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# UTILIZATION OF USED OIL

Final Report

By
G. J. Mascetti
H. M. White

MASTER

August 1978

Work Performed Under Contract No. EY-76-C-03-1101-003

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Government Support Operations
The Aerospace Corporation
El Segundo, California

## U. S. DEPARTMENT OF ENERGY

## Division of Industrial Energy Conservation

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ATR-78(7384)-1
Distribution Category UC-95e

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THE AEROSPACE CORPORATION
Government Support Operations
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U. S. DEPARTMENT OF ENERGY
Division of Industrial Energy Conservation
Washington, D. C. 20545

Contract No. EY-76-C-03-1101
Project Agreement No. 3

DOE Project Monitor: Dr. Jerome F. Collins

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# ACKNOWLEDGEMENTS

Appreciation is acknowledged for the assistance and guidance provided by Dr. Jerome F. Collins of the Department of Energy (DOE), Division of Industrial Energy Conservation, who was the program monitor during the latter stages of the study, and by Mr. E. Eugene Ecklund of the DOE, Division of Transportation Energy Conservation, who initiated the program and acted as program monitor during the initial phases of the study. The cooperation and assistance provided by many members of industry and government agencies (Appendix A) are also gratefully acknowledged.

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# SPONSOR'S FOREWORD

Effective utilization of drained auto and industrial oils can make a tangible and significant contribution to the Nation's energy conservation efforts. Presently, some oils in relatively low amounts are recovered for use, but overall, effective and beneficial reuse is in decline. A desirable goal is to reverse this decline.

The specific object of this study is to assess two classes of drained oil utilization: (1) as a re-refined lubricating oil, and (2) as a boiler or furnace fuel. As with any complex problem, there is rarely any one best way. Either alternative can be achieved by any of a number of different processes and all require varying degrees of pretreatment.

The contractor was directed to develop a general analytic methodology to analyze and compare the energy, materials, and economic factors associated with several generic process types required to utilize waste drain oils either as lubricants or as fuels. Analyses were then performed on a chosen set of processes. This study reports on that effort.

Reviews of and comments on the findings were solicited from representatives of the four groups seen as having direct and significant interest in the problem of waste oil and its utilization. The groups represented were:

- American Petroleum Institute
- Association of Petroleum Re-refiners
- Society of Automotive Engineers, Inc.
- U. S. Environmental Protection Agency

There was general agreement on the coverage and utility of the data, with some clarifying comments on a few definitions. Variations of interpretation of the findings, leading to differing conclusions, stem primarily from the underlying assumptions chosen in making those interpretations. Two critical areas of assumption, which still lack sufficient specificity, are: (1) the energy requirement to produce a unit quantity of virgin lube oil, and (2) the constraints and likely controls to be imposed on uses of untreated waste oil -- a material which may be obtained from a variety of sources. The letter responses are included in Appendix B without further comment.

In conclusion, I feel that the information and data brought together and analyzed in this report will be of great value in making effective decisions in the Department of Energy Conservation programs. The report should be of value to others also having an interest in waste oil and its utilization by providing to them a reference source of basic process engineering, economic data and status reports on the important current and pending processes, together with a disciplined way to analyze this issue.

Jerome F. Collins, Chief
Alternative Materials Utilization Branch
Office of Assistant Secretary
Conservation and Solar Applications

# AUTHOR'S FOREWORD

This report, prepared by The Aerospace Corporation for the Department of Energy, Division of Industrial Energy Conservation*, provides an assessment of the potential impact on petroleum consumption due to available options for utilizing used oil. The technical base for this assessment is derived from a comprehensive review of current information related to lubricating oils and processes for refining from virgin crude and re-refining from used oil.

Both the technical and economic aspects of re-refining used oil are addressed. Institutional and legislative impediments to the re-refining of used oil are also considered. Finally, an analysis is made to determine the impact on crude petroleum consumption that would occur if (1) all used oil would be re-refined and recycled as lube oil or (2) all used oil would be burned to recover its heat content.

This report is organized in two parts, preceded by an Executive Summary. Part I provides data on the status of the re-refining industry and makes projections of the future demand for re-refined oil. In addition, it provides descriptions for virgin oil and re-refined oil processes, and addresses institutional impacts on re-refining, utilization of used oil as a fuel, and resource conservation. Part II presents an assessment of the economics of producing re-refined oil, and of the energy conservation potential of re-refining. Also provided is a summary of major findings and recommendations for future DOE action in the area of lube oil re-refining.

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* The study was initiated under the sponsorship of DOE's Division of Transportation Energy Conservation.

# ABSTRACT

This report assesses the potential impact of re-refining used automotive and industrial lubricating oils on the national petroleum consumption. The technical base for this assessment is derived from a comprehensive review of the processes utilized in re-refining used oil and those processes used to produce lube oil from crude. Both existing and recently proposed processes are considered. Additionally, an extensive review of processes described in the patent literature is provided.

Re-refining processes are surveyed and evaluated. Process descriptions are provided; hardware is identified; and process energy and economic requirements are calculated. Factors affecting the profitability of a re-refining operation are discussed. Economic projections of the demand for lube oil and the ability to satisfy this demand from crude oil are made and the value of lube oil as a vital resource and the need for conservation are addressed. Other factors related to re-refining are discussed, including lube oil characteristics, degradation, lube oil quality and engine sequence testing, and legislative and institutional barriers. Finally, an energy assessment of used oil utilization is made. Two options are considered in this assessment: (1) All used oil is re-refined and recycled back to lube oil; (2) All used oil is burned to recover its heat content.

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# EXECUTIVE SUMMARY

## 1. INTRODUCTION

This report, prepared by The Aerospace Corporation for the Department of Energy, Division of Industrial Energy Conservation, provides an assessment of the potential impact on petroleum consumption of available options for utilizing used oil. The technical base for this assessment is derived from a comprehensive review of current information related to lubricating oils and processes for refining from virgin crude and re-refining from used oil.

Re-refining processes are surveyed and evaluated. It must be emphasized that a degree of uncertainty is associated with some of the process evaluations, which will be reflected in the final conclusions. Process data have been furnished based on experience ranging from laboratory "glassware," to pilot level, to full production level by different people using different methods of materials, energy, and financial accounting. With the foregoing always to be kept in mind, process descriptions are provided, hardware identified, and process energy and economic requirements calculated. Factors affecting the profitability of a re-refining operation are discussed. Economic projections of the demand for lube oil, the ability to satisfy this demand, the value of lube oil as a vital resource, and the need for conservation are addressed.

An energy assessment of the utilization options is made by use of a closed-loop energy model, and re-refining processes are rated in terms of their potential for energy conservation. Finally, potential petroleum savings are projected to the year 2000.

## 2. BACKGROUND

Large amounts of lube oil are used in the transportation and industrial sectors of the United States. These oils deteriorate in use, are replaced periodically, and require disposal. In the past, much of the used lube oil was re-refined and recycled. With a decline in re-refining for various technical and economic reasons, other disposal methods such as dumping or burning were utilized. The negative environmental effects of these methods fostered interest by governmental agencies seeking safe disposal methods for protection of the environment.

However, with a growing awareness in the finite limits of natural resources and energy, interest in the available options for utilizing used oil for purposes of energy and resource conservation has grown. Primary interest in this study is related to its use either as a fuel, or by re-refining, for use as a lubricant. Because re-refining processes require the supply of energy and waste a portion of the used oil feedstock, the energy conservation potential of re-refining is intimately related to the specific re-refining process used. Therefore, an energy conservation evaluation of the utilization options for used oil also requires an examination of re-refining processes.

## 3. LUBE OIL CHARACTERISTICS

Lubricating oils may be generically grouped into four categories: (1) mineral oils, (2) synthetic oils, (3) animal oils, and (4) vegetable oils. Today, the use of petroleum-derived lube oils predominates in the transportation and industrial sectors. Synthetic lube oils, which are manufactured by chemically reacting petroleum-derived or other source materials, have been utilized for many years in specialty applications, such as jet aircraft engine lubrication. In general, animal oils and vegetable oils are used in the transportation and industrial sectors only in combination with a base petroleum oil, and their function is that of an "additive".

Historically, lubricating oils have been classified by generic attributes of the petroleum crude from which they were derived: (1) paraffinic or Pennsylvania, (2) naphthenic or Coastal (asphaltic), and (3) intermediate or Mid-Continent. Actually, the bulk of the hydrocarbons found in lubricating oils are naphthenics. The natural lubricating properties of mineral oils have proven insufficient for use in modern automotive and industrial applications. Therefore, these oils are compounded with additives to provide the desired service characteristics. Additives function as detergents, oxidation inhibitors, rust inhibitors, antifoamants, and so on.

Lube oils degrade in use due to additive depletion, thermal stress, and contamination from external and internal sources. Generally, all mechanisms are normally slow processes, are interrelated, and occur simultaneously. Eventually, lube oils reach the end of their service life and must be replaced. Periodic replacement of lube oil results in the generation of large amounts of used oil, which poses a disposal problem. Used lubricating oil, particularly automotive crankcase oil, is highly contaminated with both liquid and solid materials including water, gasoline, wear metals, lead and other metallic compounds, oxidation products, acids, and carbonaceous particles.

## 4. USED OIL GENERATION AND DISPOSAL

In 1975, approximately 2.8 billion gallons of lube oil were produced, including 1.2 billion gallons of automotive lube oil, 1.0 billion gallons of industrial lube oil (including railroads), and 0.6 billion gallons of other industrial oils (predominantly process oils). It is estimated that approximately 50 percent of this total amount of lube oil is consumed in service. Recoverability as a used oil depends on the application. While some process oils are totally consumed, other oils have high recovery rates, with transformer oil approaching 100 percent recoverability. Therefore, about 1.4 billion gallons of used lube oil were generated and disposed of in 1975. Disposal was accomplished in many different ways, including combustion, road oiling, manufacture of asphaltic paving materials, secondary lubricating applications, and re-refining. A large fraction is unaccounted for and is presumably dumped, often in an indiscriminate manner. Currently, re-refining accounts for only about 4 percent of the total amount of used oil generated in the U. S. transportation and industrial sectors.

## 5. BACKGROUND OF THE RE-REFINING INDUSTRY

Initially, the re-refining industry, which dates back to the early part of this century, utilized simple dehydration/clarification techniques for the removal of liquid and solid contaminants from used oil. Processes of this type proved satisfactory for the unsophisticated oil formulations and lubrication demands prevalent at that time. After World War II, the re-refining industry expanded continuously, reaching a peak in 1960 when 300 million gallons were produced, which amounted to about 14 percent of the lube oil market. Since then, a rapid decline has occurred as a result of various technical and economic factors, with only 50 million gallons of re-refined oil produced in 1975, amounting to only 2 percent of the lube oil market. Consistent with this decline in production volume, the number of re-refiners declined from about 150 to less than 40.

One of the major factors causing this decline was the introduction of additives to satisfy the severe performance and service life demands placed upon modern lubricants. Although the acid-clay process, which had found near universal acceptance since its introduction in the 1930s, was capable of producing a quality product, the increased severity of treatment required to process used oils resulted in (1) a reduction in product yield, (2) a rise in production costs, and (3) a growing inability of the re-refiners to compete with virgin products produced from low-priced crude oil. Additionally, disposal of process wastes in an economical and environmentally safe manner became more difficult and costly. As a result, interest in new, advanced, re-refining processes has increased.

## 6. RE-REFINING PROCESSES

Re-refining processes currently used or proposed are based on petroleum refining and chemical production techniques covering the spectrum from acid contacting to various degrees of hydrogen treatment. The attempt to economically remove contaminants from used oil has led investigators to explore a wide variety of physical and chemical treatments.

### 6.1 EXISTING PRODUCTION PROCESSES

To date, four re-refining processes have reached at least some production plant utilization. These processes include (1) acid-clay, (2) clay, (3) caustic-clay treatment, and (4) propane solvent extraction. These processes are briefly described in the following paragraphs.

> Acid-Clay Process: Currently, the acid-clay process shown in Figure 1 is in predominant use by re-refiners, particularly for processing highly contaminated used oil such as crankcase drainings. This process, which has the potential for producing a good product, is relatively simple and adaptable to batch operations typical of small-volume re-refiners. In principle, it involves the treatment of used oil with sulfuric acid, which preferentially attacks oxygen compounds, asphaltic and resinous substances, other nitrogen and sulfur-based compounds, and soluble metallic components, while leaving paraffinic and naphthenic hydrocarbons essentially intact. Color and odor bodies are subsequently removed through treatment with activated clay.
>
> In this process, the used oil is first pumped to a flash dehydrator where bound water and light hydrocarbons are removed at elevated temperatures. The overhead mixture of water and oil is condensed and separated, with the oil going to storage and the water to treatment prior to disposal. Dehydration is an initial step common to most re-refining processes. The dehydrated oil is then cooled to 100°F and transferred to a vertical tank with a conical bottom where 2 to 6 volume percent (depending on the type of feedstock) of 93 percent sulfuric acid is added. The mixture is agitated for several hours and the sludge is allowed to

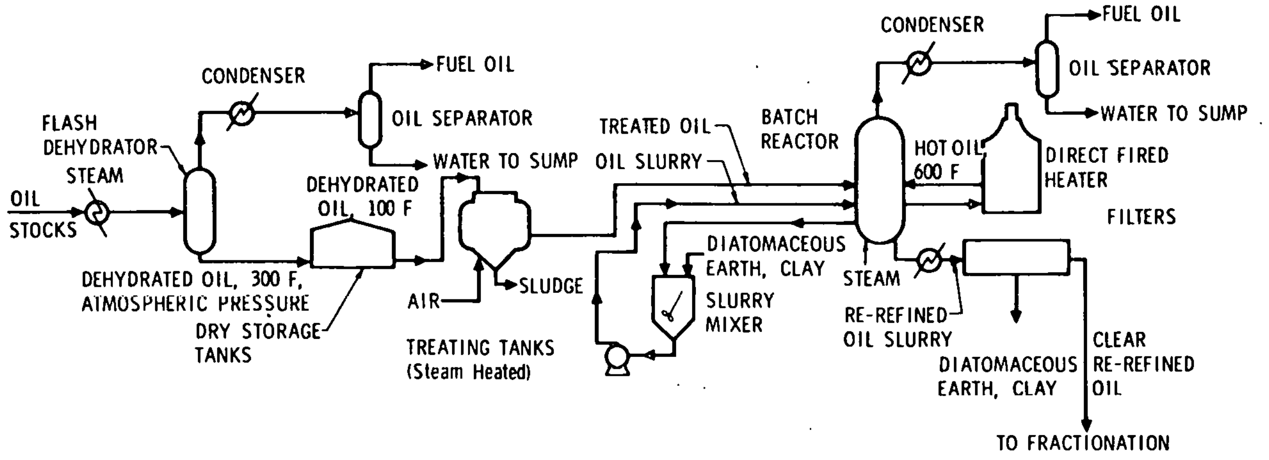


Figure 1. Schematic of Acid-Clay Type Re-Refinery

settle for 1 to 3 days. Temperatures of 100°F are maintained in the settling tank. The sludge, containing unreacted acid and most of the used oil contaminants, is then drained, and the partially purified oil pumped to an atmospheric tower. The oil is circulated through an external heater to raise its temperature to about 500 to 600°F. Steam is introduced to remove acidic and malodorous compounds, and any remaining light ends. Heating is discontinued and about 0.2 to 0.6 pounds of activated clay and, frequently, a lesser amount of diatomaceous earth, which serves as a filter precoat, are added per gallon of oil treated. Upon cooling to below 300°F, the oil-clay mixture is filtered for clay removal. Steam stripping and clay contacting are finishing steps which are also used in other processes. The resulting lube oil product is a neutral solvent base stock which is then blended to achieve the desired viscosity, and compounded to meet specific service requirements.

Clay Process: The clay process is a simple process, consisting of dehydration, followed by clay contacting. In the past, when automotive lube oils were uncompounded and drain intervals were short, the clay process was widely used. While this process does not appear suitable for processing today's crankcase drainings into automotive lube oil, and does not see much use in this manner (one known re-refiner is currently using it to produce automotive lube oil), it still represents one of the major re-refining processes used for industrial oils.

Caustic-Clay Treatment: Caustic treatment, or washing, has been used as a re-refining process both by itself and in conjunction with clay contacting. Similar to the clay process, use of the caustic process declined with the advent of highly compounded motor oils, because the re-refined product was considered to be a poor lube oil base stock for automotive applications. One re-refiner currently uses caustic treatment, in conjunction with a silicate, followed by clay contacting, for the production of automotive lubes. This process is illustrated in Figure 2, which shows a recycle loop intended to increase oil recovery and minimize chemical costs.

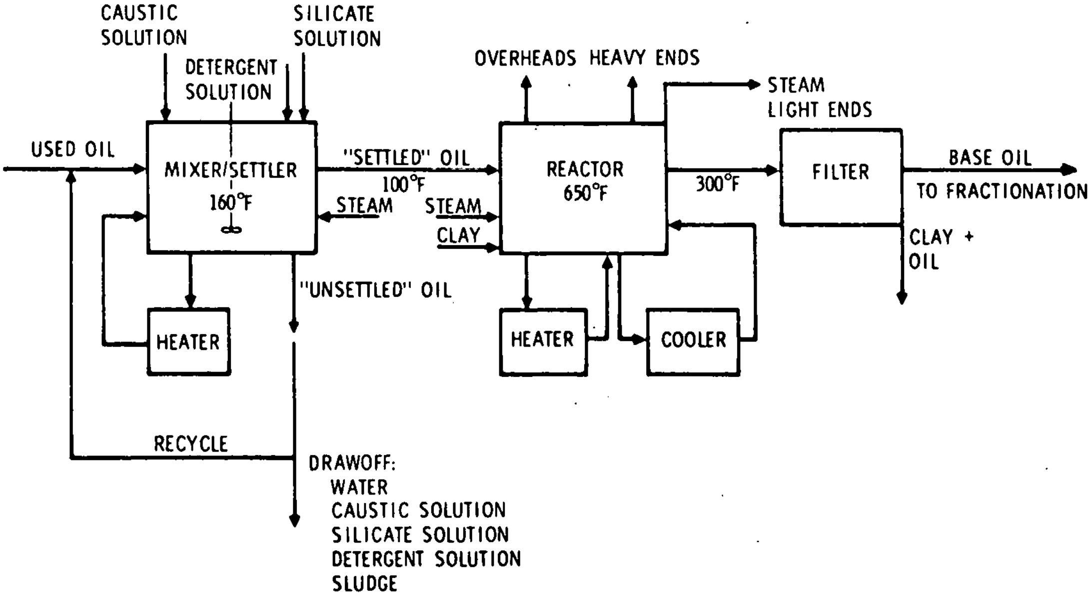
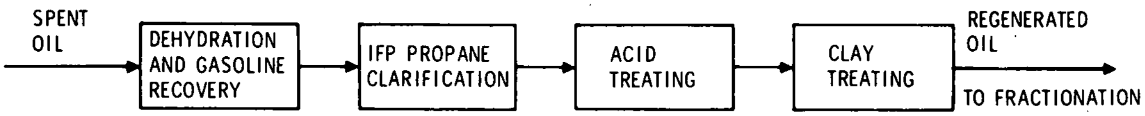
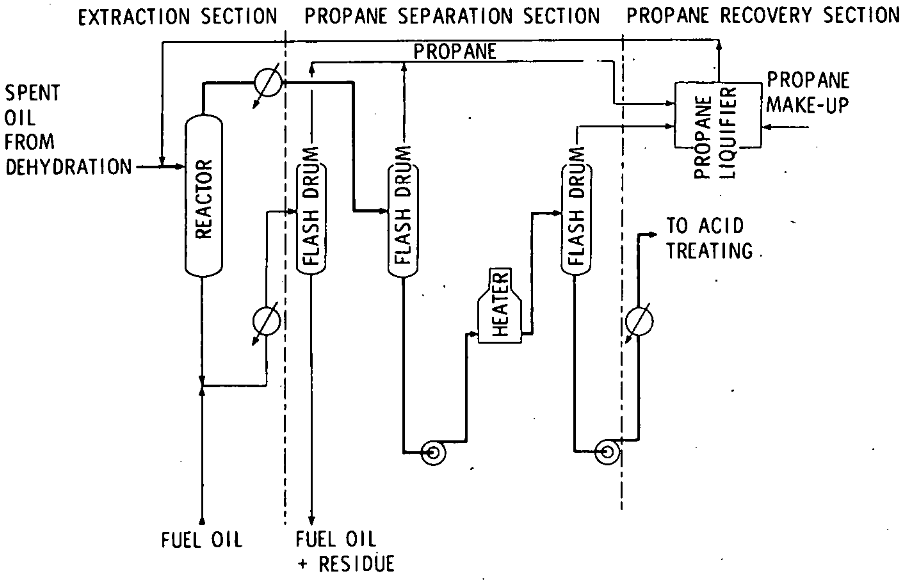


Figure 2. Schematic for the Caustic-Clay Process

Propane Solvent Extraction: Although solvent extraction systems have been studied for many years, the Selectopropane process developed by the French Petroleum Institute (and available for licensing) is the only process of this kind which has been placed in production to date. This process, which is illustrated in Figure 3, utilizes propane to selectively dissolve and extract the desirable paraffinic and naphthenic hydrocarbons from used oil. Dehydrated and preheated used oil is mixed with recycled liquid propane (oil-to-propane ratio 1 to 15) and sent to



a. IFP PROPANE CLARIFICATION OF USED CRANKCASE OIL



b. IFP PROPANE CLARIFICATION SECTION

Figure 3. Schematics for the Propane Solvent Extraction Process

a reactor operating at a pressure of several hundred psi. The propane-oil mixture is removed from the top while the contaminant-containing insoluble residue is drawn from the reactor bottom. Propane is recovered by vaporization at reduced pressure and returned to the process after compression and liquefaction. The partially purified oil is then further processed in an acid-clay finishing step, followed by fractionation

## 6.2 PROPOSED PROCESSES

A number of new processes have been proposed for re-refining used oils. These processes fall either into the category of distillation or solvent extraction, and are in various stages of development, ranging from laboratory testing to production plant construction. To date, none has reached commercial operation.

### 6.2.1 Distillation

Distillation is the basis of a number of re-refining processes which are under development or have appeared in the literature. In this context, the term "distillation" denotes processes in which distillation represents the major contaminant removal step, and not those processes which rely on a pretreatment step for primary contaminant removal, or those that include distillation for secondary contaminant removal or for fractionation. A comparatively simple pretreatment step and subsequent finishing step (hydrotreating or clay contacting) may be used in conjunction with distillation. In principle, distillation consists of heating oil under vacuum conditions to separate the feedstock into a lube oil distillate, a light overhead fraction, and a non-volatile heavy bottom containing a major part of the contaminants.

A distillation-hydrotreating re-refinery is shown schematically in Figure 4. The used oil is dehydrated and then heated in a furnace before entering a high-vacuum distillation column. The lube distillate is then mixed

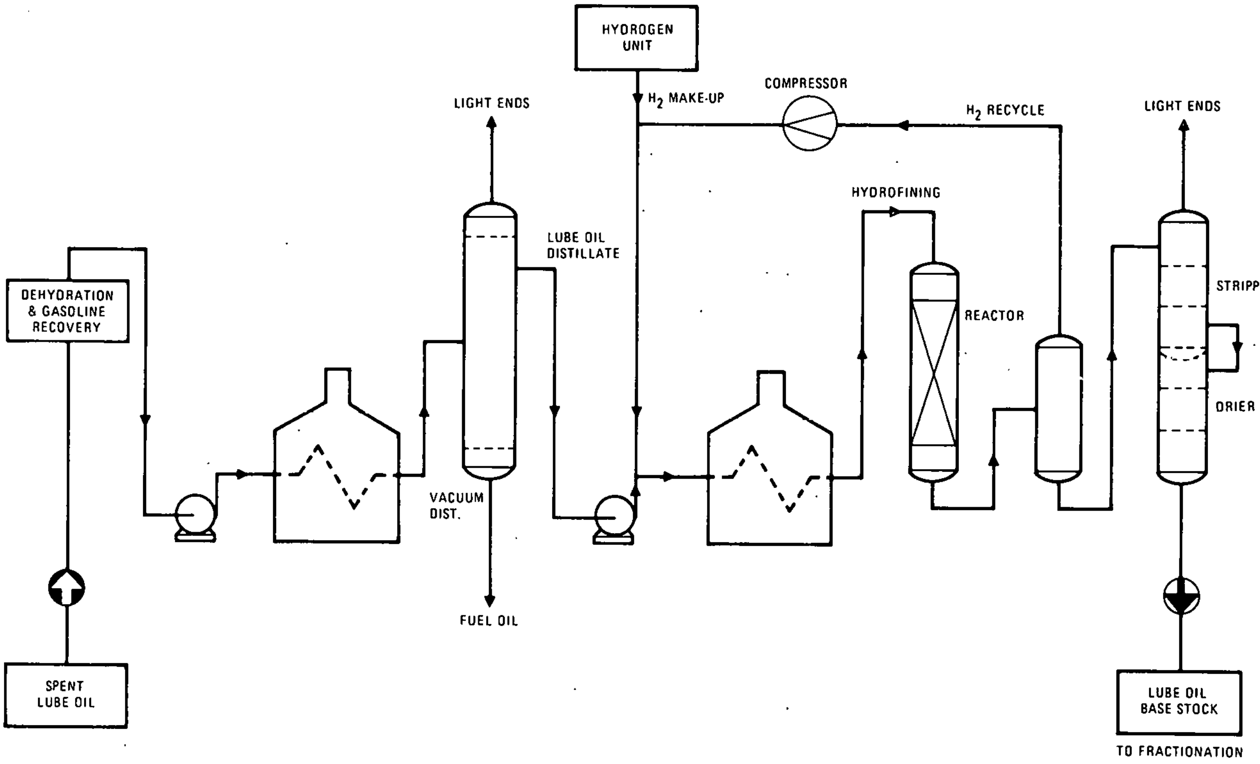


Figure 4. Distillation-Hydrotreating Process

with hydrogen, heated further in a furnace, and then sent to a reactor where it passes through a fixed catalyst bed operating at elevated pressure. The reactor products enter a flash drum where the hydrogen-rich gas is separated and compressed for recycling. The oil is then steam-stripped and dried in a vacuum column. The distillation-hydrotreating process described is similar to that planned for implementation in the Netherlands by Kinetics Technology International (KTI); a demonstration plant is under construction by KTI for Haberland of West Germany.

