible] waste [illegible]
[illegible] III [illegible] Army [illegible] Engineering
Research Laboratory. Technical Report [illegible]

MED

83