Two other processes employing distillation are in various stages of implementation. NORCO, Bayonne, New Jersey, has a plant under construction in which distillation and hydrotreating will be used without any pretreatment to reduce operating costs. Intended use of the re-refined product is for cutting oil rather than motor oil. The Gladieux Refining Company, Fort Wayne, Indiana, has a pilot plant in operation and is in the process of designing a distillation-hydrotreating re-refinery for industrial oils. The process used by Gladieux appears to be unique in that severe hydrotreating precedes rather than follows distillation. *

ECO-Separator, Ventura, California, is currently investigating a distillation process based on a thin film heat exchanger having high heat transfer rates and flow velocities. Coking and fouling problems are believed to be manageable because heat exchanger volumes are small and adaptable to low-cost automatic cleaning. The pilot plant in operation is capable of dehydrating at a rate of 800 barrels per day and distilling at the rate of 350 barrels per day. Currently, no effort is being made to market the product of this experimental plant as lube oil; all of the product produced is disposed of as fuel.

Although distillation processes are considered as proposed processes, two of these processes are in production. The first is that of Berks Associates of Pottstown, Pennsylvania, who use conventional distillation followed by clay treatment to produce automotive lube oil. A mild caustic pretreatment is used prior to distillation and a narrow boiling point cut is taken to minimize fouling, which permits plant operation for six months prior to shutdown for cleaning. Low lube oil yield, resulting from the narrow cut, is offset

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*Recent communications indicate that NORCO has been liquidated and Gladieux may have changed its plans.

economically by marketing the relatively large amounts of overheads and bottoms produced. The second process is that of Coral Refining, Kansas City, Kansas. The distillation process is proprietary, with no details available. It is termed the O'Blasny Process, after its developer. Conventional dehydration and clay finishing are used in conjunction with the proprietary distillation process. It is claimed that fouling of the distillation unit does not occur. The plant in operation has a 5-million-gallon-per-year capacity and is currently producing railroad journal oil, with engine sequence tests on a motor oil product currently in progress.

### 6.2.2 Solvent Extraction

In addition to the propane solvent extraction process described in Section 6.1, numerous other solvent processes have been proposed. Two of these processes are briefly described in the following paragraphs.

> BERC Solvent Process: The solvent extraction process developed by the Bartlesville Energy Research Center (BERC), Bartlesville, Oklahoma, and shown in Figure 5, uses a mixture of isopropyl alcohol, methyl ethyl ketone, and butyl alcohol. After dehydration, the used oil is combined with the solvent mixture at a ratio of 1 to 3. After settling, the oil-solvent mixture is separated from the precipitated sludge. Both the oil-solvent mixture and sludge are then passed through strippers for solvent recovery. The partially purified oil then goes to distillation and clay treatment. The BERC process has progressed to the pilot plant level, with pre-design cost estimates completed for a production plant. The State of Iowa is currently conducting fleet tests using oil produced by BERC technology, which appears to be providing satisfactory service after 15 months' use.

> MZF Solvent Process: The MZF solvent extraction process, proposed by MZF Associates and shown in Figure 6, uses an aqueous isopropyl alcohol solution in conjunction with small amounts of alkali. In this process, nondehydrated used oil diluted with naphtha is mixed at a 1 to 1 ratio with the solvent mixture. After settling, the oil-naphtha top layer and bottom alcohol-water layer, which contains the sludge, are separated. Each phase is stripped to recover the naphtha and alcohol for recycling. According to the inventor, the phase separation technique used in lieu of centrifugation requires no expenditure of energy and is based on use of a small amount of a low-cost, readily available chemical as a de-emulsifier. To date, the process has not been developed beyond a limited amount of small-scale laboratory testing, and it still remains to have its technical viability established.

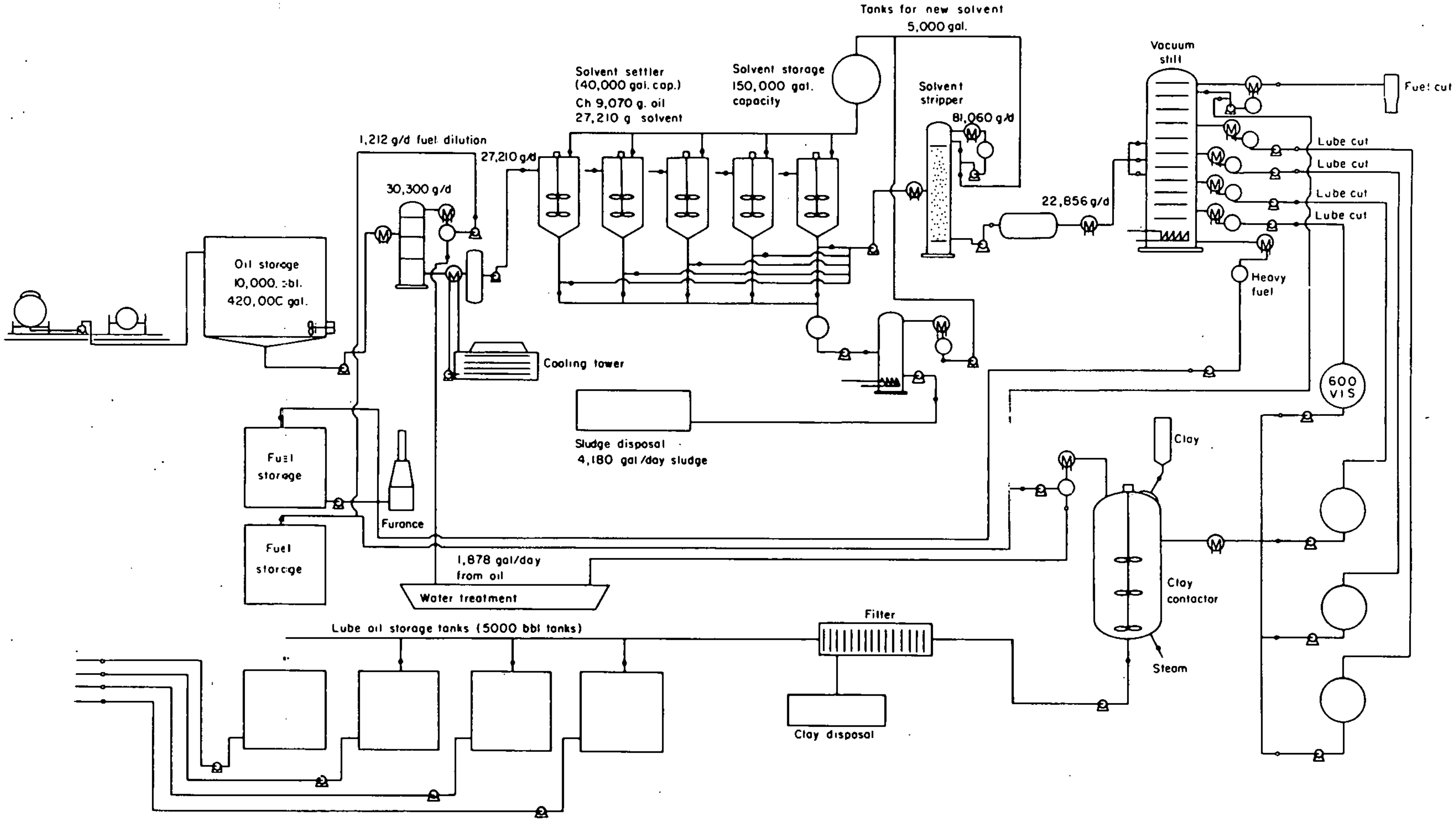

Figure 5. BERC/DOE Re-refining Process; 10 x $10^6$ Gal Per Year Capacity

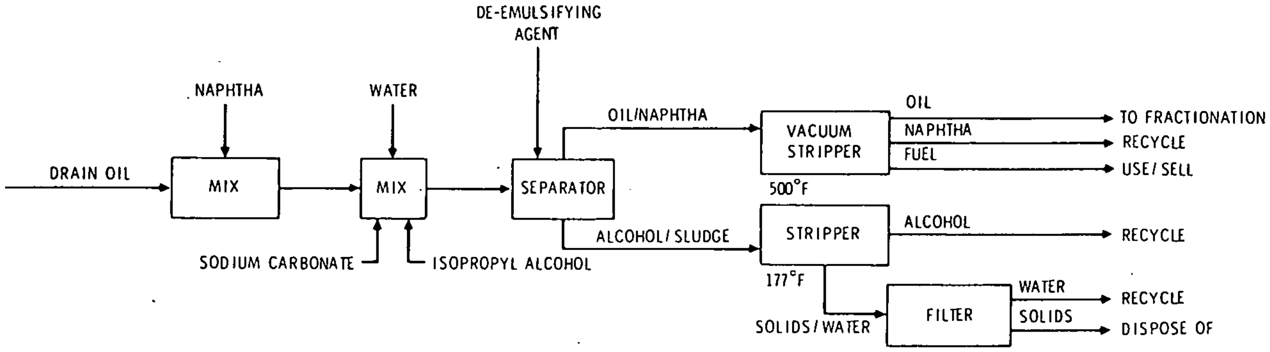

Figure 6. MZF Re-refining Process

### 6.2.3 Phillips Re-refined Oil Process (PROP)

Phillips Petroleum Company of Bartlesville, Oklahoma, announced a new re-refining process with the signing of a contract with the State of North Carolina to deliver a plant for operation by mid-1978. The Phillips process is proprietary, and Phillips' marketing approach is to deliver a skid-mounted self-contained plant with a guarantee of product yield and quality. Process claims include high yields, rapid startup/shutdown, low processing time, environmentally acceptable waste products, and a side stream of diesel fuel. Although no process details were divulged, the contractual arrangement with the State indicates that the process may make use of two patented processes assigned to Phillips, one that uses an aqueous solution of ammonium sulfate or bisulfate and one that uses ammonium phosphate. The only other process-related factors released by Phillips are that 150 psi steam must be available and that the feedstock must be restricted to normal crankcase drainings. This lack of technical details precludes a detailed analysis of the process.

## 6.3 OTHER PROCESSES AS DESCRIBED IN THE PATENT LITERATURE

A review of the patent literature, covering the 1950 to 1977 time period, revealed 33 patents related to re-refining used oil, with about one-third assigned to major oil companies. Many of the processes described appear attractive and might be potential candidates for implementation. However, a detailed assessment to identify meritorious processes for inclusion as candidate processes was considered to be beyond the scope of this study.

## 7. REFINING PROCESSES FOR VIRGIN LUBE OIL

There is no single processing sequence that would be universally descriptive of lube oil plants; indeed, it is doubtful that any two plants are substantially identical. There are many reasons for this variability, ranging from differences in crude stock and product slate to refinery size and age, degree of modernization, the patent situation, and company economics. There are many processes that employ specific catalysts or solvent combinations, often uniquely combining several treatment steps to improve yield, to reduce cost and energy consumption, and to provide operating flexibility. Typical generic process steps used for the production of lube oils intended for automotive service are shown in Figure 7, including (1) Vacuum Distillation, (2) Propane Deasphalting, (3) Solvent Refining, (4) Solvent Dewaxing, and (5) Finishing, and are described in the following paragraphs.

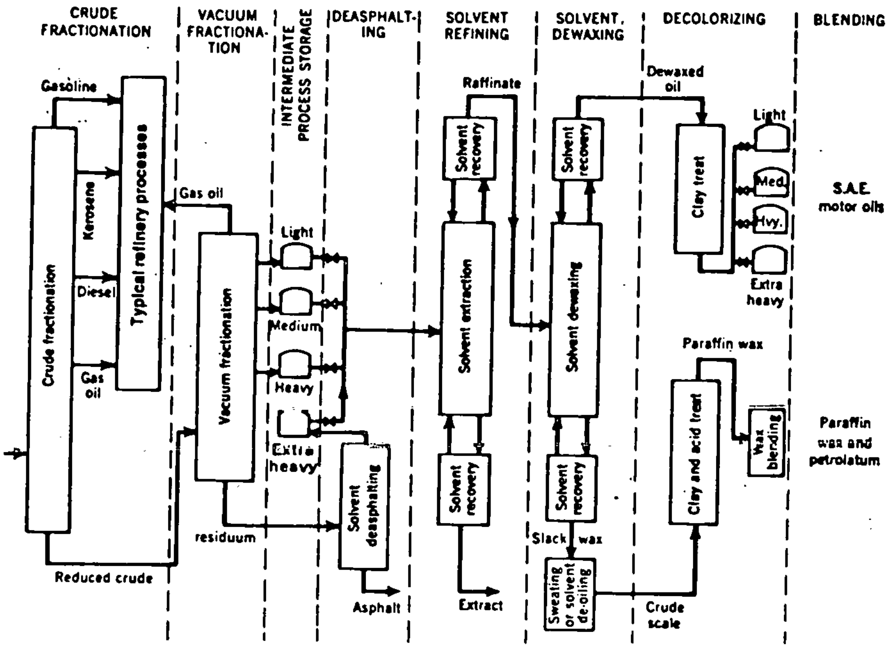

Figure 7. Schematic Diagram of a Refinery for Producing Lubricating Oils

Virgin Lube Process: The feedstock of a lube oil refinery is high boiling point (700°F to 1,000°F) reduced crude obtained from atmospheric distillation of crude petroleum. The reduced crude is then distilled under vacuum conditions, producing a lube stock and an asphaltic bottom. Since these bottoms also contain a desirable heavy lube fraction, they are subjected to a solvent extraction step using propane. Propane has selective solvent properties that are temperature dependent. For example, at temperatures between 100°F and 140°F, propane will dissolve paraffinic hydrocarbons and precipitate asphaltic and resinous compounds. After extraction of the heavy lube oil fraction from the asphaltic bottoms, the propane is recovered and recycled.

In addition to desirable hydrocarbons, the lube stock obtained from the vacuum distillation step contains aromatics, unsaturated hydrocarbons, sulfur and other inorganic elements. These materials are removed in a solvent refining step that is based on the use of selective solvents. Many solvents have been used for this purpose, including furfural, phenol, liquid sulfur dioxide, etc. The oil and solvents are contacted and the refined oil and extract layers are then separated. Solvent is recovered from the oil and the extract solution, and then recycled. However, the refined oil still contains wax. Dewaxing, which was once done by chilling and filtration, is now accomplished by solvent processes for economic and operational reasons. After dewaxing, the nearly purified oil still contains traces of resinous and chemically active compounds. These are removed in a finishing step, such as clay contacting or, hydrotreating.

## 8. ECONOMICS OF USED OIL COLLECTION

In the past, collection of used lube oil was a marginally economic enterprise due to a plentiful and cheap supply of virgin crude. However, following the OPEC imposed petroleum price increase, used oil has become an eagerly sought after commodity. The major source of used oil is the automotive sector, generating between 51 and 59 percent of the total, with the remainder coming from the industrial sector.

The price of used oil varies for a number of reasons, such as regional differences and competition for various end uses. Re-refiners tend to compete with fuel users for used oil supplies. For each end use, the price of virgin products imposes an effective ceiling. Currently, fuel users are offering about 17 cents per delivered gallon of used oil, while re-refiners are only able to economically pay from 10 to 15 cents. As a result of this price difference, used oil tends to go to fuel users, leaving re-refiners with a shortage of feedstock. Today, most re-refiners are operating at less than capacity and below the demand level for re-refined products.

## 9. THE FUTURE MARKET FOR RE-REFINED LUBE OIL

Viability of the re-refining industry rests heavily on market demand for re-refined lube oils. The market for re-refined products depends on (1) the ability to satisfy demands with virgin oil, and (2) economic competition relative to virgin oil.

Availability of virgin lube oil to supply demand was determined in this study from estimates of lube oil demand, refinery capacity, and crude petroleum availability to the year 2000. Estimates of lube oil demand were obtained by statistically projecting historical data and from marketing projections made by ARCO, Sun Oil Company, and Frost and Sullivan. Refinery capacity was estimated by projecting historical data, while petroleum availability was based on estimates obtained from the National Energy Plan.

Total lube oil demand projections for the year 2000 range from 2,860 to 4,420 million gallons. In comparison, refinery capacity is estimated to be 4,300 million gallons, which indicates either a small shortfall or a large overcapacity. Estimates of petroleum supplies indicate a potential availability of as much as 13 billion gallons of lube oil if sufficient refinery capacity would be available. In light of these projections of the supply/demand situation, it appears that re-refiners should not make plans based on a shortage of lube oil. Rather, they should seek marketing opportunities based on the economic advantage of re-refined oils.

Demand for automotive lube oils varies regionally, with excellent growth potential projected for the East, North Central and Pacific areas. Within all regions, cost savings achievable through the use of re-refined products should be most attractive to large commercial users and governmental agencies. Acceptance of re-refined products in these applications should then stimulate demand in the private sector. A market for re-refined automotive lube oils of between 195 and 300 million gallons is estimated in the year 2000.

Similar to the automotive sector, opportunities for marketing re-refined industrial oils are regional in nature. The Mountain states should provide excellent growth potential due to anticipated expansion of coal mining operations. Expansion of the electric utility industry suggests that re-refining transformer and turbine oils is a growing market. The estimated market for re-refined industrial oils is between 190 and 350 million gallons in the year 2000.

Availability of used oil feedstock is estimated to be in excess of the amounts needed to supply the potential demand for re-refined products, with 900 to 1,170 million gallons available. Re-refining capacity will have to be increased from five to almost nine times to supply the estimated market of 385 to 650 million gallons projected for the year 2000. This expansion represents a capital investment of 100 to 280 million dollars which may prove difficult for re-refiners to raise.

## 10. INSTITUTIONAL IMPACTS ON RE-REFINING

The question of re-refined lube oil quality has been of major importance in its acceptance and widespread use, particularly for automotive applications. The importance of this issue, and an apparent belief that re-refined oils are inferior to virgin products, has led to past legislation and government regulations that have impeded or prohibited the use of re-refined oils.

Lube oil quality is of interest to both industrial and automotive lube oil users. In industrial applications, service conditions are better known and are neither as severe nor as variable as those encountered in automotive use. Therefore, the question of quality for re-refined industrial oil is easier to resolve. For automotive lube oils, quality is addressed in the private sector by a classification system devised by the American Petroleum Institute (API), which defines engine service conditions that range from light to severe. Suitability of an oil for a particular service classification may be demonstrated by the use of engine sequence tests which have been devised for this purpose. However, there are no formal requirements for an oil to either undergo or pass these tests in order to be designated acceptable for the particular service conditions.

In the governmental sector, the military has devised specifications which must be met before a lube oil qualifies for purchase. These specifications require that candidate lube oils undergo and pass appropriate engine sequence tests as well as a number of other tests. Qualification remains in effect for four years provided no changes to base stock, process, or additives are made. However, irrespective of whether re-refined lube oils could pass appropriate engine sequence tests, re-refined oil is explicitly prohibited in the specification. This is particularly significant to re-refiners in that most federal agencies, many state and local governments, and private organizations, purchase lube oil based on military specifications.

Other governmental actions have also served to restrict the use of re-refined oils. For example, Federal Trade Commission regulations requiring re-refined oils to be labeled as coming from used oil denotes inferior quality. Also, the Internal Revenue Service disallows tax rebates on virgin oil blended with re-refined oil for off-highway use, which effectively increases the price of re-refined oil relative to a virgin product in this application.

Recent federal legislation related to energy conservation and environmental protection should provide an affirmative impact on the use of re-refined oils. Re-refined oils are addressed directly by Public Law 94-163, the Energy Policy and Conservation Act, which provides for the development of test procedures to demonstrate substantial equivalency to virgin products. These procedures are under development by the National Bureau of Standards. Once equivalency has been established, labeling requirements must be changed to only reflect an acceptable end use of the product. Public Law 94-580, the Resource Conservation and Recovery Act of 1976, which amends the Solid Waste Disposal Act, does not specifically address re-refined oils but is potentially significant to re-refining. If the Environmental Protection Agency rules that used oils are a hazardous waste, the procedures established for handling and disposal may result in a funneling of feedstock to re-refiners. Also, removal of existing federal specifications prohibiting the use of recycled materials, and establishment of mandatory purchase requirements for recycled materials for government use, will create new markets for re-refiners.

## 11. COMBUSTION OF USED OIL

Currently, about 50 percent of the available used oil is utilized as a fuel. In general, primary virgin fuel is mixed with small amounts of used oil to facilitate usage in existing equipment. Used oils contain metallic contaminants which, in the case of crankcase drainings, are predominantly lead compounds that form ash particulates during combustion. Approximately one half of these particulates are emitted from the stack and enter the environment. The other half is deposited within the furnace, causing corrosion and fouling. Removal of these deposits adds to the operating cost of the plant and places additional pollutants into the environment.

Burning all available used crankcase oil would result in about 10,000 tons of lead entering the environment each year, which is less than 6 percent of the 180,000 tons emitted from autos using leaded gasoline. However, these emissions could be significant, representing a highly concentrated point source of pollution. Concern has also been expressed about other trace metals and polynuclear aromatics contained in used oil.

The largest annual consumers of energy in the United States are the industrial and electrical generation sectors. The trend in recent years with regard to fuels consumed by electric utilities demonstrates their flexibility for fuel switching, indicating that used oil might potentially be used by this industry. The energy available from used oil, as shown in Table 1, is a relatively small but nearly constant fraction of the energy obtained from coal and petroleum sources.

Table 1. Comparison by Region of Energy Available from Used Oil to Total Oil and Coal Energy Consumption 1971

| Region | Coal Consumption | | Petroleum Consumption | | Total Energy Consumption, quad | Used Oil Generated | | |
|---|---|---|---|---|---|---|---|---|
| | $10^6$ ton | Quad[(a)] | $10^6$ gal | Quad[(b)] | | $10^6$ gal | Quad[(c)] | Total, %quad |
| New England | 2.5 | 0.06 | 16,900 | 2.41 | 3.01 | 40.2 | 0.0053 | 0.176 |
| Middle Atlantic | 83.4 | 2.08 | 39,200 | 5.60 | 7.68 | 147.6 | 0.0196 | 0.255 |
| South Atlantic | 90.5 | 2.26 | 31,400 | 4.48 | 6.74 | 108.9 | 0.0145 | 0.215 |
| East South Central | 72.4 | 1.81 | 10,100 | 1.44 | 3.25 | 66.6 | 0.0089 | 0.274 |
| East North Central | 188.3 | 4.71 | 33,400 | 4.77 | 9.48 | 240.2 | 0.0319 | 0.336 |
| West North Central | 35.5 | 0.89 | 16,000 | 2.29 | 3.18 | 92.0 | 0.0122 | 0.384 |
| West South Central | 0.4 | 0.01 | 25,500 | 3.64 | 3.65 | 134.9 | 0.0179 | 0.490 |
| Mountain | 21.6 | 0.54 | 8,700 | 1.24 | 1.78 | 44.0 | 0.0059 | 0.331 |
| Pacific | 4.1 | 0.10 | 24,800 | 3.54 | 3.64 | 120.9 | 0.0168 | 0.462 |
| Total | 498.7 | 12.46 | 206,000 | 29.41 | 41.87 | 995.3 | 0.1330 | 0.318 |

(a) Based on 0.025 quad per $10^6$ ton coal.

(b) Based on 0.143 quad per $10^9$ gallon petroleum.

(c) Based on 0.133 quad per $10^9$ gallon used oil.

## 12. ALTERNATIVES TO BURNING OR RE-REFINING

In addition to re-refining or burning, used oil is currently utilized in the manufacture of asphalt, as a road oil, as a secondary lubricant, and as an admixture to diesel fuel. While other applications for used oil have been considered, including chemical process feedstocks, lube oil refinery feedstocks, and synthesis gas manufacture, there are uncertainties relative to equipment contamination, particularly catalyst poisoning.

The potential energy savings derived from the utilization of used oil in these alternative applications are equal to the amount which would be saved if the oil were used as a fuel, provided that the energy content of the virgin petroleum products normally used for these applications is similar to that of lube oil.

## 13. RESOURCE CONSERVATION

Resource conservation aspects related to re-refining used oil become important considerations in case of a future lube oil shortage which might occur due to a number of factors. These include a reduction in crude oil supplies, a lower lube cut obtained from available crudes, and insufficient virgin lube production capacity. Should these events occur, the re-refining industry could play a vital part in supplementing virgin lube oil supplies through re-refining of used automotive and industrial oil.

## 14. PROCESS ENERGY REQUIREMENTS

The energy saving potential of re-refining is dependent on the process used as well as the energy consumed in producing virgin lube oil. Therefore, the various re-refining processes and the production of virgin lube oil were evaluated in this study with respect to their energy requirements. Indirect energy expenditures, for the manufacture and transport of chemicals (except for the manufacture of caustic, which is energy intensive) were excluded because they were found to be small energy consumers relative to direct consumption values.

Process energy inputs consist of heat, steam, and electricity in some combination. These requirements have been converted to fuel consumption values by consideration of efficiencies for electric generation and transmission, steam raising in the boiler, and heat transfer in furnace operations. A standard used oil composition was selected and an average oil temperature of 60°F was assumed. Energy requirements for tank farm heating or steam tracing, or for non-process functions such as lighting and space heating, are relatively small and have been omitted from the calculations. Flowsheet schematics for the various re-refining processes are presented in Figures 8 and 9, showing operating conditions and material flows for the major steps.

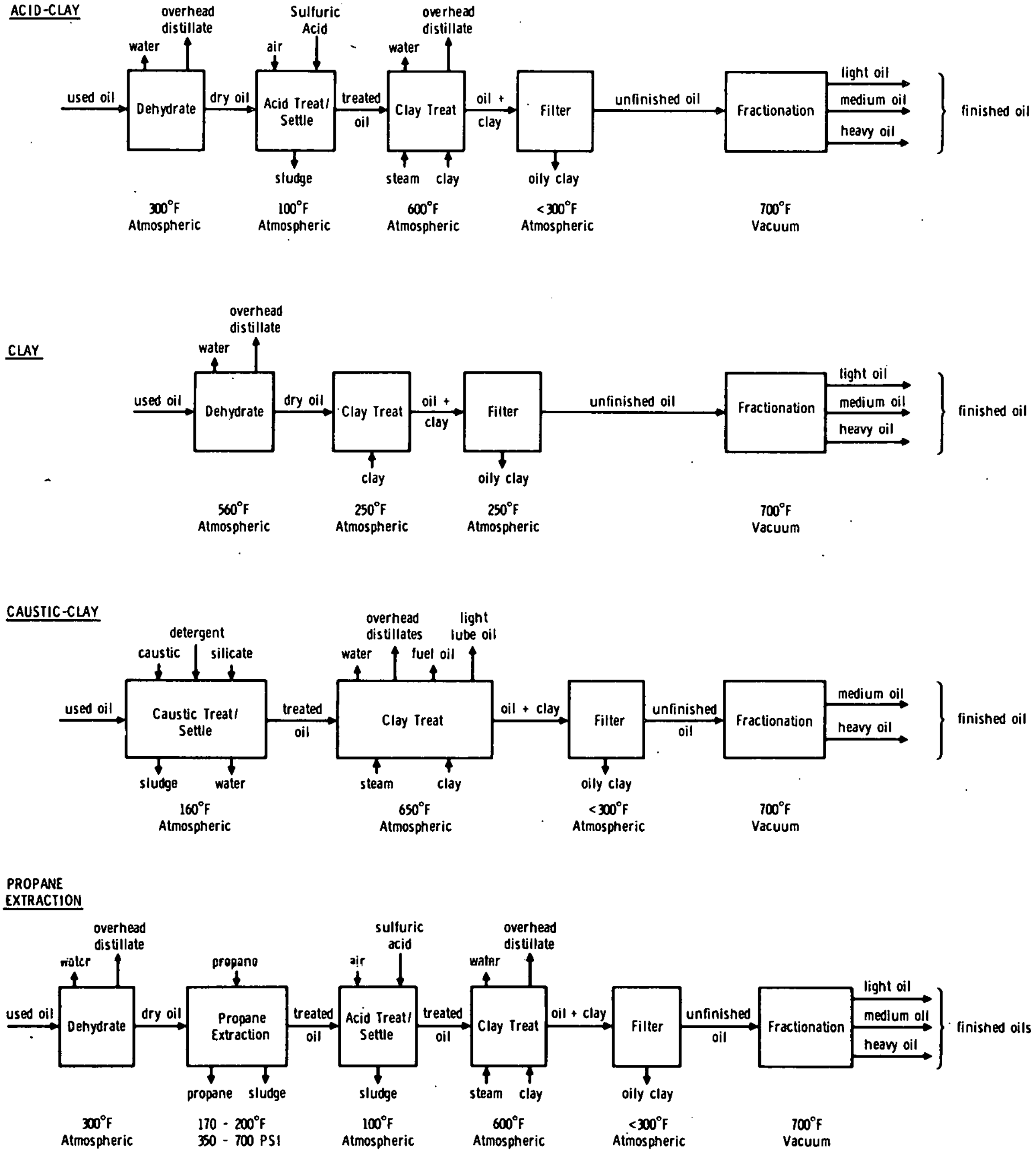

Figure 8. Summary of Flow Schemes for Various Lube Oil Re-Refining Processes

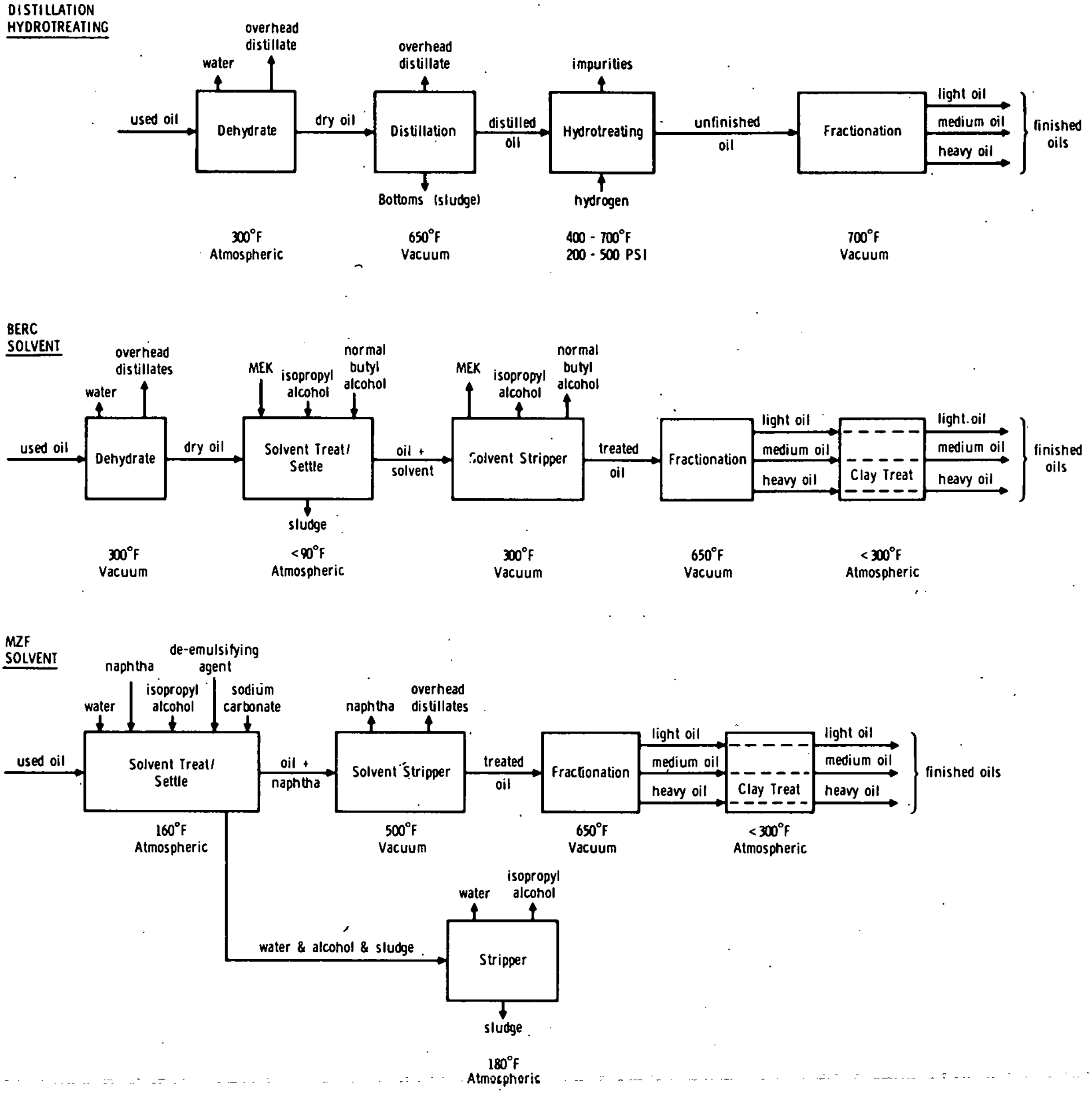

Figure 8. Summary of Flow Schemes for Various Lube Oil Re-Refining Processes (continued)

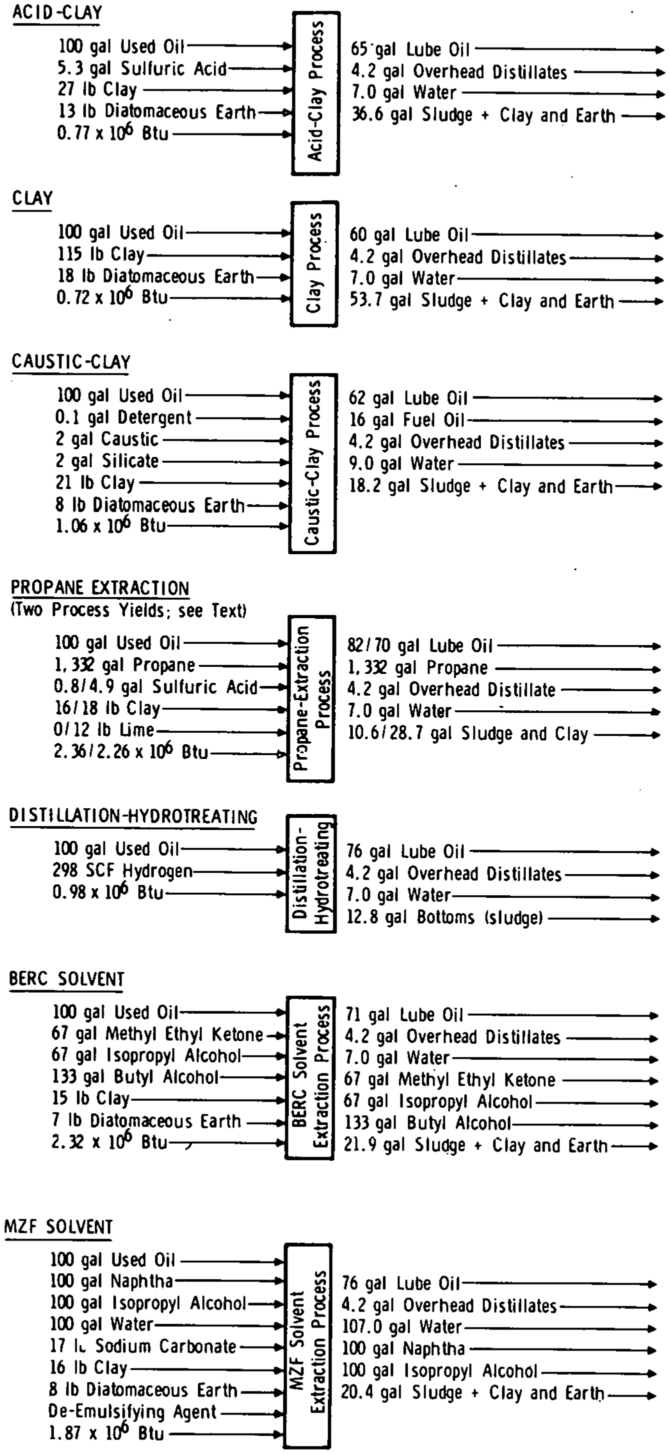

Figure 9. Summary of Material Balances for Various Lube Oil Re-Refining Processes

Process energies for used oil pretreatment prior to combustion were computed in a similar manner. It appears reasonable to assume that some sort of pretreatment will eventually be required to meet environmental regulations. The most effective pretreatment technique considered in this study is an adaptation of the BERC solvent extraction process, with the fractionation and clay treatment steps eliminated. In an effort to reduce energy requirements, the basic BERC process with a lower solvent-to-oil ratio was also considered, based on the assumption that sufficiently clean oil might be obtained. As a minimum level of pretreatment, simple dehydration and filtration were also considered.

Virgin lube oil process energy requirements were based on processing a Texas Mixed Base Crude by (1) propane deasphalting, (2) solvent extraction, (3) solvent dewaxing, and (4) hydrotreating, as shown in Figure 10. In accordance with the usual convention, energy consumed in vacuum distillation is not included inasmuch as this step would be carried out to recover other products even in the absence of lube oil production.

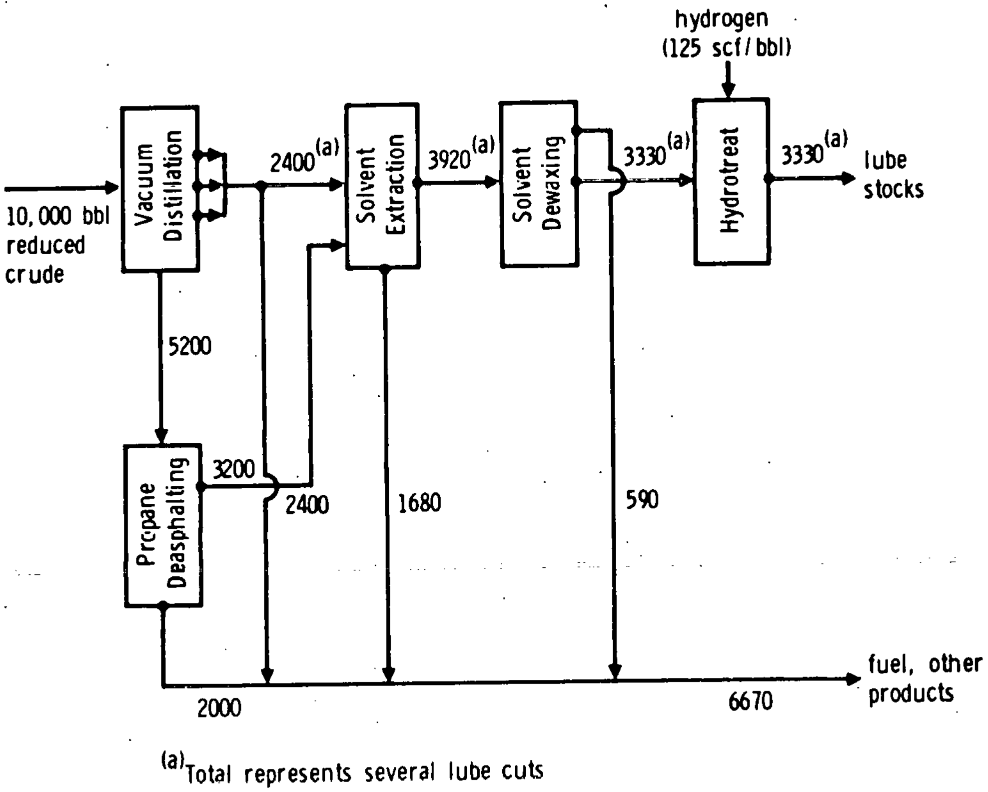

Figure 10. Flow Scheme for Virgin Lube Oil Refining Process

Results of all process energy calculations, including both those for re-refining of used oil and those for refining of virgin oil, are summarized in Table 2.

Table 2. Summary of Process Energy Requirements

| Process | Process Yield, %[a] | Process Energy: $10^6$ Btu per Barrel Used Oil Feedstock[b] | Process Energy: $10^6$ Btu per Barrel Fractionated Product[c] |
|---|---|---|---|
| Acid-Clay | 65 | 0.32 | 0.49 |
| Clay | 60 | 0.30 | 0.50 |
| Caustic-Clay | 62[d] | 0.45 | 0.57 |
| Propane Solvent Extraction[e] | 70<br>82 | 0.95<br>0.99 | 1.35<br>1.21 |
| Distillation- Hydrotreating | 76 | 0.41 | 0.54 |
| BERC Solvent Extraction | 71 | 0.97 | 1.37 |
| MZF Solvent Extraction | 76 | 0.79 | 1.03 |
| Pretreatment (3:1 Solvent to Oil Ratio) | 79 | 0.79 | 1.00 |
| Pretreatment (1:1 Solvent to Oil Ratio) | 84 | 0.33 | 0.39 |
| Pretreatment (Dehydration-Filtration) | 87 | 0.10 | 0.12 |
| Virgin Lube Oil | | | |
| Average | - | - | 2.10 |
| Minimum | - | - | 1.70 |
| Maximum | - | - | 3.10 |

(a) Barrels of product per barrel of used oil feedstock.
(b) Standard feedstock containing 7 percent water and 4.2 percent light ends, which is typical of automotive crankcase drainings.
(c) Product is base oil, and contains no additives.
(d) Process also produces a 16 percent fuel fraction.
(e) Two different yields have been reported (see text).

## 15. ECONOMICS OF CRANKCASE LUBE OIL RE-REFINING

Investment requirements and lube oil manufacturing costs were developed for the seven re-refining processes shown in Figures 8 and 9, which are (1) acid-clay, (2) clay, (3) caustic-clay, (4) propane extraction, (5) distillation-hydrotreating, (6) BERC solvent, and (7) MZF solvent. Equipment and material requirements are in accordance with the flow schematics shown in the figures. To permit normalization of equipment cost as completely as possible, process hardware was grouped into major categories such as pumps, boilers, and storage-tanks, with unit costs scaled and simplified to obtain average costs without consideration of cost factors attributable to specific operating requirements, such as a pump's operating load. Similarly, cost of chemicals common to different processes are the same, with no price variations relative to quantities purchased. Specialized equipment costs, such as for hydrotreating and propane extraction sections, are based on purchase as a complete unit, with cost data as reported in the literature by manufacturers. While there may be some reservations regarding absolute costs, it is believed that the relative costs of the various processes are accurately reflected.

Although the cost analysis of the various processes are based on the process flows shown in Figures 8 and 9, the following comments must be made relative to the status of advanced processes and the ultimate feasibility of their implementation:

> Propane Extraction: Two plants are currently in commercial operation in Europe and the process is available from IFP under license as the Selectopropane process. Conflicting data on process yields have been reported.
>
> Distillation-Hydrotreating: Has been under development for years with major effort directed towards a solution of column fouling problems. These process steps are commonly used in petroleum refining, but have yet to be successfully adapted to re-refining used automotive oils. However, one plant is in operation which uses distillation with pretreatment and periodic shut down for column cleaning.
>
> BERC Solvent: Lube oil is currently being produced in a pilot plant, The oil has been subjected to engine sequence tests, and is currently being fleet tested.
>
> MZF Solvent: In the laboratory stage of development. There is concern relative to the ability to break emulsions when the process is operated at commercial production volumes. The technical viability of the process has yet to be demonstrated.

## Table 3. Salient Features of Various Re-Refining Processes

| Process | Implementation | Product Quality | Process Yield | Process Energy Requirements | Process Complexity | Other |
|---|---|---|---|---|---|---|
| Existing Processes | | | | | | |
| Acid-Clay | Widely used | Can produce a quality lube oil | Low (65 percent) when processing used automotive lube oils | Low (12,000 Btu per gallon of product) | Simple, and adapted to small volumes and batch operations. Can be adapted to semi-continuous operations | Produces acidic sludge and oily clay waste products |
| Clay | Limited use, one known plant producing automotive lube oil | Questionable for highly contaminated oils, acceptable for industrial oils | Low (60 percent) for automotive lubes and high (90 percent) for industrial oils | Same as acid-clay (12,000 Btu per gallon of product | Very simple | Produces oily clay waste product |
| Caustic-Clay | Limited use, one known plant producing automotive lube oil | Although thought questionable for highly contaminated oils, production of a quality lube oil is claimed | Low lube oil yield (62 percent) offset by concurrent production of fuel oil (16 percent) | About 40 percent higher than acid-clay (17,000 Btu per gallon product) if all energy is charged to lube production | Comparable to acid-clay process | Produces caustic sludge and oily clay waste product |
| Propane Extraction | Newly developed process with two European plants in production | Can produce a quality product | Yield unresolved. High yield (82 percent) claimed by process developer. Moderate yield (70 percent) reported by plant operator | Very high, more than 2 x acid-clay (28 to 32,000 Btu/gallon of product) | Relatively complex and suited to large scale operations. Propane section operates on a continuous basis. The acid-clay finishing step can be either batch or semi-continuous | Requires an acid-clay finishing step |
| Proposed/Under Development | | | | | | |
| Distillation - Hydrotreating | Several variations of process exist. Two distillation (no hydrotreating) plants in production. Demonstration plant under construction in W. Germany, and small pilot plant in operation in the U. S. | Should be capable of producing a quality lube oil | Significantly higher than for acid-clay (76 percent) | Slightly higher than for acid-clay (13,000 Btu per gallon of product) | Somewhat complex and suited to large scale continuous operations | Requires solution of distillation column fouling and catalyst poisoning problems |
| BERC Solvent | Pilot plant operation has produced re-refined oil for engine sequence and field tests | Producing high quality oil that nearly passed all engine sequence tests for an SE oil rating (and probably would have with slightly larger quantities of certain additives) | Higher than acid-clay (71 percent) | Highest of any process evaluated due to need to recover large volumes of solvent (33,000 Btu per gallon of product) | Relatively complex. Currently engineered for semi-continuous operation. Could be used for batch operations | Product lube oil currently undergoing vehicle field testing |
| MZF Solvent | Laboratory (test tube) stage. Process evaluation based on this data. Has least development work of processes reported | Laboratory data reports good removal of metallic contaminants, which should produce quality lube oil after undergoing subsequent fractionation and clay contacting | Significantly higher than acid-clay process (76 percent) | About 2 x acid-clay (25,000 Btu per gallon of product) | Should be comparable to other solvent extraction processes, and suited for semi-continuous or batch operations | Emulsion separation by centrifugation replaced by use of an undisclosed de-emulsication agent, who's cost is claimed to be low |

Table 3 summarizes the status of the various processes and lists the salient features of each process. It should be emphasized that a process which may appear to be economically attractive may still require a demonstration of its technical feasibility.

Estimated plant and equipment costs are shown in Table 4 for the various re-refining processes. These data include a nominal cost of $100,000 for land and site improvements, but exclude inventory of feedstock and chemicals, and numerous miscellaneous items needed to operate an actual plant, such as vehicles, spare parts, office equipment, and so on. Pretreatment equipment costs for the distillation-hydrotreating process and costs for phase separation equipment (other than settling tanks) for the MZF process are not included in the Table 4 data.

Table 4. Estimated Plant and Equipment Costs for Several Re-Refining Processes, Millions of Dollars (a) (b)

| Acid-Clay | Clay | Caustic-Clay | Propane Extraction | Distillation Hydrotreating | BERC Solvent | MZF Solvent |
|---|---|---|---|---|---|---|
| 1.8 | 1.9 | 1.8 | 3.2 | 2.3 | 2.5 | 2.3 |

(a) 10 million gallons per year feedstock capacity

(b) 3 shifts per day, 250 days per year operation.

Manufacturing costs, consisting of the total charge for chemicals, used oil feedstock, waste disposal, process energy, maintenance, insurance, taxes, and labor, are listed in Table 5. A fixed labor cost of $216,000 per year was used for all processes, assuming all plants are operated with the same number and type of personnel. The cost of maintenance, insurance, and taxes is set at 8 percent of the total plant and equipment investment. No costs were assigned for replacement catalysts for the distillation-hydrotreating process or for the undisclosed (but claimed to be inexpensive) de-emulsifying agent used in the MZF process.

Table 5. Estimated Manufacturing Costs for Several Re-Refining Processes, Cents per Gallon[a]

| Acid-Clay | Clay | Caustic-Clay | Propane Extraction | Distillation Hydrotreating | BERC Solvent | MZF Solvent |
|---|---|---|---|---|---|---|
| 43 | 52 | 34 | 32/41[b] | 29 | 38 | 34 |

(a) Lube oil base stock produced.
(b) For reported process yields of 82/70 percent.

Marketing and related costs considered in this study were limited to those for compounding and packaging. Costs for compounding lube oil base stock into either single or multi-viscosity API service SE motor oils were identified as 18 cents per gallon and 26 cents per gallon, respectively. Costs associated with packaging lube oil were determined to be 55 cents per gallon for quart containers, 25 cents per gallon for 55 gallon drum containers, and 8 cents per gallon for bulk tank car loads.

Potential profitability of re-refining by use of the various processes investigated may be judged by comparing total production costs to the selling price of lube oil. Total costs for producing a single viscosity API service SE motor oil, packaged in drums, is the sum of manufacturing cost, compounding cost, and packaging cost. For an SAE 20W re-refined motor oil, this price was identified as $1.18 per gallon when purchased in drum lots. For an equivalent virgin SAE 20W oil, the selling price was found to range from $1.47 to $1.85 per gallon. Potential profitability of re-refining is illustrated by Table 6, which shows total production costs for re-refined oil and its differential with the selling prices of re-refined and virgin lube oils.

Process yields are not definitive for numerous reasons, such as feed stock variation and specific process operating conditions. Therefore, to provide insight into process costs as affected by yield, cost sensitivity data are provided in Figure 11, which illustrates the inherent cost differences between processes. For example, yield from the distillation-hydrotreating process would have to drop from 76 to about 66 percent before the MZF process becomes cost competitive, or yield from the acid-clay process would have to increase from 65 to about 72 percent to become competitive with the BERC process.

Table 6. Potential Profitability of Various Re-Refining Processes, Cents per Gallon[a]

| Process | Acid-Clay | Clay | Caustic-Clay | Propane[b] Extraction | Distillation-Hydrotreating | BERC Solvent | MZF Solvent |
|---|---|---|---|---|---|---|---|
| Total Production Costs | 83 | 92 | 75 | 73/82 | 70 | 79 | 75 |
| Profitability Relative to Re-Refined Oils[c] | 35 | 26 | 43 | 45/36 | 48 | 39 | 43 |
| Profitability Relative to Virgin Oils[d] | 64 to 102 | 55 to 93 | 72 to 110 | 74/65 to 112/103 | 77 to 115 | 68 to 106 | 72 110 |

[a] Plant amortization and marketing/distribution costs not included.

[b] Data shown for both reported yields.

[c] Relative to selling price of $1.18/gal in bulk drum packaging.

[d] Relative to selling price of $1.47 and $1.85/gal in bulk drum packaging.

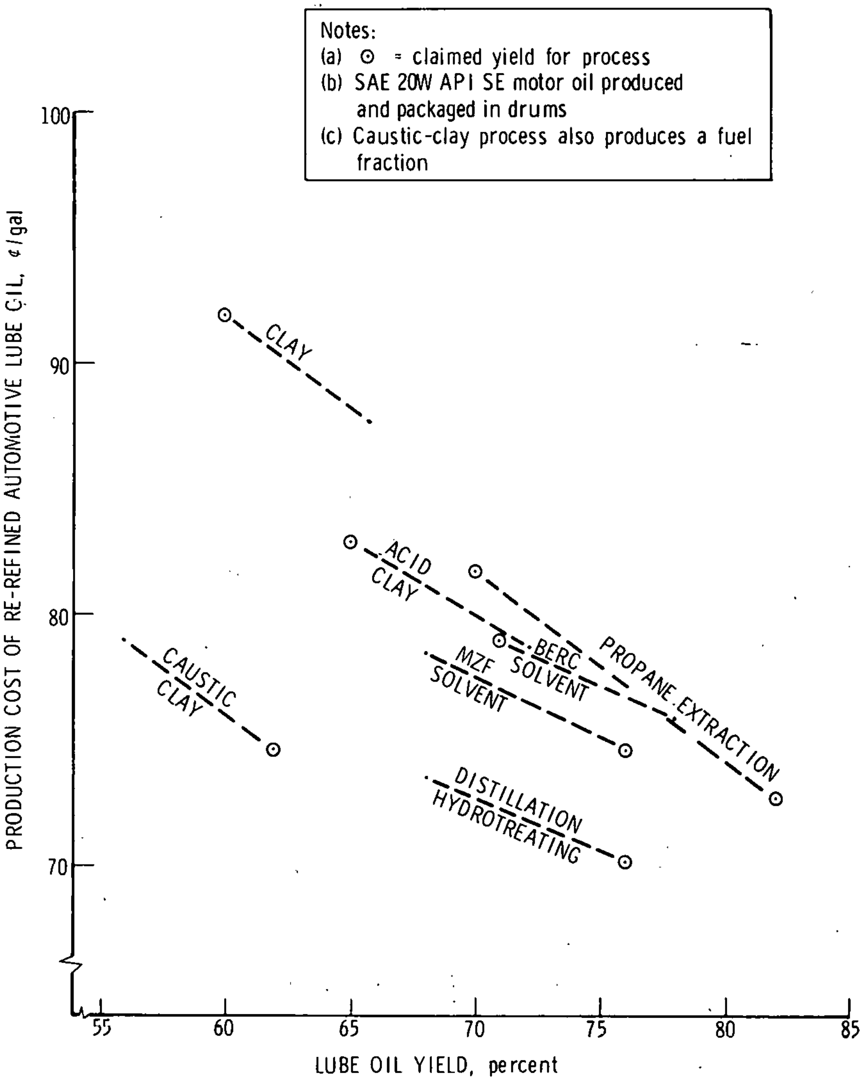

Figure 11. Sensitivity of Production Costs to Lube Oil Yield for Various Re-Refining Processes

## 16. ASSESSMENT OF USED OIL UTILIZATION

A parametric analysis was made to evaluate the energy savings potential of re-refining used oil in lieu of using it as a fuel. This analysis provides visibility into the elements affecting energy savings, and considers the following parameters:

1. Process energy for refining virgin lube oil
2. Process energy for re-refining used oil
3. Process yield for re-refined oil
4. Process energy to pretreat used oil prior to burning
5. Process yield of pretreated used oil to be used as a fuel

Results of this parametric analysis are presented in Figures 12 and 13. Figure 12 shows energy savings due to re-refining when pretreatment prior to burning is not required, whereas Figure 13 shows the incremental energy saving that accrues due to the energy loss in pretreatment.

To accurately assess the effect of re-refining on total petroleum consumption, an evaluation of the net change in total energy consumption was made by means of a closed loop energy model. The basic difference in this approach relative to the parametric analysis is that the energy requirements of operating a refinery are considered. Contrary to common convention, energy requirements of all process steps are assigned to the production of some product. This analysis uses the closed loop energy models shown in Figures 14 through 16, which represent disposal of used oil by dumping, and utilizing used oil by either burning or re-refining. Equations were developed from the closed loop energy models and applied in the evaluation of the various utilization methods. As shown in Table 7, relative to dumping, all utilization methods have energy recovery rates above 100,000 Btu per gallon.

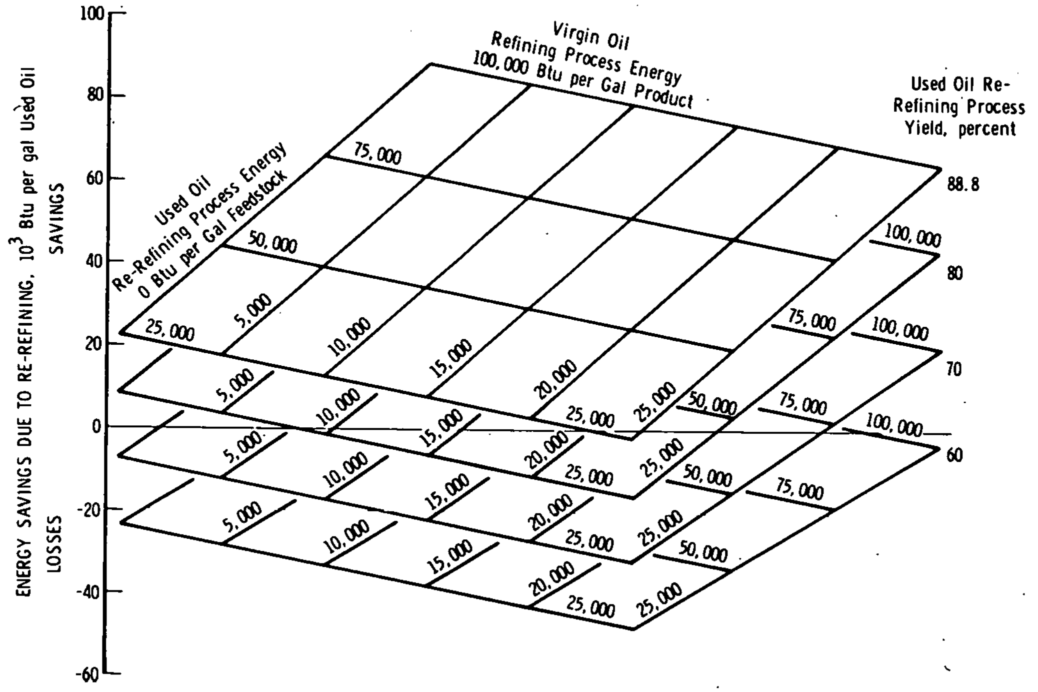

Figure 12. Energy Savings Due to Re-Refining

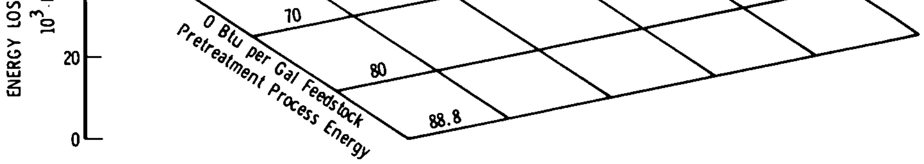

Figure 13. Energy Losses due to Pretreating Used Oil Prior to Burning

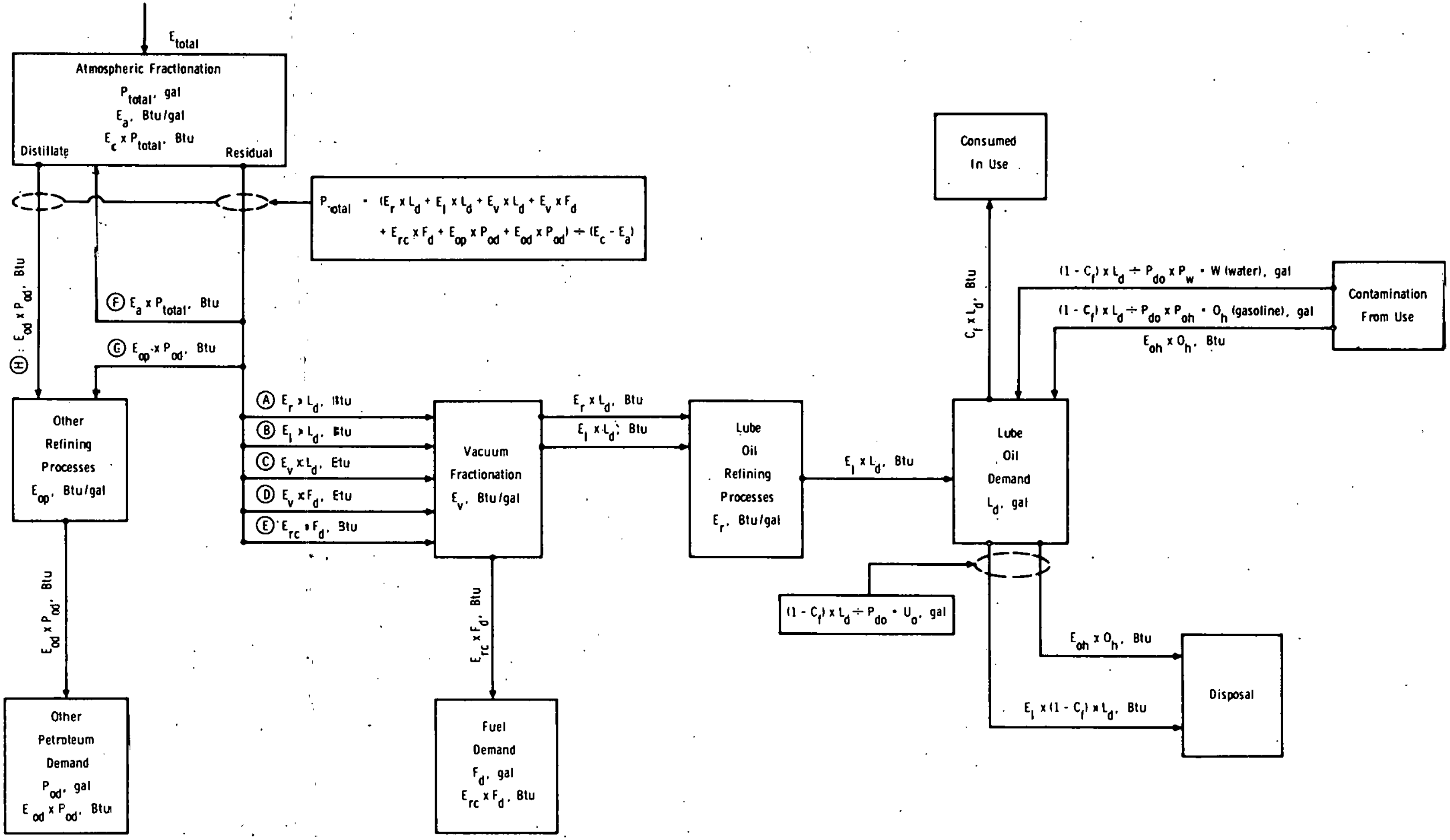

Figure 14. Closed Loop Energy Model for Disposal of Used Oil by Dumping

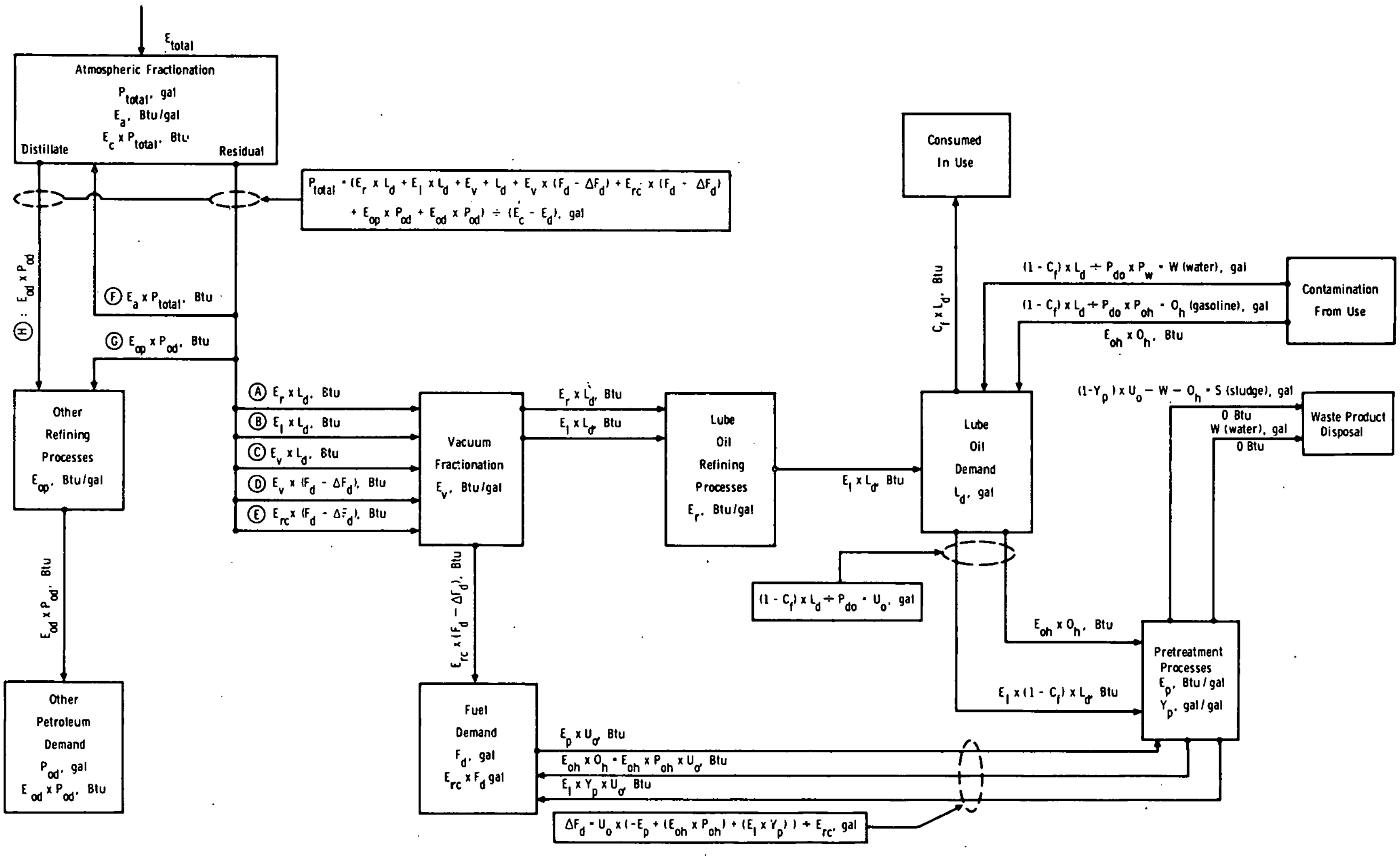

Figure 15. Closed Loop Energy Model for Utilization of Used Oil by Burning

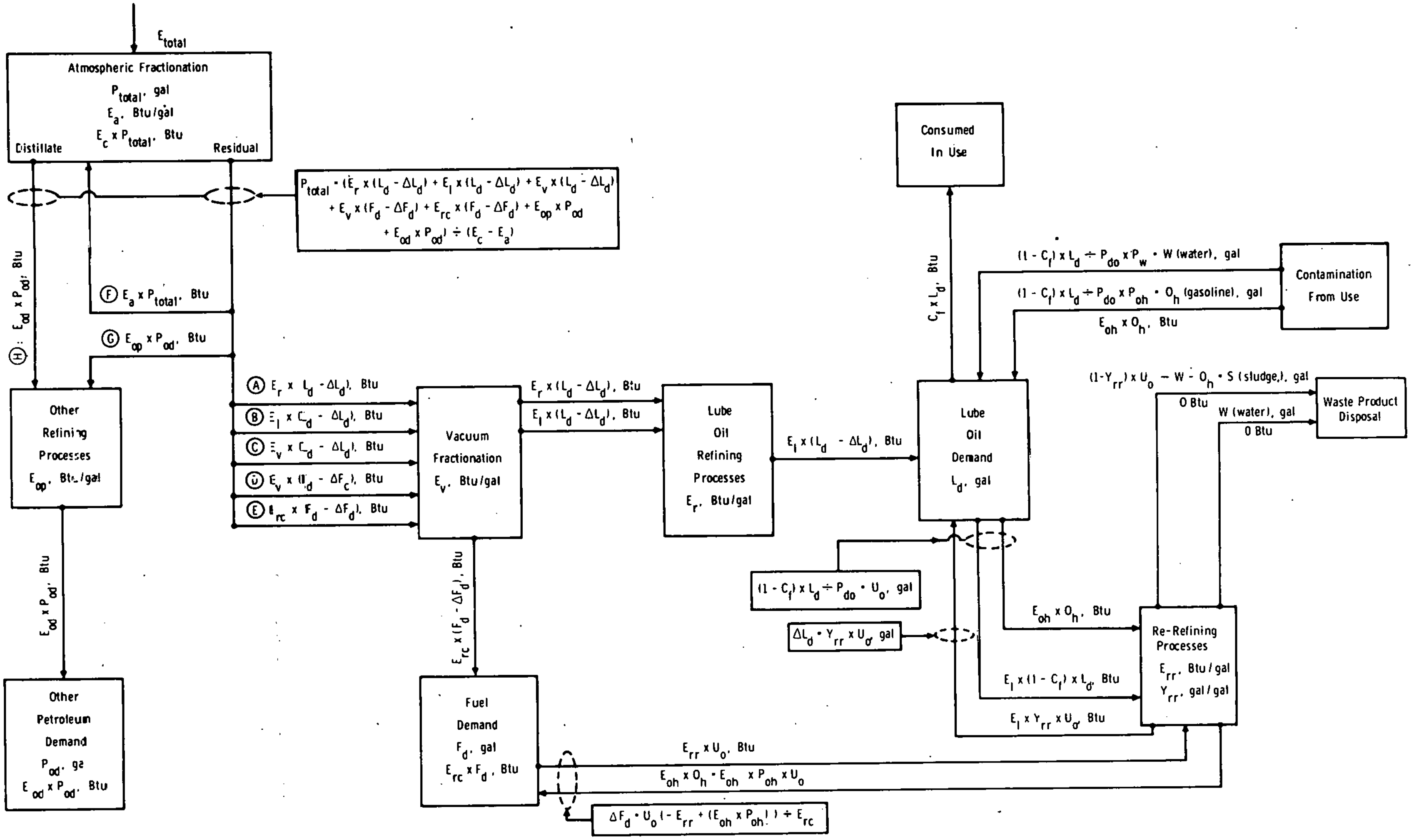

Figure 16. Closed Loop Energy Model for Utilization of Used Oil by Re-Refining

## Table 7. Comparison of Energy Savings for Various Used Oil Utilization Methods Relative to Disposal by Dumping

| Method and Process | Process Parameters | | | Energy Savings, Btu/gal used oil | Status of Operations |
|---|---|---|---|---|---|
| | Yield, % used oil | Energy, Btu/gal used oil | Confidence Level* | | |
| Burning | | | | | |
| Without pretreatment for contaminant removal | 89(a) | 0 | HIGH | 131,210 | Common Practice |
| With pretreatment for contaminant removal | 84 | 7,860 | MED(b) | 116,160 | Not in Use |
| Re-refining | | | | | |
| Acid-Clay | 65 | 7,660 | HIGH | 122,960 | Extensive Commercial |
| Clay | 60 | 7,160 | MED | 113,850 | Limited Commercial |
| Caustic-Clay | 62(c) | 10,640 | MED | 135,900 | Limited Commercial |
| Propane Extraction | 70(d) | 22,570 | LOW(e) | 116,900 | Limited Commercial in Europe |
| | 82(d) | 23,550 | LOW(e) | 138,980 | Limited Commercial in Europe |
| Distillation-Hydrotreating | 76 | 9,820 | LOW(f) | 141,870 | Pilot in Construction |
| BERC Solvent | 71 | 23,150 | MED | 118,210 | Pilot Plant |
| MZF Solvent | 76 | 18,700 | LOW(f) | 132,520 | Laboratory Glassware |

(a) Represents lube oil content of used oil.

(b) For a medium level of pretreatment using solvent extraction process.

(c) Process also produces 16 percent fuel oil.

(d) Based on References 4-6 and 4-5, respectively.

(e) Conflicting yield data reported

(f) Inadequate data to substantiate yields.

*Degree to which Aerospace has confidence in the reported process parameters.

Since it is reasonable to assume that pretreatment of used oil for contaminant removal will be required in the future, a number of re-refining processes were compared to the case of burning the oil after pretreatment. As shown in Table 8, the currently used acid-clay process shows modest energy savings, three re-refining processes show substantial savings, one shows minimal savings, another shows a small loss, while the propane extraction process shows either large or minimal savings depending on the real yield of the process.

Sensitivity analysis data are provided in Figure 17 showing energy savings as affected by process yield and illustrating the inherent differences in the energy requirements of the various processes. For example, the yield of the distillation-hydrotreating process would have to drop from 76 to about 71 percent before the MZF process would become an equivalent energy saver, and the yield of the BERC process would have to increase to 74 percent before this process would be equivalent to the acid-clay process.

Again, for lack of definitive data relative to virgin lube oil process energy requirements, sensitivity analysis data are provided in Figure 18 to show energy savings as affected by virgin lube oil process energy. If virgin lube can be produced with a process energy requirement of 19,000 Btu per gallon, as claimed by one manufacturer, then only the caustic-clay and distillation-hydrotreating processes produce energy savings.

Total potential future energy savings, based on a least squares projection of historical demand data, and the assumption that half of the lube demand is recovered for re-refining, are presented in Figure 19. As illustrated in the figure, efficient processes have the potential of providing additional energy savings of about 7 x $10^6$ barrels of petroleum in the year 2000 relative to the widely used acid-clay process. At the current price of imported crude oil of about $12.70 per barrel, these savings would result in an annual balance of payments differential of about 89 million dollars.

### Table 8. Comparison of Energy Savings for Various Re-Refining Processes Relative to Utilization by Burning[(a)]

| Re-Refining Process | Process Parameters | | Energy Savings, Btu/Gal Used Oil |
|---|---|---|---|
| | Yield, % Used Oil | Energy, Btu/Gal Used Oil | |
| Acid-Clay | 65 | 7,660 | 6,780 |
| Clay | 60 | 7,160 | - 2,330 |
| Caustic-Clay | 62[(b)] | 10,640 | 19,720 |
| Propane Extraction | 70 | 22,570 | 720 |
| | 82 | 23,550 | 22,810 |
| Distillation Hydrotreating | 76 | 9,820 | 25,690 |
| BERC Solvent | 71 | 23,150 | 2,040 |
| MZF Solvent | 76 | 18,700 | 16,350 |

(a) Used oil pretreated for contaminant removal prior to burning

(b) Process also produces 16% fuel oil

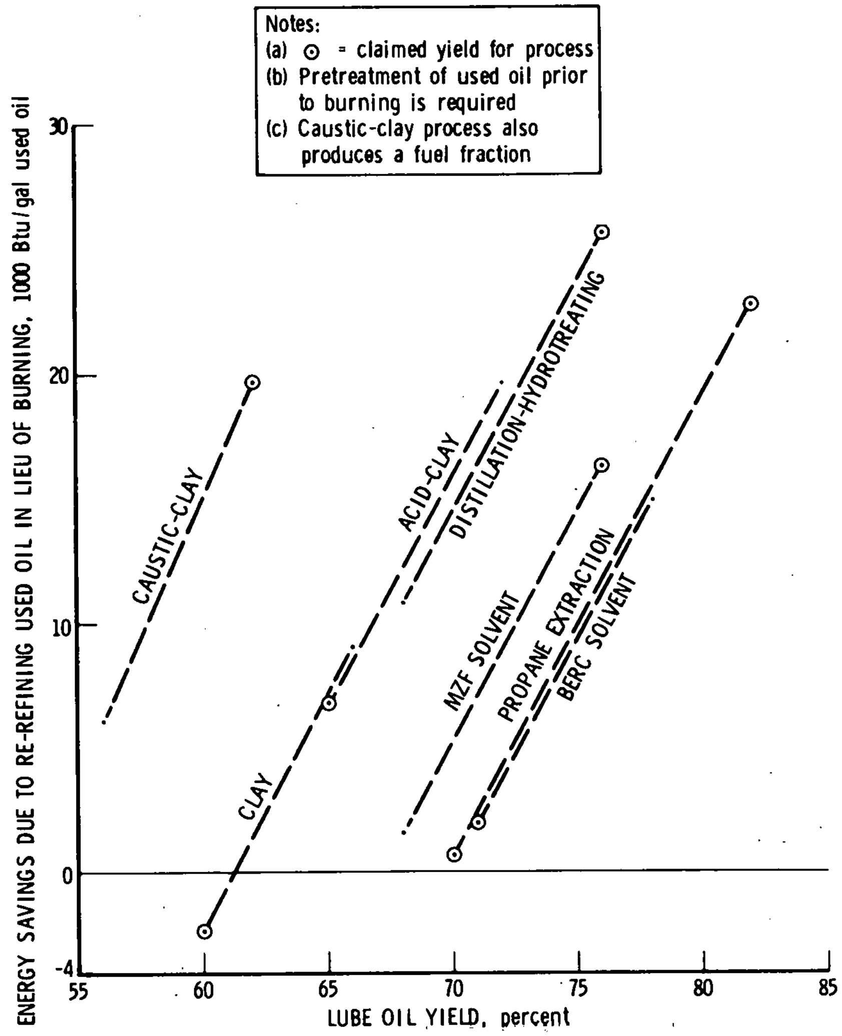

Figure 17. Sensitivity of Energy Savings to Process Yield for Various Re-Refining Processes

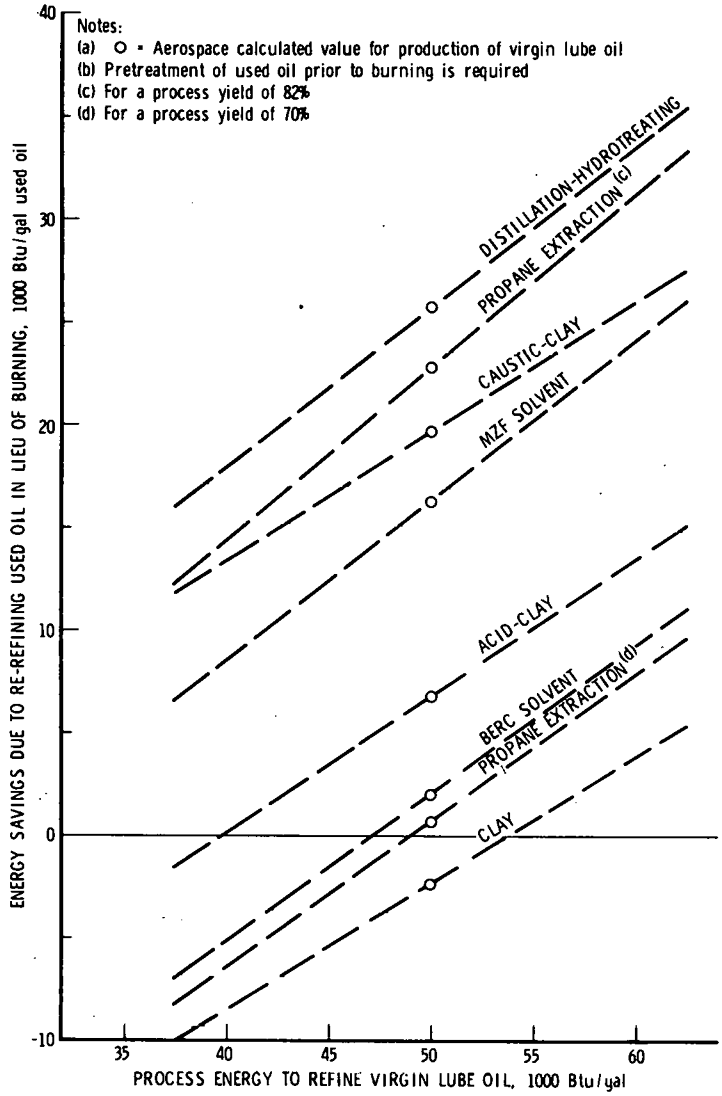

Figure 18. Sensitivity of Energy Savings to Virgin Lube Oil Process Energy for Various Re-Refining Processes

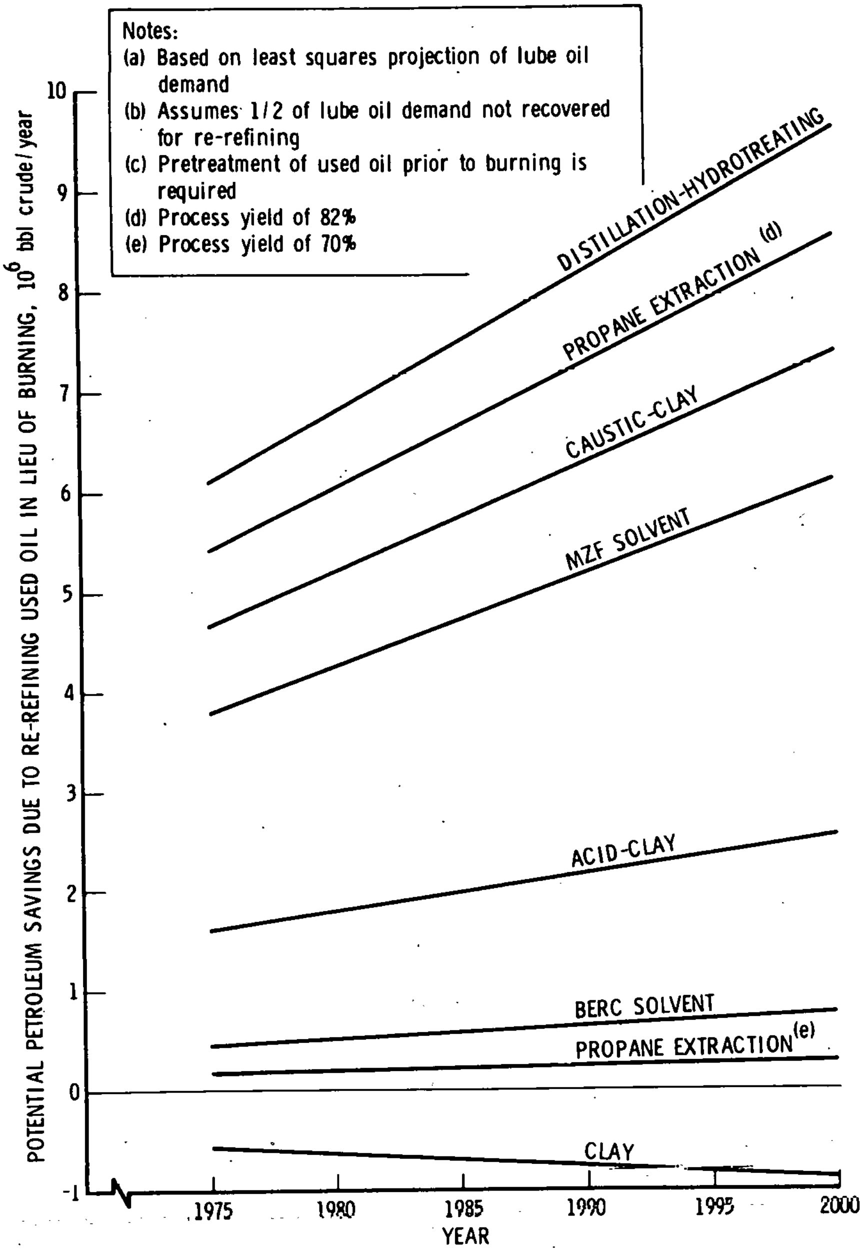

Figure 19. Potential Petroleum Savings to the Year 2000 for Various Re-Refining Processes

## 17. MAJOR FINDINGS

Major findings were developed from data acquired and analyses performed during the course of this study. These findings are structured to address (1) used oil utilization options, (2) energy savings potential of utilization options, (3) resource conservation, (4) protection of the environment, (5) re-refining technology, (6) re-refining economics, and (7) factors governing expansion of the re-refining industry.

### 17.1 USED OIL UTILIZATION OPTIONS

Two utilization options were considered in this study: (1) burning used oil as a fuel, and (2) re-refining used oil for recycling as a lube oil.

### 17.1.1 Used Oil Generation and Disposal

Large amounts of lube oil are used in the transportation and industrial sectors, amounting to about 1.3 and 1.6 billion gallons respectively in 1975.

Oils degrade in service and must be periodically replaced, with recovery factors estimated at 57 percent for automotive lube oil and 43 percent for industrial oils. As a result, approximately 1.4 billion gallons of lube oil were removed from service in 1975, requiring disposal.

### 17.1.2 Utilization as a Fuel

Some used oil is burned as a fuel for recovery of its heat content Generally, it is added to virgin fuel oil in small amounts, about 5 percent, without any prior pretreatment for contaminant removal. Settling for removal of free standing water is commonly done.

Pretreatment processes which could be used for contaminant removal range from simple steps such as dehydration and filtration, for the removal of bound water, volatile hydrocarbons, and coarse solids, to sophisticated processes, such as solvent extraction, which also removes soluble metallic contaminants contained in the used oil.

### 17.1.3 Recycling by Re-Refining

A number of different re-refining processes are in current use or have been proposed for implementation. Existing processes for re-refining, which were identified for inclusion in the analysis of utilization options, are (1) acid-clay, (2) clay, (3) caustic-clay, and (4) propane extraction. Among the numerous advanced processes proposed, the following three were selected for detailed analysis: (1) distillation-hydrotreating, (2) BERC solvent, and (3) MZF solvent. Other advanced processes, such as the Phillips Re-Refined Oil Process (PROP), were excluded because of a lack of process data required in the analysis.

Projections for advanced re-refining processes rely on data which are either not verified or not firmly established. Accurate yield data are lacking, particularly for propane extraction, indicating that a degree of caution should be exercised in reaching conclusions related to specific results.

## 17.2 ENERGY SAVINGS POTENTIAL OF UTILIZATION OPTIONS

The energy savings potential related to used oil burning, either with or without pretreatment, and re-refining with any of the seven processes considered, are addressed in this study relative to (1) non-utilization disposal methods (dumping), and (2) utilization as a fuel with pretreatment for contaminant removal prior to burning. Savings were computed by use of a closed loop energy model which accounts for the overall change in energy consumption resulting from the specific utilization options employed.

### 17.2.1 Pretreatment Energy Requirements

Pretreatment processes consume energy and suffer additional energy losses in the form of discarded hydrocarbons, expressed in terms of process yield. Pretreatment process yields and energies are shown in Table 9 for a used oil composition consisting of 89 percent lube oil and 11 percent water and gasoline contaminants.

Table 9. Process Yield and Energy for Pretreating Used Oil

| Level | Representative Process | Yield, % | Energy, Btu/gal feedstock |
|---|---|---|---|
| None | | 89 | 0 |
| Low | Dehydration, Filtration | 87 | 2,400 |
| Medium | Solvent extraction at 1:1 solvent to oil ratio | 84 | 7,900 |
| High | Solvent extraction at 3:1 solvent to oil ratio | 78 | 18,800 |

### 17.2.2 Re-Refining Energy Requirements

Re-refining processes also consume energy and lose a portion of the processed oil. Process energies and yields are shown in Table 10, with data included for the two propane extraction yields reported in the literature.

Table 10. Process Yield and Energy for Re-Refining Processes

| Process | Yield, % | Energy, Btu per Gallon Feedstock |
|---|---|---|
| Acid-Clay | 65 | 7,700 |
| Clay | 60 | 7,200 |
| Caustic-Clay | 62 | 10,600 |
| Propane Extraction | 82/70 | 23,600/22,600 |
| Distillation-Hydrotreating | 76 | 9,800 |
| BERC Solvent | 71 | 23,200 |
| MZF Solvent | 76 | 18,700 |

### 17.2.3 Comparison of Utilization Options

Energy savings based on process energies and yields for the various utilization options, lower (net) heating values for fuels, inclusion of refinery process energy for crude fractionation, and a process energy of 50,000 Btu per gallon for the production of virgin lube oil, are shown in Table 11, along with the potential petroleum savings which would accrue if all used oil generated (1.4 billion gallons in 1975) would be utilized in this manner.

Table 11. Comparison of Energy Savings for Various Used Oil Utilization Methods Relative to Disposal

| Method and Process | Energy Savings, Btu/gal used oil | Potential Petroleum Savings, millions of barrels per year |
|---|---|---|
| Burning | | |
| **Without any Pretreatment for Contaminant Removal** | 131,210 | 31.1 |
| **With Medium Level of Pretreatment for Contaminant Removal** | 116,160 | 27.5 |
| Re-refining | | |
| Acid-Clay | 122,960 | 29.2 |
| Clay | 113,850 | 27.0 |
| Caustic-Clay | 135,900 | 32.2 |
| Propane Extraction | 116,900/138,980 | 27.7/33.0 |
| Distillation-Hydrotreating | 141,870 | 33.7 |
| BERC Solvent | 118,210 | 28.0 |
| MZF Solvent | 132,520 | 31.4 |

Burning without pretreatment is often considered environmentally unacceptable, and may be prohibited in the future. Therefore, utilization by burning with some pretreatment has been used as a baseline to evaluate the various utilization methods, as shown in Table 12. For reference purposes burning without any pretreatment step is included also in Table 12.

Table 12. Comparison of Energy Savings for Various Used Oil Utilization Methods Relative to Burning with Pretreatment

| Method and Process | Energy Savings, Btu/ gal used oil | Potential Petroleum Savings, millions of barrels per year |
|---|---|---|
| | Burning | |
| Without any Pretreatment for Contaminant Removal | 15,000 | 3.6 |
| With Medium Level of Pretreatment for Contaminant Removal | Baseline | Baseline |
| | Re-Refining | |
| Acid-Clay | 6,800 | 1.6 |
| Clay | -2,300 | -0.5 |
| Caustic-Clay | 19,700 | 4.7 |
| Propane Extraction | 700/22,800 | 0.2/5.4 |
| Distillation-Hydrotreating | 25,700 | 6.1 |
| BERC Solvent | 2,000 | 0.5 |
| MZF Solvent | 16,400 | 3.9 |

Additional energy savings would accrue in the case of re-refining if environmentally acceptable uses could be found for the process waste streams, such as the hydrocarbon rich acidic sludge produced by the acid-clay process (which is in predominant use). Other benefits related to sludge utilization include:

1. Elimination of dumping sludge into the environment.
2. Conversion of a process cost into an operating profit.
3. Permitting activation of those re-refineries which had been shut down due to nonavailability of approved dump sites, and permitting construction of new re-refineries to be built in such areas.

## 17.3 Resource Conservation

Resource conservation is an important criterion for evaluation of the utilization options in that the molecular makeup of lube oil is uniquely suitable for its intended purpose, that of lubrication, whereas many other molecules are suitable for fuel purposes, including nonpetroleum products.

> Re-refining could serve as a strategic resource by providing lube oil for vital applications in case of insufficient virgin crude supplies, particularly from foreign sources, during times of emergency.
>
> Available lube cut quantities from new petroleum discoveries such as Nigeria, Indonesia, and Alaska are lower than from older sources. This has the following implications relative to energy conservation.
>
> 1. Process energy requirements for virgin lube oil production increase with decreasing yield.
> 2. An increase in virgin lube oil process energy enhances the energy conservation aspects of re-refining used oil.

## 17.4 Protection of the Environment

Historically, the disposal of used oil has created environmental problems, which remain largely unresolved. To provide an overall assessment of merit, environmental aspects of the various utilization options must also be considered.

> Burning used oil without pretreatment results in the emission of lead, additive associated trace metals, wear metals, and particulates into the environment. As much as 9800 tons of lead per year would be emitted into the atmosphere if all used automotive lube oil would be burned. Compared to the 180,000 tons currently emitted from automobiles this is a relatively small quantity, amounting to less than 6 percent, but it may pose significant point source problems. Also, polynuclear aromatics, known carcinogens which require temperatures above 2,000°F for decomposition, are of concern.
>
> Re-refining minimizes the amount of used oil entering the environment by recycling it and concentrating the contaminants for controlled disposal. While the currently favored acid-clay process generates additional waste streams, consisting of acidic sludge and oily clay, a number of known new re-refining processes have fewer and less toxic waste products. Emissions and effluents from re-refineries can be controlled with simple and currently available technology.

## 17.5 Re-Refining Technology

The commonly used acid-clay process is capable of producing quality lube oil, but is seriously deficient because it has a low lube oil yield and produces large amounts of toxic waste products.

A number of candidate replacement processes which have claimed or demonstrated advantages over the acid-clay process are under development, under investigation, or in limited use. These include (1) propane extraction, (2) distillation, and (3) other solvent extraction processes.

Salient features of all processes investigated in this study are shown in Table 3, providing pertinent information on the status of selected advanced processes and their ultimate feasibility. As stated in Section 15 there are a number of uncertainties regarding process yield and technical feasibility.

## 17.6 Re-Refining Economics

Regardless of the potential energy savings that may be attributable to re-refining, re-refining must be economically feasible to achieve widespread implementation, unless sponsored under subsidy.

### 17.6.1 Production Costs

Plant and equipment costs of the various processes investigated do not differ greatly. For a 10 million gallon per year feedstock plant, the projected costs vary from 1.8 to 3.2 million dollars. Currently, only one re-refining plant in the United States exceeds 10 million gallons per year capacity, while a number of European plants fall into that category.

Total projected manufacturing costs for the different processes vary from 29 cents per gallon of uncompounded base stock for the distillation-hydrotreating process to 52 cents per gallon for the clay process. It should be noted that these cost figures are sensitive to process yield, which lacks substantiation for some of the processes investigated in this study.

A comparison of production cost factors of the various processes investigated, as indicated by investment, chemical inventory, and manufacturing costs, is shown in Table 13.

Table 13. Comparison of Production Cost Factors for Selected Automotive Lube Oil Re-Refining Processes[a]

| Process | Plant and Equipment Investment Millions of Dollars[b] | Chemical Inventory, Thousands of Dollars[c] | Total Manufacturing Costs, Cents per Gallon Product[d] |
|---|---|---|---|
| Acid-Clay | 1.8 | 20 | 43 |
| Clay | 1.9 | 41 | 52 |
| Caustic-Clay | 1.8 | 23 | 34 |
| Propane Extraction | 3.2 | 7[e] | 32/41[f] |
| Distillation-Hydrotreating | 2.3 | 7 | 29 |
| BERC Solvent | 2.5 | 14[e] | 38 |
| MZF Solvent | 2.3 | 12[e] | 34 |

[a] Plant capacity of 10 million gallons per year used oil feedstock.

[b] Excludes inventory of feedstock, chemicals, vehicles, spare parts, office furniture, etc.

[c] Consumed chemicals for two weeks of plant operation.

[d] Lube oil base stock (uncompounded).

[e] Does not include stock of solvents recycled during process operation.

[f] Reflects reported yields of 82/70 percent.

### 17.6.2 Profitability

To meet service requirements, re-refined base oils require additives, particularly for automotive applications. Additive cost to produce a single viscosity API service SE oil amounts to about 18 cents per gallon, and constitutes 35 to 65 percent of the total manufacturing cost of the base oil.

Packaging, particularly in quart containers, represents a significant cost, about 55 cents per gallon, which exceeds total manufacturing cost of the uncompounded base oil. Bulk packaging is less costly, amounting to about 8 cents per gallon for tank car loads. This cost accounts for cleaning and handling but does not include amortization of the tank car.

Re-refined oil can be profitably transported long distances via tank truck if used oil is hauled back on the return trip. Current practice involves distances as great as 650 miles each way, with an estimated cost per gallon of about 1 cent for each 30 miles of trip radius.

An illustration of profitability, based on total production cost and the difference between production cost and the current $1.18 per gallon selling price of a comparable SAE 20W re-refined lube oil, is shown in Table 14. For comparison, the bulk selling price of an equivalent virgin lube on the West Coast ranges from $1.47 to $1.85 per gallon.

## 17.7 Factors Governing Industry Expansion

Until recently, survival, rather than expansion, was uppermost in the minds of re-refiners. Currently, product demand is outstripping re-refining capacity, with production limited because of the non-availability of economically priced used oil feedstock. Aside from non-availability of adequate quantities of feedstock, production capacity has not expanded because of a lack of investment capital.

### 17.7.1 Feedstock Availability

Availability of used oil feedstock for re-refining is related to the price competition between re-refiners and other used oil users. Currently, those who utilize used oil for fuel purposes are outbidding the re-refiners.

A large fraction of the used oil generated, about 25 percent, is not available for re-refining or other uses. This amount is presumably discarded into the environment.

Recent environmental legislation, depending on EPA interpretation, may place controls over the collection, transportation, and disposal of used oil. These regulations could have the effect of shifting the supply of used oil towards re-refining.

Legislated markets for re-refined oil, and the resultant price that could be charged, should increase potential profitability sufficiently for re-refiners to outbid other users for available used oil supplies.

### 17.7.2 Capital Availability

Difficulties in obtaining loans from the private sector for plant expansion, modernization, and/or construction are related to (1) the lack of familiarity with the re-refining industry, (2) an apprehension in investing in an industry that does not have an assured supply of feedstock, (3) wariness of new, untried processes, and (4) fears that market demand for the product does not exist.

Table 14. Potential Profitability of Various Re-Refining Processes, Cents per Gallon[a]

| Process | Acid-Clay | Clay | Caustic-Clay | Propane Extraction[b] | Distillation-Hydrotreating | BERC Solvent | MZF Solvent |
|---|---|---|---|---|---|---|---|
| Total Production Cost | 83 | 92 | 75 | 73/82 | 70 | 79 | 75 |
| Potential Profitability[c] | 35 | 26 | 43 | 45/36 | 48 | 39 | 43 |

[a] Plant amortization and distribution costs not included.

[b] Reflects reported yields of 82/70 percent.

[c] Relative to current selling price of $1.18 per gallon in bulk drum packaging.

Availability of outside capital for process development, testing, and demonstration appears nonexistent, but is available for those who are demonstrating profitability and only want to expand an existing operation, such as an acid-clay plant. However, a few re-refiners who are part of a larger corporate structure are able to raise capital from internal sources.

Ability to generate capital from the private sector will increase as fears of lending institutions relative to re-refining are removed. This situation may occur as a result of (1) improved profitability of existing operations, and (2) government involvement through such programs as the setting of quality standards, purchase of re-refined products, and investment credits or loan guarantees.

### 17.7.3 Product Acceptance

Major impediments to acceptance of re-refined oil by the private sector are related to uncertainties as to quality, and lack of recognition of brand names belonging to local re-refiners, in contrast to the heavily advertised virgin lube oil products marketed on a national basis.

In the past, specific government regulations have served as impediments to marketing re-refined oil products. These include:

1. Military specifications specifically prohibit the use of re-refined oil. These constraints reach beyond the military in that most federal agencies and many state, local, and private agencies utilize Mil-Spec requirements in their purchase orders.
2. Requirements to label the origin of re-refined oil as coming from used oil results in a connotation of product inferiority.
3. Internal Revenue Service prohibition of tax rebates on the virgin lube oil portion blended with re-refined oil when used in off highway service results in a price disadvantage of re-refined oil relative to virgin oil.

Current government legislation relative to energy conservation should eliminate past impediments, and stimulate the use of re-refined oil, through the following actions:

1. The question of re-refined oil quality should be resolved through tests formulated by the NBS to show substantial equivalency to virgin products.

2. Labeling requirements will be limited to those that state acceptable end use of the product, and may not be worded so as to connotate product inferiority.
3. Regulations prohibiting the use of recycled products by federal agencies will be changed.
4. Federal agencies will purchase recycled products at the maximum extent feasible, even if price is not competitive with virgin products.

## 18. Recommendations

Even though the magnitude of potential energy savings achievable through re-refining is not very large, this form of conservation should be a part of the nation's overall effort to conserve petroleum. Therefore, DOE is encouraged to take an active role in re-refining activities in order to maximize energy savings.

### 18.1 Process Evaluations

As a stimulus to the development and commercialization of energy efficient re-refining processes in the private sector, it is recommended that the DOE undertake a program to verify and evaluate the technical feasibility of proposed processes.* Then, by means of publications, workshops, and other methods of communication, knowledge of this technology will be transferred to industry, who may then implement it in accordance with product demand and other economic factors.

For the purpose of initiating this program, it is recommended that the evaluation be initially performed for two of the more energy efficient processes investigated in this study, the caustic-clay and the MZF solvent processes. The most energy efficient process, distillation-hydrotreating, is excluded from this recommendation because its feasibility is related to distillation column design to prevent coking, and innovative hardware designs are not available for testing. Also, the propane extraction process, which

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*The objective is to resolve the uncertainties underlying the comparative results.

has the potential of large energy savings, is excluded because it is commercially available from the developers, with operating plants to demonstrate all facets of the process to candidate users.

## 18.2 Sludge Utilization

As a near term enhancement of energy savings from re-refining, it is recommended that uses be developed for the waste products of re-refining processes, particularly for the sludge from those processes, which are rich in hydrocarbons, such as acid-clay. Utilization of products manufactured from this sludge in place of those produced from virgin hydrocarbons increases the energy conservation aspects of re-refining and, in addition, converts a process cost into a profit.

## 18.3 Program Implementation

It is recommended that the programs outlined be carried out by reputable organizations with experience in the areas of lubricating oils and chemical processes. The Bartlesville Energy Technology Center, of Bartlesville, Oklahoma, and the Southwest Research Institute, of San Antonio, Texas, are two facilities which fall into this category.

# PART I

# INDUSTRY STATUS AND PRO

# PART I

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## TABLES (Continued)

# SECTION 1

# INTRODUCTION

## 1.1 BACKGROUND

Large amounts of lubricating oil are used in the transportation and industrial sectors of the United States. Annual consumption of such oil is currently about 2.8 billion gallons. Of this total, about 1.2 billion gallons are used for automotive purposes, 1.0 billion gallons for industry (including railroads), and 0.6 billion gallons for other uses, predominantly as process oils.

Lube oils deteriorate in use and must be replaced periodically. Deterioration is caused by a loss of lubricating properties and contamination from external and internal sources. Since as much as 50 percent of the lube oils are consumed in service, the remainder, about 1.4 billion gallons yearly, must be disposed of.

Recycling of used oil reached a peak in 1960, with 300 million gallons re-refined. However, for various technical and economic reasons, re-refining has since declined with only 50 million gallons re-refined in 1975. As a result, large amounts of used lube oil are being disposed of by other means, such as dumping or burning. Aside from the negative environmental aspects of these disposal methods, a valuable natural resource is wasted.

The re-refining industry has long relied on the acid-clay process. This process supplanted the activated-clay and filtration process utilized for reclaiming oil in the days of 500-mile oil changes and straight mineral oil. The primary advantages of the acid-clay process are that (1) the process steps are straightforward, and (2) an acceptable product can be obtained on a consistent basis. Process equipment is simple and economical, and the process is amenable to batch operation on a small scale, which is of interest to the contemporary small operators typical of the re-refining industry. One important disadvantage of the acid-clay process is that the oil yield has declined in recent years, reflecting the increase in complexity of modern highly compounded motor oils and the increased contamination and degradation due to extended drain periods. Furthermore, the sludge produced by the acid-clay process is highly acidic and poses the problem of environmentally safe disposal.

Much interest in used oil and its disposal has been shown by various governmental agencies in the past few years. The Environmental Protection Agency (EPA) has been notable for its work in this area. EPA's primary concern has been the environmentally safe disposal of used oil, of which re-refining may be considered an acceptable method. The concern for safe disposal of used oil still remains. However, with the growing awareness of the finite limits of natural resources and energy, interest in re-refining used oils is expanding.

This desire for energy conservation, resource conservation, and protection of the environment has been evidenced by increasing interest in new re-refining processes to supplant the acid-clay process; i.e., processes which economically and efficiently produce a quality product with minimum waste products requiring disposal.

## 1.2 OBJECTIVES

The primary objective of this study is the assessment of the energy saving potential of re-refining used oil relative to the alternative utilization of used oil as a fuel to recover its heat content by combustion.

The energy saving potential of re-refining is dependent on the process or processes used for re-refining, as well as the energy consumed in producing virgin lube oil. Therefore, the various re-refining processes currently used (of which acid-clay is in predominance) or projected by industry must be critically evaluated with respect to both technical and economic factors. A superior technical process, having high product yields and producing a quality product with a minimum of wastes, is only attractive if it is economical. Currently, re-refining is an unsubsidized private industry that cannot survive unless it is profitable.

Secondary objectives include the assessment of the re-refining industry in terms of its ability to expand and convert to new and more sophisticated processes and its prospects for marketing increasing amounts of re-refined lube oil.

## 1.3 SCOPE

This study addresses (1) the technical and economic aspects of re-refining processes currently in use, (2) processes which have been proposed for use, and (3) processes described in the patent literature. These processes are investigated with the intent of assessing energy intensity and developing capital investment and operating cost requirements.

Production of virgin lube oil is also addressed. A refinery processing sequence typical of the industry is used to assess energy intensity. Economic and cost data for the production of virgin lube oil are not included. These data are not needed in the analysis of the energy saving potential of re-refining, and were considered beyond the scope of this study.

Economic factors related to marketing re-refined oil are examined. This examination is concerned with the various elements involved in marketing which, in conjunction with process economic data, permit an evaluation of the profitability of a re-refinery operation. A marketing analysis is made to project the ability of the industry to expand or convert to new processes. In conjunction with this analysis, institutional impacts on re-refining are addressed.

Utilization of used oil is analyzed from the standpoint of energy conservation. This analysis makes use of two scenarios: (1) All used lube oil is re-refined; (2) all used oil is burned. Other uses of used oil, as viewed from the energy saving potential, are also considered. Finally, recommendations are made for possible future action by DOE or other government agencies.

## 1.4 APPROACH

The approach adopted to execute the study objectives is to draw upon all applicable data from recent studies on lube oil re-refining appearing in the literature, including text books, journal articles, and patent disclosures. This information is augmented by data obtained from those involved in the field of lubricating oil, including refiners, re-refiners, research agencies, and governmental agencies. The data acquired provide the basis for the various analyses required to satisfy the study objectives.

# SECTION 2

# LUBE OIL CHARACTERISTICS

## 2.1 GENERAL

Lubrication is the art of minimizing friction and wear by interposing between rubbing surfaces a film of material, known as a lubricant, which may be gaseous, liquid, or solid (Ref. 3-1). Liquid lubricants are predominantly used in engineering applications because they readily provide separation of surfaces when correctly applied and have a high cooling ability when circulated through the bearing area. Auxiliary materials are increasingly employed to enhance the properties of these lubricating oils for specific applications. Thus, almost all modern engine and industrial lubricants are composed of a neat base stock oil and an additive package, each tailored to meet certain end use requirements. Such lubricants are commonly called compounded oils.

The following paragraphs review the various types, properties, and purposes of base stocks and additives, as well as their degradation with use. Engine, industrial, and specialty oils are discussed in order of decreasing detail. The presentation is not intended to replace the wealth of material available in the literature but only to provide a minimum technical background for later sections of the report.

## 2.2 COMPOSITION AND PROPERTIES

### 2.2.1 Base Stocks

There are three generic categories of liquid lubricating media: animal and vegetable oils, mineral oils, and synthetic oils. Animal and vegetable oils provided the first widely used lubricants. However, their poor chemical stability, exemplified by the ease of attack of atmospheric oxygen at slightly elevated temperatures, often coupled with their relatively high cost, has led to their almost complete substitution as major ingredients in lubricants. Castor oil, palm oil, and sperm oil are still used in this way for special applications. On the other hand, significant quantities of rape seed, lard, castor, palm, and fish oils are compounded with mineral oils when certain lubrication characteristics are needed in such products as cutting fluids, emulsified steam engine lubricants, and textile oils. Inasmuch as the animal and vegetable oils function more as additives than as base oils in these products, they are not treated further in this report. Rather, the discussion addresses, in turn, mineral oil and synthetic oil base stocks.

### 2.2.1.1 Mineral Oil Base Stocks

These lubricants are produced from petroleum and represent the least expensive and most widely used of all the available lubrication products. The hydrocarbons found in mineral oils fall primarily in the following categories (Ref. 2-1).

a. Straight- and branched-chain paraffinic compounds

b. Polycyclic and fused-ring saturated hydrocarbons based on cyclopentane and cyclohexane, collectively known as naphthenes

c. Aromatics, both mononuclear and polynuclear, which are unsaturated ring structures

The straight, long-chain paraffins are wax-like; thus, their concentration must be kept low, especially in oils for use at low temperatures. Conversely, branched-chain paraffins are desirable constituents in a lubricant because of their stability and viscosity-temperature characteristics. The longer the side chains in the molecule, the more marked are these attractive features.

The desirable properties of branched-chain paraffins still exist in those naphthenes in which the number of rings per molecule is low but the side chains and connecting links are long and paraffinic. Ring condensation and short paraffinic chains tend to reduce the favorable viscosity-temperature characteristics and, thus, the suitability of these hydrocarbons for lubricants.

Crude oils and unrefined lubricating oils contain some hydrocarbons in which aromatic rings are a part of the molecular structure. Any sulfur, nitrogen, and oxygen present in the oil is primarily associated with these rings. Inasmuch as lube oil refining has, as one objective, the reduction of aromatics (because of their poor oxidation stability), the concentration of sulfur, nitrogen, and oxygen will also be significantly reduced.

Crude oils and lubricating oils derived from them have historically been classified into three types (Ref. 2-2):

a. Paraffin base or Pennsylvania

b. Intermediate base, also called mixed base or Mid-Continent

c. Naphthene base, also called Coastal, California, or asphalt base

In addition to these three common base designations, a few crude oils contain significant amounts of aromatic hydrocarbons and are called aromatic or benzoid base; such oils are rare in the United States.

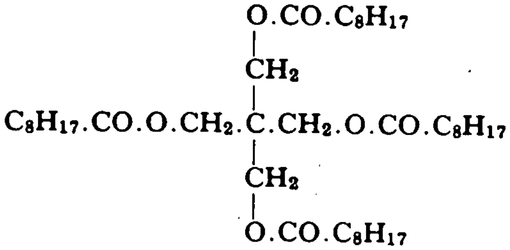
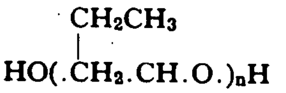
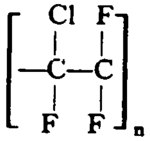
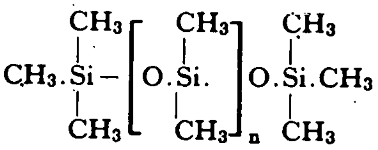
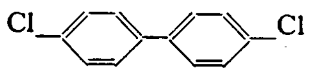
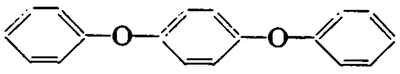
This classification is often misleading because the base of an oil is not necessarily related to the region of origin or to the presence of asphalt or paraffin wax. One danger is the tendency to imbue a crude oil with all the attributes of its base, whereas data show that wide ranges of properties exist in each of the oil bases. Actually, most of the hydrocarbons found in lubricating oils are naphthenes. The three bases can be validly interpreted as referring roughly to the relative proportions of paraffinic chains and saturated rings in the average hydrocarbon molecule in each oil. Several more quantitative systems, such as Viscosity Gravity Constant, Correlation Index, and Characterization Factor, have been developed for classifying mineral oils, but the three common designations of base stock are still widely used.

Paraffin base oils have a high viscosity index (VI), particularly suitable for engine lubrication, but frequently contain a high wax content which must be removed. Naphthenic crudes do not produce high VI oils, but they are quite suitable for many industrial lubrication applications. These crudes do not require dewaxing but usually contain asphalt which must be separated. In general, the high temperature stability required of high-grade engine lubricating oils can be obtained by solvent extraction to remove unstable constituents. A finishing treatment with clay or hydrogen may be desirable to remove the last traces of unstable bodies and to improve color. Although color is not indicative of oil quality, it plays an important role in marketing automotive lubes in that it can connote quality to the buyer. Indeed, removal of all color bodies, as is done for the water white mineral oils used as pharmaceuticals, can result in the loss of normally desirable properties, such as providing corrosion resistance. Additional processing details for mineral oils are presented in Section 6.

### 2.2.1.2 Synthetic Oil Base Stocks

A synthetic fluid is defined as a product made by chemically reacting lower molecular weight materials to produce a fluid of higher molecular weight with planned and predictable properties (Ref. 2-3). Table 2-1

Table 2-1. Synthetic Fluids Used as Lubricants (Ref. 2-1)

| Type | Structure |
|---|---|
| Esters | |
| Di-esters | $C_8H_{17}.O.CO.C_8H_{16}.CO.OC_8H_{17}$ |
| Complex esters |  $\begin{array}{c} O.CO.C_8H_{17} \\ \vert \\ CH_2 \\ \vert \\ C_8H_{17}.CO.O.CH_2.C.CH_2.O.CO.C_8H_{17} \\ \vert \\ CH_2 \\ \vert \\ O.CO.C_8H_{17} \end{array}$ |
| Polyglycols |  $HO(.\overset{\overset{CH_2CH_3}{\vert}}{C}H_2.CH.O.)_nH$ |
| Hydrocarbons | $CH_3.(CH_2.CH_2.CH_2.CH_2.)_nH$ |
| Phosphate esters | $(C_8H_{17}O)_3P{=}O$ |
| Chlorofluorocarbons |  $\left[\begin{array}{cc} Cl & F \\ \vert & \vert \\ -C- & C \\ \vert & \vert \\ F & F \end{array}\right]_n$ |
| Silicones |  $\begin{array}{c} CH_3 \\ \vert \\ CH_3.Si- \\ \vert \\ CH_3 \end{array}\left[\begin{array}{c} CH_3 \\ \vert \\ O.Si. \\ \vert \\ CH_3 \end{array}\right]_n\begin{array}{c} CH_3 \\ \vert \\ O.Si.CH_3 \\ \vert \\ CH_3 \end{array}$ |
| Silicate esters | $Si(O.C_{10}H_{21})_4$ |
| Chlorinated hydrocarbons |  |
| Polyphenyl ethers |  |

shows the principal classes of synthetic fluids and their chemical formulas. The ester lubricants have been available for many years and are now used in all jet aircraft engines. Mobil-1, an automotive engine oil recently introduced by Mobil Oil Corporation, is a mixture of hydrocarbon and ester synthetic fluids (Ref. 2-4). Phosphate esters are used increasingly as fire-resistant lubricants and hydraulic fluids.

Many of these synthetic base stocks are derived in whole or part from petroleum. For example, several types of hydrocarbon oils are manufactured exclusively from petroleum, while the esters vary from 10 to 80 percent in their dependence on petroleum. Other raw materials that are utilized in the manufacture of these products are vegetable and animal oils as well as natural gas. As in the case of mineral oils, the finished synthetic lubricant is an oil comprising the base stock plus supplementary additives.

Lubricants produced entirely by synthetic means cannot generally compete with mineral oils on price, and indeed, some are at present quite expensive. Whereas current automotive mineral oils average about $1 per quart at gas stations for less expensive grades and $0.50 per quart when purchased at discount stores, synthetic oils range in price from $3.50 to over $5 per quart (Ref. 2-4). Accordingly, they find application primarily where some property offers an advantage which mineral oils cannot match; e.g., in cases of extremely high or low temperature operation. Most of the automotive crankcase oil re-refiners contacted during the study indicated that there appeared to be little synthetic oil in the drainings they have been receiving. At least, there appeared to be no effect on yield and no novel operational problems.

### 2.2.2 Additives

The additives in lubricating oils augment the natural properties of the base stock and provide the additional capability required in modern automotive engines and industrial machinery. In 1950, additives comprised less than 5 percent of crankcase oil by volume, whereas the figure is now over 15 percent. Table 2-2 lists some of the many functions these additives are required to perform and the kinds of chemical compounds utilized. Note that a number of the additives perform several functions.

Crankcase oils are not the only lubricants, of course, that contain additives. In fact, almost every lubricating oil, from automatic transmission fluid to industrial cutting oil and hydraulic oil, is carefully formulated with a

Table 2-2. Lubricating Oil Additives (Ref. 2-5)

| Type | Typical Compounds | Reason for Use |
|---|---|---|
| Detergents, Dispersants | Succinimides, neutral metallic sulfonates, phenates, phosphates, polymeric detergents, amine compounds. | Keep sludge, carbon, and other deposit precursors suspended in the oil. |
| Oxidation Inhibitors | Zinc dialkyl dithiophosphates. Compounds of nitrogen and sulfur. Hindered phenols. Bis-Phenols. | Prevent or control oxidation of oil, formation of varnish, sludge, and corrosive compounds. Limit viscosity increase. |
| Alkaline Compounds | Overbased metallic sulfonates and phenates. | Neutralize acids, prevent corrosion from acid attack. |
| Extreme Pressure (EP) Antiwear, Friction Modifiers | Zinc dialkyl dithiophosphates. Tricresyl phosphates. Organic phosphates. Chlorine compounds. | Form protective film on engine parts. Reduce wear; prevent galling and seizing. |
| Rust Inhibitors | High base additives, sulfonates, phosphates, organic acids or esters, amines. | Prevent rust on metal surfaces by forming protective surface film or neutralizing acids. |
| Metal Deactivators | Zinc dialkyl dithiophosphates, metal phenates, organic nitrogen compounds. | Form film so that metal surfaces do not catalyze oil oxidation. |
| Viscosity Index Improvers | Polyisobutylene, methacrylate, acrylate polymers. May incorporate detergent groups. | Reduce the rate of viscosity change with temperature; reduce fuel consumption. Maintain low oil consumption. Allow easy cold starting. |
| Pour Point Depressants | Methacrylate polymers. | Lower "freezing" point of oils, assuring free flow at low temperatures. |
| Antifoamants | Silicone polymers | Reduce foam in crankcase and blending. |

specific additive package for the particular service. Although these additives have significantly increased the performance and life of both oil and equipment, they have also made the job of re-refining the used oil much more difficult. Such elements as barium, calcium, magnesium, zinc, sodium, sulfur, nitrogen, chlorine, and phosphorus found in the crankcase drainings come primarily from the additive compounds and must be substantially reduced, during processing, before reformulation with fresh additives.

With this brief review of the major components of lubricating oils, it is now appropriate to discuss the processes by which the oils are degraded with use and the resultant composition of drain oils which make up the feedstock to the re-refiner.

## 2.3 USED OIL DEGRADATION

There are two basic reasons why a lubricant fails to lubricate (Ref. 2-6):

a. During service, the lubricant loses some of the lubricating properties provided by the additives; i.e., the additives are depleted.

b. The oil becomes contaminated from internal and external sources.

Oils do not suddenly wear out; loss of lubricating properties and buildup of contaminants are normally slow processes. Moreover, both mechanisms usually occur simultaneously and are interrelated. The organization of this discussion follows this sequence and points out the interaction of these mechanisms.

Additives are either consumed or reach the limit of their capability. Consider first the case of oxidation. Oxygen chemically combines with oil molecules, particularly in engine lubricating systems where the oil is exposed to high temperatures, blowby gases and air, and metal surfaces. Such oxidation can form corrosive acids that attack metals, the resultant metal salts further catalyzing the oxidation. Oxidation inhibitors can reduce the rate of oxygen attack but, in the process, are themselves chemically changed or consumed. Continued oxidation then yields products that are, eventually, insoluble in the bulk oil, forming varnish and sludge. Oil viscosity increases, resulting in higher engine friction and operating temperature.

Rust inhibitors are also sacrificial, but they are expended in a somewhat different manner. Because of their surface activity, they are attracted to the interface between oil and contaminating water or between oil and metal particles. Removal of these contaminants by filters or separation in the crankcase or sump results in loss of inhibitor content and failure of the oil to provide the rust prevention it originally possessed.

Another example of additive depletion occurs when extreme pressure (EP) additives are used up under severe service conditions. Also, multiviscosity or multigrade oils incorporate polymeric additives called VI improvers. The large VI improver molecules are subject to shearing and high-temperature breakdown in high-speed engine operation, resulting in viscosity reduction. Although there have been major improvements in shear stable additives of this type, they are not always used in lower-cost oils.

Dispersant and detergent additives illustrate the second type of additive failure. These compounds are essential in controlling deposits caused by contaminants and oxidation. They keep this debris in a fine state of suspension until it is removed from the system at the time of oil drain. These additives function by forming an envelope around the contaminant. Under severe conditions or extended oil usage, the dispersant material is expended in the formation of these envelopes. Gradually, the fine particles agglomerate. When they can no longer remain suspended, the sludge and resins that form deposit in the engine.

The other mechanism whereby lubricating oil quality is degraded is contamination, both solid and liquid. Solid contaminants found in crankcase oils include soot and lead compounds from engine blowby, dirt and atmospheric dust, engine wear metals, and rust. In industrial lubricants, sand and other atmospheric debris may be prevalent in the local environment and find their way into the oil system through faulty filters and seals. Mill scale and machining particles are other sources of solid contamination. Filters remove all but the extremely fine particles if properly designed and operated, but some damage can be done before this is accomplished.

Liquid contaminants come from several sources. Water is most prevalent in both automotive crankcase oil and industrial lubricants. In the former case, the vapor enters from blowby or atmospheric humidity, while coolant liquid may enter from a leaking gasket or cracked head. Water itself causes rust, weakens the lubricating film, interferes with some additives, and can form emulsions. Unburned fuel in the crankcase reduces oil viscosity and thus promotes bearing wear.

Industrial oils may become contaminated with aqueous process fluids, which may be more deleterious than water alone. Specialty oils, such as those used in transformers, provide insulation and cooling. In time, the oil oxidizes and the reservoir breathes. Both oxidation products and water reduce insulating properties, while the former eventually foul the cooling surfaces.

## 2.4 CHARACTERISTICS OF USED OIL

Many of the components in used lubricating oils have been identified in the preceding section. Additional, more quantitative data on the composition and properties of these oils are presented on the following pages.

Because automotive crankcase drainings represent the single largest, homogeneous source of used oil, it has been studied and characterized the most in recent years. Therefore, the preponderance of available data relates to this type of used oil.

It should be noted at this point that the properties generally reported for crankcase oil, particularly those included here, are not for oil as it comes from the vehicle but rather as it has been sampled at some point in the collection system. The latter approach is more meaningful for a study of re-refining technology since it represents the feedstock that must be processed. While compositing of individual drainings provides a more uniform product, the collection sequence also allows additional opportunity for contamination of the oil. The largest single contaminant is water, which usually enters through careless handling of the drainings but may occasionally be added intentionally. The only other identifiable contaminant, albeit in minor concentrations, is antifreeze (ethylene glycol). Undoubtedly, other materials, e.g., paint, solvents, and refuse, find their way into the drainings, but these contaminants are either in small amounts or indistinguishable from other constituents.

Probably the most recent and comprehensive examination of used automotive oil was accomplished by the Bartlesville Energy Research Center (BERC) (Ref. 2-7). Thirty waste-oil samples were collected from twenty states at different times of the year. They were analyzed by standard physical and chemical tests to measure contaminant levels, while chromatographic and mass spectral techniques were used to estimate the quantity of probable compound types and the distribution of major structural groups.

Table 2-3 contains physical properties of used lubricating oils, including measurements of water, sediment, insolubles, fuel dilution, and antifreeze. The viscosity of two samples, No. 1487 and 1489, indicates that these oils were not wholly derived from automobile crankcase drainings; the high viscosity suggests an SAE 40 or 50 weight oil. Water content varied from 0.2 percent to a high value of 33.8 for the No. 1489 sample; the average was 7.9. Fuel dilution varied from 0.4 to 9.7 percent with an average of 4.0.

Table 2-4 contains other physical and chemical properties of the 30 used oils, including saponification number, acid number, and base number, all of which reflect the additive content of the oils. Sulfur and nitrogen values

Table 2-3. Physical Properties of 30 Used Lubrication Oils (Ref. 2-7)

| Sample No. | Viscosity SUS[(a)] 100°F | Viscosity SUS 210°F | Viscosity Index | Specific Gravity 60/60°F | BS&W,[(b)] % | Water, % | Pentane Insolubles, % | Benzene Insolubles, % | Fuel Dilution, % | Anti-freeze[(c)] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1465 | 255 | 56.7 | 168 | 0.904 | 8 | 2.8 | 1.15 | 0.81 | 5.7 | Positive |
| 1466 | 435 | 72.4 | 158 | 0.932 | 14 | 5.7 | 4.38 | 1.26 | 2.0 | Trace |
| 1467 | 340 | 61.7 | 145 | 0.908 | 13 | 7.9 | 1.75 | 0.64 | 4.7 | Positive |
| 1468 | 425 | 69.0 | 145 | 0.917 | 14 | 11.5 | 2.62 | 0.82 | 2.9 | Positive |
| 1469 | 295 | 55.2 | 124 | 0.904 | 8 | 4.0 | 0.74 | 0.56 | 3.4 | Positive |
| 1470 | 345 | 62.3 | 146 | 0.920 | 12 | 7.5 | 2.42 | 0.99 | 2.6 | Positive |
| 1471 | 220 | 53.7 | 168 | 0.904 | 10 | 5.3 | 1.30 | 0.82 | 9.7 | Positive |
| 1473 | 286 | 61.4 | 176 | 0.906 | 8 | 3.7 | 3.16 | - | 3.2 | Positive |
| 1474 | 425 | 70.9 | 154 | 0.929 | 17 | 13.7 | 4.64 | 0.95 | 3.0 | Positive |
| 1476 | 305 | 60.5 | 156 | 0.908 | 6 | 0.2 | 1.29 | 1.24 | 2.6 | Negative |
| 1477 | 315 | 58.4 | 137 | 0.901 | 10 | 5.3 | 2.13 | 0.82 | 3.6 | Positive |
| 1478 | 345 | 60.9 | 137 | 0.905 | 16 | 8.0 | 5.02 | 0.75 | 2.2 | Positive |
| 1479 | 295 | 56.8 | 137 | 0.901 | 15 | 6.3 | 2.16 | 0.76 | 2.6 | Positive |
| 1480 | 300 | 60.8 | 162 | 0.914 | 23 | 15.5 | 2.64 | 0.49 | 6.8 | Positive |
| 1481 | 310 | 59.9 | 149 | 0.906 | 14 | 4.2 | 2.82 | 1.14 | 3.6 | Positive |
| 1482 | 240 | 52.5 | 136 | 0.897 | 15 | 6.2 | 1.06 | 0.85 | 6.4 | Positive |
| 1483 | 300 | 61.8 | 168 | 0.907 | 10 | 13.3 | 1.95 | 1.24 | 5.8 | Positive |
| 1484 | 305 | 59.5 | 149 | 0.903 | 16 | 7.8 | 0.92 | 0.71 | 6.8 | Positive |
| 1485 | 315 | 59.9 | 147 | 0.905 | 15 | 5.5 | 1.95 | 1.01 | 6.2 | Positive |
| 1486 | 315 | 61.1 | 154 | 0.910 | 15 | 8.3 | 2.37 | 1.00 | 3.4 | Positive |
| 1487 | 1261 | 126.6 | 136 | 0.921 | 5 | 7.0 | 2.73 | 0.80 | 0.4 | Positive |
| 1488 | 250 | 54.9 | 151 | 0.911 | 16 | 7.5 | 2.22 | 0.97 | 7.0 | Positive |
| 1489 | 1032 | 128.6 | 164 | 0.938 | 42 | 33.8 | 3.17 | 0.68 | 2.0 | Positive |
| 1492 | 325 | 57.7 | 126 | 0.901 | 6 | 0.7 | 1.27 | 1.15 | 1.2 | Negative |
| 1493 | 395 | 57.4 | 96 | 0.910 | 16 | 8.8 | 1.09 | 0.75 | 5.0 | Negative |
| 1494 | 350 | 64.5 | 156 | 0.916 | 22 | 14.8 | 2.98 | 0.89 | 2.0 | Positive |
| 1495 | 285 | 56.5 | 141 | 0.891 | 4 | 0.6 | 0.82 | 0.52 | 2.0 | Positive |
| 1496 | 300 | 58.9 | 176 | 0.906 | 20 | 8.9 | 3.00 | 0.99 | 6.5 | Positive |
| 1497 | 375 | 66.1 | 152 | 0.914 | 1 | 10.6 | 1.69 | 0.91 | 5.8 | Positive |
| 1498 | 415 | 67.7 | 143 | 0.908 | 0.4 | 0.4 | 2.09 | 1.86 | 1.6 | Positive |

[(a)] Saybolt universal seconds.

[(b)] Bottom solids and water (BS&W).

[(c)] Positive = greater than 0.1 percent; trace = less than 0.1 percent.

also derive principally from the additives, although there are some naturally occurring sulfur and nitrogen compounds in petroleum-based lubricating oil stocks. Flash and pour points are affected by volatile contaminants such as solvents and fuel; these values are less significant in defining quality than in indicating the degree of contamination.

Table 2-5 shows the metal content of the oils in parts per million (ppm) as obtained primarily by atomic absorption. The first six elements, barium, calcium, magnesium, sodium, phosphorus, and zinc, are commonly associated with additive compounds. The wear and contaminant metals include aluminum, chromium, copper, iron, potassium, manganese, nickel, lead, silicon, and tin. Lead accumulates in the automotive crankcase

Table 2-4. Chemical and Physical Properties of 30 Used Lubricating Oils (Ref. 2-7)

| Sample No. | Carbon Residue, % | Ash, % | Flash Point, °F | Pour Point, °F | Saponification No. | Total Acid No. | Total Base No. | Nitrogen, % | Sulfur, % |
|---|---|---|---|---|---|---|---|---|---|
| 1465 | 3.78 | 1.47 | 204 | -35 | 11.38 | 5.28 | 1.46 | 0.104 | 0.39 |
| 1466 | 4.43 | 1.81 | 427 | -25 | 15.51 | 6.85 | 1.10 | 0.094 | 0.38 |
| 1467 | 2.99 | 1.41 | 360 | -30 | 9.74 | 4.35 | 1.90 | 0.068 | 0.36 |
| 1468 | 2.86 | 1.46 | 403 | -25 | 12.17 | 4.28 | 2.32 | 0.073 | 0.45 |
| 1469 | 1.82 | 0.95 | 367 | -35 | 13.04 | 3.04 | 1.36 | 0.062 | 0.44 |
| 1470 | 3.26 | 1.56 | 398 | -25 | 20.95 | 5.64 | 1.95 | 0.076 | 0.38 |
| 1471 | 2.46 | 1.18 | 222 | -45 | 13.44 | 3.55 | 1.97 | 0.095 | 0.42 |
| 1473 | 4.30 | 1.71 | 365 | -30 | 14.37 | 5.63 | 1.48 | 0.084 | 0.45 |
| 1474 | 3.52 | 1.51 | 406 | -30 | 12.47 | 5.37 | 2.12 | 0.072 | 0.34 |
| 1476 | 4.30 | 1.63 | 335 | -40 | 15.49 | 5.04 | 1.22 | 0.099 | 0.54 |
| 1477 | 2.99 | 1.29 | 360 | -40 | 9.40 | 3.75 | 2.35 | 0.075 | 0.50 |
| 1478 | 2.74 | 1.08 | 370 | -35 | 10.27 | 4.06 | 1.66 | 0.070 | 0.40 |
| 1479 | 2.86 | 1.06 | 380 | -35 | 10.72 | 3.72 | 1.32 | 0.071 | 0.46 |
| 1480 | 2.72 | 0.99 | 380 | -45 | 13.19 | 2.87 | 2.29 | 0.060 | 0.46 |
| 1481 | 3.26 | 1.38 | 380 | -40 | 12.26 | 5.00 | 1.53 | 0.087 | 0.53 |
| 1482 | 2.30 | 0.94 | 255 | -45 | 10.17 | 3.45 | 1.54 | 0.061 | 0.45 |
| 1483 | 2.59 | 1.25 | 350 | -40 | 12.03 | 3.85 | 2.18 | 0.077 | 0.33 |
| 1484 | 2.86 | 1.10 | 375 | -40 | 11.90 | 3.36 | 1.55 | 0.070 | 0.41 |
| 1485 | 3.39 | 1.39 | 250 | -40 | 10.85 | 4.25 | 2.55 | 0.102 | 0.44 |
| 1486 | 3.12 | 1.27 | 355 | -40 | 14.34 | 4.92 | 1.05 | 0.086 | 0.41 |
| 1487 | 4.17 | 1.66 | 440 | -30 | 17.94 | 6.78 | 1.84 | 0.177 | 0.44 |
| 1488 | 2.30 | 1.18 | 315 | -40 | 15.64 | 3.97 | 1.77 | 0.078 | 0.40 |
| 1489 | 1.90 | 0.94 | 405 | -25 | 9.34 | 3.65 | 1.66 | 0.053 | 0.22 |
| 1492 | 2.43 | 1.56 | 380 | -40 | 12.41 | 4.65 | 1.41 | 0.096 | 0.40 |
| 1493 | 2.57 | 0.70 | 310 | -20 | 6.07 | 2.44 | 1.16 | 0.069 | 0.37 |
| 1494 | 2.59 | 1.17 | 405 | -40 | 13.66 | 3.93 | 1.72 | 0.055 | 0.35 |
| 1495 | 2.99 | 1.13 | 355 | -40 | 10.64 | 3.80 | 1.46 | 0.089 | 0.46 |
| 1496 | 3.39 | 1.39 | 305 | -40 | 14.40 | 4.98 | 1.24 | 0.062 | 0.38 |
| 1497 | 2.33 | 1.37 | 370 | -40 | 13.30 | 4.90 | 1.80 | 0.077 | 0.38 |
| 1498 | 2.18 | 2.20 | 365 | -40 | 16.85 | 5.70 | 1.52 | 0.100 | 0.47 |

as the lubricant becomes contaminated with leaded gasoline and combustion products. Note that the lead content reached almost 14,000 ppm (1.4 percent), with an average of about half this value. Sample No. 1493 appears to be unique in both its content of additive-associated elements and low lead, which suggests the possibility of industrial origin.

The composition of the petroleum-based materials of these oils was characterized in Reference 2-7 by use of a chromatographic separation procedure to produce saturate, monoaromatic, diaromatic, and polyaromatic polar fractions. These fractions were further analyzed by mass spectral techniques. The data are too voluminous to include here but are briefly summarized. Only one sample, No. 1487, showed what may be a significant difference in base composition. Even sample No. 1493, which showed unusually low concentrations of many metallic components, indicated a base composition deviating only slightly from the other crankcase drainings. On the basis of all the analyses conducted, BERC concluded that feedstock to re-refiners is similar in

## Table 2-5. Metals and Phosphorus Content of 30 Used Lubricating Oils (Ref. 2-7)

| Sample No. | ELEMENT: ppm | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ba | Ca | Mg | Na | P[a] | Zn | Al | Cr | Cu | Fe | K | Mn | Ni | Pb | Si | Sn | V |
| 1465 | 180 | 1775 | 311 | 64 | 1080 | 1201 | 12 | 9 | 33 | 137 | 31 | 3 | 1 | 4, 720 | < 15 | 6 | 0 |
| 1466 | 693 | 1480 | 325 | 42 | 1118 | 1267 | 27 | 22 | 33 | 306 | 13 | 4 | 1 | 13, 885 | < 15 | 7 | 0 |
| 1467 | 286 | 1245 | 236 | 142 | 889 | 1000 | 15 | 12 | 27 | 200 | 34 | 3 | 1 | 7, 070 | <15 | 2 | 0 |
| 1468 | 175 | 1393 | 323 | 41 | 1006 | 952 | 12 | 14 | 27 | 162 | 33 | 8 | 1 | 5, 225 | <15 | 2 | 0 |
| 1469 | 131 | 1260 | 138 | 55 | 740 | 629 | 41 | 7 | 17 | 164 | 9 | 8 | 1 | 3, 730 | <15 | 5 | 0 |
| 1470 | 148 | 1308 | 384 | 132 | 1012 | 1239 | 13 | 10 | 26 | 222 | 26 | 6 | 1 | 8, 460 | <15 | 6 | 0 |
| 1471 | 229 | 1315 | 236 | 207 | 782 | 1023 | 10 | 10 | 39 | 151 | 72 | 3 | 2 | 5, 860 | < 15 | 3 | 0 |
| 1473 | 176 | 1675 | 425 | 54 | 1138 | 1316 | 15 | 12 | 20 | 249 | 20 | 3 | 1 | 10, 560 | 19 | 4 | 0 |
| 1474 | 204 | 1295 | 312 | 79 | 1074 | 1151 | 15 | 12 | 31 | 212 | 16 | 3 | 1 | 8, 450 | < 15 | 3 | 0 |
| 1476 | 124 | 1413 | 599 | 8 | 895 | 1169 | 12 | 21 | 6 | 170 | 5 | 2 | 1 | 11, 575 | <15 | 3 | 0 |
| 1477 | 430 | 1401 | 225 | 115 | 871 | 990 | 13 | 7 | 22 | 119 | 41 | 3 | 0 | 6, 495 | 43 | NA[b] | 0 |
| 1478 | 485 | 1317 | 165 | 72 | 672 | 668 | 14 | 8 | 43 | 203 | 79 | 4 | 0 | 7, 595 | 25 | NA | 0 |
| 1479 | 428 | 1072 | 259 | 95 | 815 | 780 | 13 | 5 | 41 | 150 | 24 | 2 | 0 | 6, 560 | 39 | NA | 0 |
| 1480 | 260 | 1431 | 227 | 660 | 764 | 860 | 10 | 7 | 41 | 129 | 20 | 8 | 0 | 4, 890 | 38 | NA | 0 |
| 1481 | 203 | 1358 | 458 | 102 | 1015 | 1233 | 12 | 8 | 38 | 212 | 33 | 3 | 0 | 10, 410 | 36 | NA | 0 |
| 1482 | 144 | 1267 | 261 | 89 | 708 | 910 | 7 | 6 | 37 | 116 | 25 | 2 | 0 | 4, 165 | 27 | NA | 0 |
| 1483 | 278 | 1008 | 297 | 357 | 778 | 1040 | 21 | 24 | 37 | 655 | 83 | 8 | 0 | 8, 005 | 87 | NA | 0 |
| 1484 | 520 | 1170 | 182 | 100 | 674 | 660 | 11 | 8 | 18 | 179 | 57 | 4 | 2 | 4, 560 | 37 | NA | 0 |
| 1485 | 333 | 1704 | 209 | 81 | 996 | 1140 | 13 | 8 | 41 | 173 | 37 | 3 | 2 | 7, 680 | 32 | NA | 0 |
| 1486 | 319 | 1435 | 375 | 125 | 961 | 980 | 20 | 11 | 31 | 216 | 36 | 4 | 2 | 7, 570 | 51 | NA | 0 |
| 1487 | 185 | 2225 | 999 | 45 | 1393 | 2500 | 17 | 8 | 7 | 153 | 5 | 2 | 4 | 7, 730 | 25 | NA | 0 |
| 1488 | 494 | 1263 | 286 | 127 | 747 | 933 | 11 | 12 | 37 | 181 | 45 | 3 | 5 | 7, 825 | 40 | NA | 0 |
| 1489 | 200 | 969 | 171 | 150 | 675 | 705 | 14 | 11 | 13 | 178 | 15 | 2 | 4 | 6, 885 | 8 | NA | 0 |
| 1492 | 494 | 3126 | 220 | 23 | 982 | 1409 | 19 | 6 | 56 | 171 | 17 | 3 | <1 | 6, 980 | 16 | 6 | 0 |
| 1493 | 10 | 3986 | 8 | 67 | 81 | 80 | 4 | 8 | 13 | 88 | 14 | 1 | <1 | 19 | 14 | 0 | 0 |
| 1494 | 297 | 1620 | 520 | 59 | 880 | 1029 | 13 | 10 | 28 | 192 | 48 | 3 | <1 | 4, 855 | 26 | 4 | 0 |
| 1495 | 377 | 983 | 147 | 34 | 1197 | 1527 | 6 | 5 | 12 | 102 | 6 | 2 | <1 | 1, 362 | 15 | 3 | 0 |
| 1496 | 547 | 1050 | 233 | 64 | 857 | 725 | 18 | 12 | 27 | 216 | 24 | 4 | 1 | 8, 655 | 25 | 1 | 0 |
| 1497 | 213 | 1505 | 310 | 169 | 881 | 1150 | 18 | 10 | 37 | 272 | 37 | 4 | 2 | 9, 420 | 17 | 8 | 0 |
| 1498 | 59 | 2670 | 338 | 69 | 1341 | 1574 | 25 | 14 | 16 | 342 | 29 | 4 | 1 | 11, 165 | 14 | 14 | 0 |

(a) Analytical method used was ASTM D1091-64; all other values by atomic absorption.

(b) Not analyzed (NA).

petroleum base composition regardless of season or geographical location within the United States. Further, the actual composition of waste oil composited by the normal combination of collected crankcase drainings can be estimated within narrow ranges (Ref. 2-7). The implications of these findings for qualification of re-refined oil are discussed in Section 9.

## 2.5 TESTING USED OIL

Used oil may be tested for many reasons, ranging from the re-refiner who wants to know how much water and sediment are in the feedstock he is buying to the plant lubricant engineer who needs to find out why there has been a sudden change in the color or odor of a machine oil. Analytical instrumentation may be the eyes or nose of the foreman or a sophisticated laboratory spectrometer. A brief review of some aspects of oil testing is presented in this section.

Most re-refiners have very limited test facilities (Motor Oils Refining Company, the country's largest, is a notable exception). Incoming used oil is only centrifuged to quickly determine water contamination. The product may be checked with a viscosimeter and visually inspected for color. It would be rare for additional analyses, e.g., metal content, to be run on a re-refiner's product. If done at all, it would be by an outside agency (commercial laboratory or customer). On the other hand, lube oil producers and additive manufacturers usually have extensive research facilities and analytical equipment.

On the using side, oil in service is tested primarily by large volume operators of automobile and truck fleets, railroads, and ships; industrial and utility plants; and government installations. Such testing is done to measure the condition of the oil and when it should be changed, as well as to monitor the proper functioning of the machine or engine lubricated.

Used oils are usually tested in two stages (Refs. 2-6 and 2-8). A series of basic tests are run first to measure key properties and determine whether any gross breakdown or contamination has occurred. These tests are relatively quick, inexpensive, and capable of being run in the field. Supplemental tests are run when quantitative data or additional information are needed.

The sensory tests are the first and easiest to run and can supply much information to a trained observer. Visual examination for color, clarity, and approximate viscosity often reveals abnormal conditions. Odor is another subjective test which can indicate oxidation or excessive fuel dilution. One of the simplest tests to make involves placing a drop of oil on special blotter-type paper, such as filter paper. The appearance of the spot gives an indication of the quantity of sludge-forming material suspended in the sample and a measure of the oil's ability to disperse such material. A quick screening-type test for water content is a "crackle" test. A few drops of oil are heated on a hot (250°

to 300°F) metal surface. If the oil crackles, pops, or splatters, water in excess of 0.1 to 0.2 percent may be present.

Viscosity is a basic physical property of lubricants and one of the first to be run after the sensory tests. A rough measurement can be made at the site, but more precise results are obtained in the laboratory. Viscosity is usually determined at 100° or 210°F by recording the time required for a given quantity of oil to pass through a calibrated orifice. An increase in viscosity over fresh oil can indicate oxidation or contamination, while a decrease may be due to fuel dilution or shearing of the VI additive. Additional tests are usually necessary to confirm the suspected causes for the viscosity change.

It is not the intent in this section to review every type of test run on lubricating oils. Most tests have been standardized by the American Society for Testing and Materials (ASTM). Table 2-6 lists the standard ASTM methods

Table 2-6. ASTM Standard Methods of Test for Engine Lubricating Oils (Ref. 2-8)

| Common Name | ASTM Designation[a] | ASTM Name for Standard Method of Test |
|---|---|---|
| Gravity or Density[b] | D 287 | API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method) |
| Color[b] | D 1500 | ASTM Color of Petroleum Products (ASTM Color Scale) |
| Carbon Residue[b] | D 189 | Conradson Carbon Residue of Petroleum Products |
| Flash and Fire Points (Cleveland Open Cup -- COC) | D 92 | Flash and Fire Points by Cleveland Open Cup |
| Flash Point (Closed Cup) | D 93 | Flash Point by Pensky-Martens Closed Tester |
| Pour Point[b] | D 97 | Pour Point |
| Viscosity (Centistokes) | D 445 | Viscosity of Transparent and Opaque Liquids (Kinematic and Dynamic Viscosities) |
| Viscosity Index[b] | D 2270 | Calculating Viscosity Index from Kinematic Viscosity |
| Viscosity Conversion | D 2161 | Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity |
| Viscosity-Temperature Charts | D 341 | Standard Viscosity-Temperature Charts for Liquid Petroleum Products |
| Fuel Dilution | D 322 | Dilution of Gasoline-Engine Crankcase Oils |
| Water | D 95 | Water in Petroleum and Other Bituminous Materials |
| Foaming Tendency | D 892 | Foaming Characteristics of Lubricating Oils |
| Insolubles | D 893 | Insolubles in Used Lubricating Oils |
| Precipitation Number | D 91 | Precipitation Number of Lubricating Oils |
| Trace Sediment | D 2273 | Trace Sediment in Lubricating Oils |
| Acid Number (TAN or TAN). Base Number (TBN or TBN). pH | D 664 | Neutralization Number by Potentiometric Titration |
| TBN by Perchloric Acid Method or Alkalinity Value | D 2896 | Total Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration |
| TAN SAN TBN (Colorimetric)[b] | D 974 | Neutralization Number by Color Indicator Titration |
| Ash[b] | D 482 | Ash from Petroleum Products |
| Ash (Sulfated) | D 874 | Sulfated Ash from Lubricating Oil and Additives |
| Metals[b] | D 811 | Chemical Analysis for Metals in New and Used Lubricating Oils |
| Phosphorus[b] | D 1091 | Phosphorus in Lubricating Oils and Additives |
| Sodium[b], [c] | D 1026 | Sodium in Lubricating Oils and Additives (Gravimetric Method) |
| Sulfur[b], [c] | D 1552 | Sulfur in Petroleum Products (High Temperature Method) |

[a] These numbers may be followed by a dash ( -- ) and other numbers or letters which indicate year of issue, revision, and/or adoption.

[b] Used primarily for fresh oils or additives.

[c] Sulfur can also be measured by other methods, including D 129, D 1551, or D 2622.

for engine oils, while Table 2-7 gives similar information for industrial lubricants. For many tests, the same ASTM method can be used for both kinds of oil.

Some tests, e.g., interfacial tension and dielectric strength, are appropriate only for special industrial oil applications. Also, several tests listed in Table 2-7 as not having an ASTM standard method are often used for engine oil analysis. In particular, metal analysis is used both to determine the level of wear or contaminant metals in used oil and the degree to which they

Table 2-7. Relative Order of Testing Used Industrial Lubricants (Ref. 2-6)

| Tests | ASTM Method No. D | Type Service(a) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Turbine | Circulating | Hydraulic | Compressor | | Gear | Heat Transfer | Insulating | Fire Resistant |
| | | | | | Refrigeration | Other | | | | |
| Appearance (relative to New Oil) | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Color | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Odor | - | | 1 | 1 | | 1 | 1 | 1 | 1 | |
| Water | Visual | 1 | 1 | 1 | | | 1 | | 1 | 1 |
| | 95(b) | | | | | | | | | |
| | 1744 | | | | 1 | | | | 1 | |
| Solids | Visual | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Millipore 96(b) | | | | | | | | | 2 |
| Specific Gravity | 1480 | | | | | | | | | 2 |
| Ash, Regular, o/o | 482 | | 2 | 2 | | | | | | |
| Ash, Sulfated, o/o | 874 | | | | | | 1 | | | |
| X-ray Diffraction | - | | 2 | 2 | | | 2 | | | |
| Viscosity at 100°F, SUS(c) | 445 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Viscosity at 210°F, SUS(c) | 445 | 1 | 1 | 1 | | 1 | 1 | 1 | | |
| Blotter Spot Test | - | 2 | 1 | 1 | | | | 1 | | |
| Pentane Insolubles | 893 | | 2 | | | | 2 | 1 | 3 | |
| Benzene Insolubles | 893 | | 2 | | | | 2 | | 3 | |
| Flash Point, °F | 92 | | | | | | | 2 | 3 | |
| Pour Point, °F | 97 | | | | 2 | | | | | |
| Foam Tendency/Stability | 892 | 2 | 3 | 3 | | | 3 | | | |
| Demulsibility | 1401 | 2 | 3 | 3 | | | | | | |
| Interfacial Tension | 971 | | | | | | | | 3 | |
| Dielectric Strength, kV | 877 | | | | 2 | | | | 2 | |
| Oxidation Resistance | 943 | 3 | 3 | | | | | 3 | | |
| Rust Protection | 665 | 2 | 2 | 3 | | | | | | |
| Corrosion | - | 3 | 3 | | | | | 3 | | |
| Extreme Pressure | 2509 | | | | | | 3 | | | |
| Acid No. | 974 | 1 | | | | | | | 1 | 1(d) |
| Base No. | 2896 | | 2 | | | | | 1 | | |
| Metal Analysis | - | | 2 | 3 | | | | 3 | | |
| Infrared Analysis | - | 3 | 3 | 3 | | 3 | | 3 | | |
| Gas Chromatography | - | | | | 3 | 3 | | | | |
| Autoignition Temperature | 2155 | | | | | | | | | 1 |

(a) 1, 2, 3: order in which tests are usually run.

(b) More precise methods for use, if required, after visual examination.

(c) Use ASTM D 2161 for conversion of centistoke to SUS viscosity units.

(d) Special methods.

have been removed after re-refining. Most oils are now tested rapidly and accurately for metal content by instrumental means, utilizing emission spectrometer, atomic absorption, and x-ray fluorescence techniques.

The results of lubricant testing must be examined in light of the particular application, operating conditions, and past experience in order to be meaningful. When so interpreted, the data can be useful in setting the drain period and indicating abnormal engine or machine operation or failure of filtration equipment. More pertinent to this report, the tests can be employed to characterize the used oil feedstock the re-refiner receives and the quality of the product he sells. Other measures of quality are discussed in Section 9.

## 2.6 REFERENCES

2-1 G.D. Hobson and W. Pohl, Modern Petroleum Technology, John Wiley & Sons, New York (1973).

2-2 W.L. Nelson, Petroleum Refinery Engineering, McGraw-Hill Book Company, New York (1958).

2-3 W.C. Gergel, "The Facts and Fiction of Synthetic Oils," Paper presented at Independent Oil Compounders Annual Meeting (7 October 1975).

2-4 "Those Synthetic 'Oils'," Industrial Research (June 1976).

2-5 Automotive Engine Oils -- What They Are and How They Work, Chevron Research Bulletin, Richmond, California (1975).

2-6 Testing Used Industrial Oils -- Why, When and How, Chevron Research Bulletin, Richmond, California (1975).

2-7 M.L. Whisman, et al., Waste Lubricating Oil Research: Part 4, Report No. BERC/RI-7614, Bartlesville Energy Research Center, Bartlesville, Oklahoma (October 1976).

2-8 Testing Used Engine Oils -- Why and How, Chevron Research Bulletin, Richmond, California (1973).

# SECTION 3

# USED OIL GENERATION AND DISPOSAL

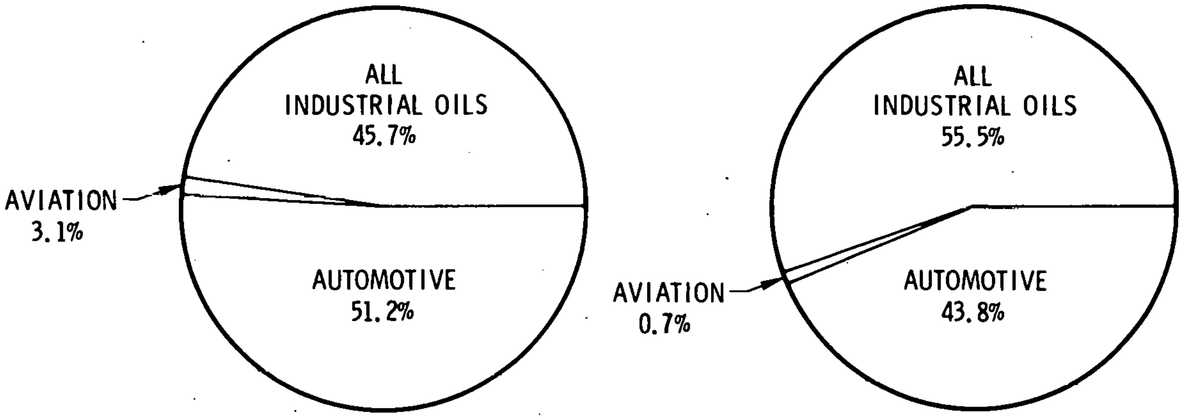
## 3.1 GENERAL

Lube oil sales are grouped in the Bureau of Census (BOC) format into three major categories: automotive, industrial, and aviation. Other sources sometimes add additional categories. In this report, the BOC classification system is used. The automotive category includes passenger autos, taxis, buses, and trucks (gasoline and diesel). The industrial category is subdivided into two groups; industrial lube oils and other lube oils. Industrial lube oils are used by industry for lubrication purposes and include lube oils for railroad diesel engines and journal boxes. The second group, identified as other lube oils, consists primarily of oils which are incorporated and consumed in a product, such as putty or paint, and specialty oils, such as hydraulic fluids, which may not normally be thought of as having a lubrication function. This study focuses principally on automotive and industrial lube oils.

In the collection of published lubricating oil production and sales data, it is extremely difficult to establish a consistent data reference. Comparison of publications by the Bureau of Mines (BOM), BOC, and Current Business Statistics reveals differences which appear to be related to different, not always stated, definitions. While the BOM provides a more complete historical record, it does not categorize by type of lube as BOC does; thus, its data do not permit detailed analysis. Also, BOM data are lower than BOC data, which precludes statistical comingling of data without prior adjustments. It appears that a large part of the observed differences in the two data sources are due to the fact that BOC reports sales of finished oil and BOM reports production of base oil stock. In the case of automotive oil this includes a significant volume of additives, as high as 17 percent for a multigrade API SE oil. In general, the larger BOC data are used in this study because they represent the volume of lube material entering the environment and available to re-refiners. Also, the BOC data permit analysis by lube oil category.

Finished lube oil products of all types are both exported and imported by the United States. About 9 million barrels, 13.5 percent of the total lube oil production, were exported in 1975, which is the lowest level since 1947.

Lubricant imports, which began in 1969, rose by 1975 to an annual level of about 1.5 million barrels (Ref. 3-1). The relative market share of industrial and automotive oils within the United States for the years 1958 and 1975 are shown in Figure 3-1. An increasing sales dominance for industrial oils is apparent. The year-to-year sales pattern between 1958 and 1975 is shown in Table 3-1.



1958 (Ref. 3-3)

1975 (Ref. 3-4)

Figure 3-1. Comparison of U.S. Lubricating Oil Market Shares: 1958 and 1975

Table 3-1. Trend in Domestic U. S. Lube Oil Sales, 1958-1975, In Millions of Gallons (Updated from Ref. 3-4)

| Year | Total | Auto | Industrial | |
|---|---|---|---|---|
| | | | Lubricating | Other |
| 1976[a] | 2641.0 | N/A[b] | N/A[b] | N/A[b] |
| 1975 | 2837.3 | 1250.7 | 996.3 | 590.3 |
| 1973 | 3156.4 | 1272.5 | 1184.2 | 699.7 |
| 1971 | 2692.0 | 1126.6 | 1027.0 | 538.1 |
| 1969 | 2767.9 | 1147.3 | 1087.5 | 533.1 |
| 1967 | 2582.9 | 1132.6 | 985.6 | 464.7 |
| 1965 | 2525.0 | 1129.8 | 908.5 | 486.6 |
| 1962[c] | 2307.4 | 1105.9 | 824.9 | 376.6 |
| 1958[c] | 2026.3 | 1070.9 | 653.6 | 301.8 |

(a)Estimated from 7 percent decline relative to 1975 (Ref. 3-5).

(b)N/A: not available as of March 1977.

(c)Ref. 3-3

Examination of Table 3-1 shows that total consumption of lube oils has increased by an average of 34 million gallons per year or 1.68 percent annually over the last 18 years. The growth pattern, however, is not uniform. It varies both in time and by oil category. In addition, the Environmental Quality Systems report (Ref. 3-2) points out that within the United States there are also significant regional differences in oil use. These variations, which are shown in Table 3-2, appear to be related to population density, degree of urbanization or industrialization, and availability of public transportation. Although these data were compiled in 1971, the implied distribution is considered currently valid because of the long time scales required to significantly alter local factors like population and industrialization. The future sales implications of historical trends and overall internal market patterns are considered in Section 8. The detailed features of current automobile and industrial oil usage are addressed separately in the following subsections.

Table 3-2. Annual Per Capita Oil Consumption By States (1971), Gallons Per Person Per Year (Ref. 3-2)

| State | Automotive | Industrial | State | Automotive | Industrial |
|---|---|---|---|---|---|
| Alabama | 5.65 | 4.88 | Montana | 9.15 | 2.45 |
| Alaska | 7.05 | 2.15 | Nebraska | 9.50 | 3.91 |
| Arizona | 5.44 | 2.44 | Nevada | 7.38 | 1.78 |
| Arkansas | 6.31 | 5.42 | New Hampshire | 3.45 | 1.18 |
| California | 5.47 | 3.39 | New Jersey | 3.82 | 8.70 |
| Colorado | 5.56 | 2.94 | New Mexico | 7.10 | 5.15 |
| Connecticut | 3.37 | 4.07 | New York | 2.66 | 2.88 |
| Delaware | 5.52 | 3.30 | North Carolina | 4.60 | 3.40 |
| District of Columbia | 3.25 | Unknown | North Dakota | 9.70 | 1.45 |
| Florida | 4.42 | 3.45 | Ohio | 5.21 | 9.45 |
| Georgia | 5.57 | 5.52 | Oklahoma | 7.28 | 5.61 |
| Hawaii | 3.66 | Unknown | Oregon | 8.71 | 4.81 |
| Idaho | 7.30 | 1.86 | Pennsylvania | 4.59 | 7.97 |
| Illinois | 5.08 | 8.02 | Rhode Island | 3.06 | 2.75 |
| Indiana | 5.17 | 8.45 | South Carolina | 4.09 | 2.38 |
| Iowa | 6.1 | 2.94 | South Dakota | 9.79 | 1.01 |
| Kansas | 10.0 | 4.62 | Tennessee | 5.38 | 4.79 |
| Kentucky | 7.02 | 7.10 | Texas | 6.39 | 9.89 |
| Louisiana | 6.31 | 11.20 | Utah | 6.65 | 3.39 |
| Maine | 5.10 | 2.8 | Vermont | 4.54 | 1.45 |
| Maryland | 3.56 | 3.38 | Virginia | 4.14 | 2.57 |
| Massachusetts | 3.57 | 3.64 | Washington | 4.91 | 2.82 |
| Michigan | 6.40 | 7.45 | West Virginia | 5.32 | 13.50 |
| Minnesota | 6.45 | 3.18 | Wisconsin | 5.92 | 3.88 |
| Mississippi | 6.39 | 4.20 | Wyoming | 11.70 | 4.79 |
| Missouri | 6.91 | 3.35 | | | |

## 3.2 AUTOMOTIVE LUBE OIL USAGE

### 3.2.1 Automotive Oil Sales

Automobile lube oil is partially consumed in the engine and is replaced by regular crankcase drainage as a function of mileage. It therefore seems reasonable to expect that automotive oil sales should be related in some consistent way to vehicle statistics. Indeed, this appears to be so but not as directly as expected. Figure 3-2 shows the relationship between oil consumption per vehicle mile and per registered vehicle for the years 1958 through 1975.

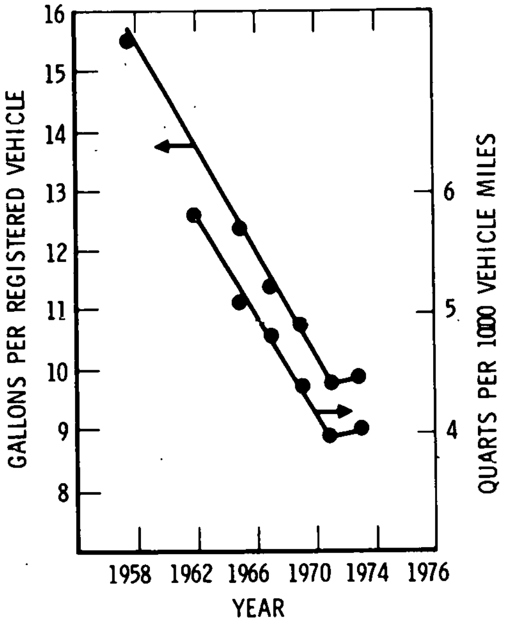


Figure 3-2. Measure of Total Automobile Lube Oil Demand Including Auto, Taxi, Bus, and Truck. (From Ref. 3-3 and Refs. 3-5 through 3-8)

Although vehicle registrations are a less direct measure, they appear to represent the trend of oil usage as well as vehicle mileage does.

The historical trend which indicates a decreasing oil consumption per vehicle has been noted by other investigators (Ref. 3-2). It is attributed to technological advances in oil additives, reduced burning during use, and the longer crankcase drain intervals recommended by vehicle manufacturers since 1960. The flattening of the trend in 1973, indeed a slight apparent increase, might be attributed to a large increase of unregistered gasoline-powered devices (e.g., chain saws, power mowers, and snowmobiles). Oil use in such devices obscures the accuracy of inferences regarding oil consumption in the automotive (transportation) sector. Even without this difficulty, it is obvious the downward trend could not continue indefinitely.

### 3.2.2 Automotive Used Oil Generation

Important aspects of automotive used oil generation are revealed by the data on classes of users. Figure 3-3 is a graphic presentation of the growth in vehicle miles by user class. In terms of growth since 1963, highway trucks (70 percent) rank first, with passenger automobiles (58 percent) second and, perhaps surprisingly, highway school buses (45 percent) third. From the relationship between vehicle miles and oil consumption previously developed, it is not difficult to apportion relative used oil generation. Railroad oils, which are grouped under industrial oils (not automotive) in the BOC classification, are shown here for reader convenience in comparing all ground transportation modes. Market implications of these data are discussed in Section 8.

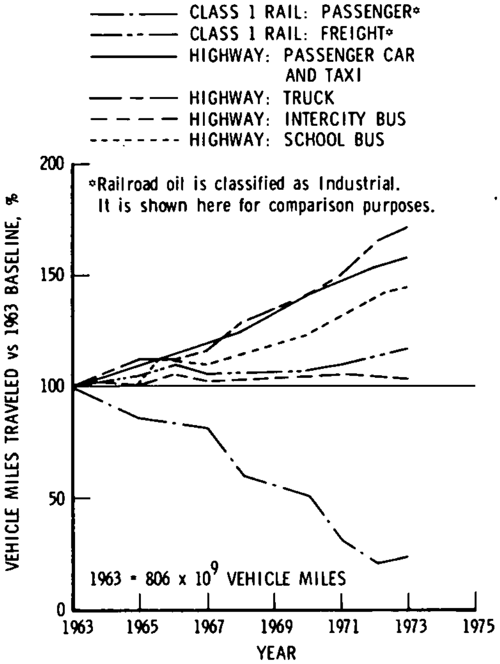


Figure 3-3. Components of Automotive Oil Use (Ref. 3-8)

Waste oil tends to accumulate at places related to the type of user and their vehicle service habits, e.g., auto dealers, fleet garages, airports, and railroad yards. Using such patterns, the Environmental Protection Agency (EPA) in its studies estimated how much of that oil might be recovered by a concerted campaign. Data for 1975 are shown in Table 3-3 using the same categories as EPA. Sales for 1975 at each source were estimated by distributing the total from Ref. 3-4 in the same proportions as the original 1970 through 1971

EPA data. Sales in discount stores may currently be a higher proportion, but the error should not be large and does not affect the total. The automotive/commercial fleet proportions do, however, appear to be at variance with those based on mileage data from the Department of Transportation (DOT) (Figure 3-3). Also, Table 3-3 includes hydraulic oil (construction equipment) and automatic transmission fluid (ATF), which are not processed the same as crankcase oil but are re-refineable. It is estimated that about half of the automotive oils might be made available for re-refining.

Table 3-3. Generation of Used Automotive Lubricating Oil[(a)] for the Year 1975, Millions of Gallons (Updated from Ref. 3-4)

| Source | New Oil Sales | Used Oil Factor[(b)] | Available Used Oil |
|---|---|---|---|
| Automobiles in Service Stations | 311 | 0.63 | 196 |
| Automobiles in Garages and Supply Stores | 68 | 0.63 | 43 |
| Automobiles at New Car Dealers | 118 | 0.90 | 106 |
| Retail Sales for Commercial Engines | 104 | 0.63 | 66 |
| Automotive Fleet and Other Lube Oil Uses[(c)] | 156 | 0.50 | 78 |
| Factory Fills, Automotive and Farm | 69 | 0.90 | 61 |
| Oil Bought at Discount Stores | 194 | 0.22 | 43 |
| Commercial Engine Fleets | 231 | 0.50 | 116 |
| Total | 1251 | 0.57 | 709 |

[(a)] Includes motor oils, transmission oils, hydraulic oils, etc.

[(b)] Ratio of used oil to oil sold.

[(c)] Marine, agricultural, etc.

## 3.3 INDUSTRIAL OIL USAGE

### 3.3.1 Industrial Oil Sales

Industrial oils, as mentioned earlier, consist of two categories: lube and other. Included in the lube oil category are railroad and marine (gasoline) engine oils. In the other category are specialty oils and process oils which are consumed in use.

Lubricating oil used by railroads and in marine engines parallels that of automotive applications; i.e., it is used for bearing lubrication in crankcases, wheels, etc. Different, but still in the lube category, are the many types of cutting oils which are used in metal working for lubricating moving parts and during fabrication of metals. In such applications, the lubricants vary from 100 percent oil to emulsions with low concentrations of oil in water.

Process oils are different from lube oils in characteristics and use. First, these oils are defined by BOC as having a viscosity of more than 45 SUS at 100°F. Second, most process oils, by definition, become a part of the product generated. Examples are the oils used in rubber, ink, textiles, and agricultural sprays. Forty to fifty percent of the process oils are consumed by the rubber industry, where they are used as plasticizers for reinforcement and as extenders (Ref. 3-4). Other examples of process oil use are belt dressing, defoamants, flotation oils, fruit and vegetable preservatives, quenching/tempering/polishing oils, and tanner products.

Included with process oils (under the other category of industrial oils) are such specialty products as turbine oils, electrical transformer oils, and refrigeration oils. After use, most of these waste oils have compositions similar to the original product but with impurities such as suspended metal particles, water, and oxidation/decomposition products. This class of industrial oil is not consumed like process oil and could therefore be re-refined and returned to service. Some of them, like transformer oils, which have special properties, soon may be in short supply.

The rate of sales growth in both industrial lube and industrial other oil categories since 1958 exceeds that of automotive oil. In 1975, industrial oils amounted to 55.5 percent of the market or 1586 million gallons. Average annual growth (see Table 3-1) between 1958 and 1971 was 4.1 percent for lube and 5.6 percent for the other category of industrial use. In 1971, with total demand already nearly twice the 1958 base, the annual growth in both categories accelerated to 5.1 percent and 10 percent, respectively. However, both have dropped precipitously since 1973.

### 3.3.2 Industrial Used Oil Generation

In a manner similar to that for automotive oil, Weinstein (Ref. 3-9) estimated the fraction of various types of industrial oil that might be recovered and re-refined. Table 3-4 shows the oil categories and recovery

Table 3-4. Generation of Used Industrial Lubricating Oils for the Year 1975, Millions of Gallons (Updated from Ref. 3-9)

| Type of Oil | New Oil Sales | Used Oil Factor | Available Used Oil |
|---|---|---|---|
| Hydraulic and Circulating System Oils | 542 | 0.42 | 228 |
| Metalworking Oils | 250 | 0.70 | 175 |
| Railroad Engine Oils | 100 | 0.53 | 53 |
| Gas Engine Oils | 103 | 0.90 | 93 |
| Process Oils | 485 | 0.10 | 48 |
| Electrical Oils | 89 | 0.90 | 80 |
| Refrigeration Oils | 16 | 0.50 | 8 |
| Total | 1586 | 0.43 | 685 |

factors for reference purposes. The data shown have been updated to reflect industrial oil consumption for 1975, by the same methodology as used for automotive oils. The overall fraction of available used industrial oil was estimated to be about 43 percent by Weinstein (Ref. 3-9), and 30 percent by Environmental Quality Systems (Ref. 3-2). For 1975, this amounts to 685 and 476 million gallons, respectively.

## 3.4 USED OIL AND PROCESS RESIDUE DISPOSAL

Used lubricating oils constitute about 0.5 percent of the total crude processing operations, but the entire 1.4 billion gallons enter the environment as a potentially toxic material. In some cases, as for example automotive oil, the latent hazard is magnified during use through contamination by lead and other materials. Under Public Law 92-500, the Federal Water Pollution Control Act of 1972, Section 104m, the EPA was authorized to investigate the problem. It reported (Refs. 3-9 through 3-11) that the problem is twofold: (1) uncontrolled disposal of the oil itself, and (2) a potential disposal problem for waste products from the major re-refining process currently in use.

### 3.4.1 Disposal of Used Oil

Used oil disposal practices are most easily discussed according to whether the oil is automotive or industrial. In the case of automotive oils, the drastic shift in marketing practices away from service stations and into discount houses and drug stores has resulted in a change in disposal method for a significant fraction of the drained oil. In 1961, about 70 percent of all oil for passenger cars was sold by service stations. Drain oil was thus concentrated at specific locations, from which it was removed by processors and collectors. By 1971, 20 percent of the service station's share of the market had shifted to discount houses. According to Teknekron (Ref. 3-12) half of the discount purchasers used the oil for a complete crankcase drain, while others merely added. These customers disposed of their drain oil primarily by dumping, either on vacant lots or in municipal trash, with the net result that this oil is no longer recoverable. Another disposal method for used automotive oil is road oiling and dust suppression (about 10 percent). However, the general pollution controls recommended by EPA are being imposed quite uniformly at the state level, so that the 70 million gallons per year once used for road oiling are now being diverted to other uses.

The disposal of vehicular oil by any type of indiscriminate surface dumping is considered undesirable by EPA. A concentration of 1 milligram per liter of oil in surface or groundwaters causes taste and odor problems. Concentrations of the order of 50 to 100 milligrams per liter can impede waste treatment processes. Still unknown are the biological effects of oil on marine life. Further investigation is required to determine differences in response among species, sublethal effects, and possible changes to the aquatic community structure (Ref. 3-13).

In recent years the utilization of used automotive oil as a fuel has increased. Since the price of fuel oil has risen dramatically since 1973, some fuel users have reduced their fuel costs by blending fuel oil with lower-priced used crankcase oil purchased from independent collectors. This diversion away from re-refiners has created two problems: (1) a shortage (and uneconomically high prices) of used oil for conversion to lube stock and (2) an adverse public health effect arising from airborne dispersion of lead and other species resulting from burning used oil. It is estimated that, currently, more than 50 percent of the used automotive oil collected is being burned as a fuel. In visits during this study, re-refiners (Refs. 3-14 through 3-16) commonly mentioned the shortage of feedstock for reprocessing to lube oil. With respect to the public health problem, Weinstein estimated that the uncontrolled burning of waste crankcase oil at the rate of 500 million gallons per year could result in as much as 40 million pounds per year of lead entering the atmosphere as fine particulates (Ref. 3-9). This figure represents about 4 percent of the total United States lead production. Used crankcase oil may be safely used as a fuel if highly efficient particulate control systems are employed or if a high level of pretreatment is used. However, as of early 1977, these precautions are voluntary with users, and in most cases the used oil is burned with little or no processing. The amount of lead in vehicular oil will decrease in the future as leaded gasoline is phased out. According to EPA estimates (Ref. 3-13), approximately 28 percent of the United States automobile pool is projected to use leaded gasoline in 1980. Problems associated with burning used crankcase oil are further discussed in Section 10.

Industrial oil disposal does not seem to be subject to the same abuses as automotive oil. Because of its concentration at industrial sites, it has been more easily controlled on a voluntary basis. While, historically, a large fraction has been used as a fuel, post-1973 fuel price increases have caused a movement toward reclaiming and return to service as a lube oil. However, sporadic shortages of fuel oil can cause a burn- or salvage-dilemma for industry, the decision being made on the basis of relative fuel oil versus lube oil cost and availability.

Reference 3-9 provides an excellent summary of the various used oil types, their associated disposal methods, and major disadvantages. Table 3-5 is a condensation of those data. Of the many conclusions reached in that investigation, those related to automotive and industrial oil disposal are pertinent here. It appears from numerous reports that EPA is in general agreement with the conclusions of Reference 3-9, particularly regarding the value of used oil as a lubrication resource. Those conclusions are as follows:

a. Uncontrolled use of lead-containing vehicular waste oils as a fuel is a poor approach to disposal because of lead and other fine particulate emissions and because of the loss of important natural resources in short supply, namely lead and lubricating oil stocks.

b. Use of vehicular waste oils for dust control and road oiling is wasteful and potentially harmful to the environment.

c. In addition to the re-refining industry, a second group of oil reclaimers, designated as waste oil processors, are engaged in converting waste oils to fuels and other products.

Table 3-5. Treatment and Disposal of Used Oils (Modified from Ref. 3-9)

| Used Oils | Source | Common Contaminants | Prime Contaminants Limiting Reuse or Simple Disposal | Principal Treatment and Disposal Methods Now Used (Disadvantages) |
|---|---|---|---|---|
| Automotive Lubricants (primarily crankcase oil but contains transmission fluid, gear lubricants, hydraulic oil, solvents, brake fluid, possibly antifreeze) | Automotive service facilities (including discarded filters and discarded vehicles) | Compounds of N, O, and Cl; water, gasoline, metal and carbon particles, Pb, and other metal compounds | Color and odor bodies (N and O compounds), suspended inorganics | 1. Re-refining (residue disposal)<br>2. Fuel (tube deposits and particle emission)<br>3. Road oil and dust control (runoff) |
| Railroad Diesel Lubricants (primarily diesel lube, but may contain journal oil, gear lubricants) | Railroad service facilities | Similar to automotive lubricants, but no Pb | Color and odor bodies (N and O compounds), suspended inorganics | 1. Re-refining (residue disposal)<br>2. Fuel (tube deposits and particle emission)<br>3. Road oil and dust control (runoff) |
| Truck Diesel Lubricants (primarily diesel lube but may contain transmission fluid, gear lubricants, hydraulic oil, etc.) | Truck service facilities | Similar to automotive lubricants but no Pb | Color and odor bodies (N and O compounds), suspended inorganics | 1. Re-refining (residue disposal)<br>2. Fuel (tube deposits and particle emission)<br>3. Road oil and dust control (runoff) |
| Metal Working Lubricants (often emulsified with water) | Metal working plants | May contain fatty oils, S, N, Cl, F from original fluid plus metal particles; oxidation and degradation compounds; and sediment | Metal particles, sediment | 1. Chip extraction and settling at elevated temperatures (oil solid wastes)<br>2. Settling and skimming (oily water waste, oil flocs, and sludges)<br>3. Incineration (particle and other emissions) |
| Other Industrial Oils (turbine oils, transformer oils, lubricants, hydraulic oils, heat transfer fluids, synthetic oils, etc.) | Industrial plants, power plants (including discarded transformers and machinery) | Turbine oils (water, oxid.-products), transformer oils (water, oxid.-products, polychlorinated oils), and gear oils (S, Pb, dirt, wear metal, water, oxid.-products) | Metal particles, water, degradation products | 1. See methods for automotive lubricants<br>2. Clay treating (spent clay waste)<br>3. Filtration (filter aid and particle waste)<br>4. Centrifugation (particle waste)<br>5. Recovery to prepare soluble oils<br>6. Incineration (air pollution) |

d. With few exceptions, the treatment systems used by waste oil processors have very limited utility in removing impurities such as lead particles, other fine particulates, and polymer precursors.

e. Of the waste oil picked up by collectors, more than one half is used as or blended with fuels, with little or no control of quality.

f. A major fraction of industrial waste oils is used as fuel at the point of generation or converted to fuel use by a processor.

g. Few industrial concerns have records of the ultimate disposal of waste oils purchased.

h. An appreciable fraction of industrial waste oils are purified and recycled to their original use.

### 3.4.2 Disposal of Re-Refining Process Residues

Nearly all re-refiners in the United States are using an acid-clay process for used crankcase oil. Various other treatments are used for industrial oils because, in general, they require less severe processing to remove contaminants. Table 3-6 provides a summary of disposal methods and environmental problems associated with both processing and disposal of process waste. The list is not exhaustive but typifies problems that might be encountered even with the alternative processes discussed in this report. Of particular interest are the first five items, as they relate directly to the widespread acid-clay process.

Re-refiners contacted during the course of this study stated that disposal of processing residuals was costly, but posed no problems. While not all re-refiners were contacted, this information is consistent with that of other more comprehensive investigations. The concentrated sulfuric acid sludge which is being generated by re-refiners at a rate of above 19 million gallons (approximately 190 million pounds) per year can be disposed of safely in certain landfills. Similarly, the spent clay does not appear to present serious environmental problems if proper practices are followed. Waste water discharged by re-refiners is generally small but oil contamination problems are common. Both water and air emissions can be controlled by existing technology, and the cost of any needed modifications to comply with acceptable environmental standards is not considered excessive (Ref. 3-16).

Despite the current absence of serious problems in the disposal of waste from re-refineries, there are a number of reasons for scrutinizing the acid-clay process. First, the residue is unquestionably environmentally undesirable and industry growth will increase the quantities of that residue. Secondly, the general problem of municipal waste cannot be divorced from its separate contributors. In 1973, municipal solid waste was generated at a rate of about 800 million pounds per day (Ref. 3-17). Approximately 90 percent of the solid waste is disposed of in landfills, yet the 1971 Report of the Council on Environmental Quality estimated that half of the major cities in the United States will run out of landfill dump space within the next 5 years. The conflict that recently occurred in California when the city of Los Angeles attempted to

Table 3-6. Treatment and Disposal of Used Oil Processing Residues (Modified from Ref. 3-9)

| Used Oil Residues | Source | Common Contaminants | Prime Contaminants Limiting Reuse or Simple Disposal | Principal Treatment and Disposal Methods (Disadvantages) |
|---|---|---|---|---|
| Acid Sludge (93-98 o/o sulfuric acid/oil sludge, on the order of 30 o/o water soluble) | Acid treating of waste oils to remove metals and other contaminants | $H_2SO_4$, Pb from crankcase oils, metals, and metallic compounds, polymers, heavy oil residues | $H_2SO_4$, Pb, other metals, and oil | 1. Landfill with or without mixing refuse (water pollution)<br>2. Lagoons (temporary) |
| Caustic Sludge (caustic, sodium silicate, water, metals, oily sludge) | Caustic treating of waste oils to break emulsions | NaOH, Na silicates, Pb, and other metallic compounds | Pb, other metals, and oil | 1. Landfill (water pollution, slow degradation)<br>2. Lagoons (temporary) |
| Spent Clay (oil and impurity contaminated clay cake) | Clay treating of waste oils to remove impurities, improve odor and color | Oil, organics containing N and O | Oil and other organics | 1. Landfill (water pollution, slow degradation) |
| Pretreat Residues (sludge of oil, water, and inorganic residues) | Residues from settling, filtration, centrifugation, and other pretreatments | Pb from crankcase oils, other metals and metallic compounds, heavy oil residues (also discarded filter papers, cloths, filter aids) | Pb, other metals, and oil | 1. Landfill (water pollution, slow degradation) |
| Odors | Acid and other processing steps, water treatment, vents, open tanks, leaks | May be trace hydrocarbons; solvents; organic acids; esters; or O, N, S containing compounds, $SO_2$, $SO_3$, $NH_3$ | Odors | 1. Scrubbers (water pollution)<br>2. Vent to furnaces |
| Distillation or Extraction Bottoms (heavy oil fraction high in inorganics) | Distillation or extraction to concentrate non-volatile contaminants | Pb from crankcase oils, other metals and metallic compounds, heavy oil residues, and coke | Pb and other metals | 1. Lagoons (temporary)<br>2. Asphalt<br>3. Fuel (air pollution) |
| Condenser Liquids (water from oil and stripping steam, light hydrocarbons; condensed steam and cooling water where steam jet vacuum with barometric condenser used) | Distillation overheads | Phenols, other dissolved organics, oil | Emulsions and dissolved organics | 1. Separators (poor efficiency, wet oil residue)<br>2. Separators, cooling towers, and recycle (water pollution from blowdown) |
| Scrubber Waters (usually aqueous $NH_3$ or caustic with impurities) | Gas scrubbing to eliminate $SO_2$, $SO_3$, and other volatile acids | NaOH or $NH_4OH$, $SO_2$, $SO_3$, and water soluble organics | Water soluble organics | 1. Recycle (water pollution from blowdown)<br>2. Acid treatment of blowdown (dissolved solids residue) |

dump neutralized sewage within the city limits of Rancho Palos Verdes is a good example of possible future events. Inasmuch as re-refiners are necessarily associated with major cities (as sources for their used oil), they rapidly become affected by outside circumstances. If re-refiners reduce or neutralize waste, they can respond more flexibly to future municipal actions. It seems inescapable that some sort of anticipatory action regarding re-refinery process waste is required for long-term industry survival. Fortunately, it appears that alternative re-refining processes are available which produce less waste or less toxic waste at an equal or better profit on the finished oil. These alternatives are discussed elsewhere in this report.

## 3.5 REFERENCES

3-1 Basic Petroleum Data Book, 1976, American Petroleum Institute, Washington, D.C. (April 1976).

3-2 Waste Oil Recovery Practices - State of the Art (1972), Environmental Quality Systems, Inc., Washington, D.C., NTIS No. PB-229 801 (December 1972).

3-3 Personal communication: R. Sweeney, U.S. Bureau of the Census, Washington, D.C. (March 1977).

3-4 "Sales of Lubricating and Industrial Oils and Greases - 1975," Current Industrial Reports, Bureau of the Census, Washington, D.C. (September 1976).

3-5 Personal communication: J. Diehl, U.S. Bureau of Mines, Washington, D.C. (March 1977).

3-6 Energy Statistics - A Supplement to the Summary of National Transportation Statistics, Annual Report, U.S. Department of Transportation, Washington, D.C. (August 1976).

3-7 Summary of National Transportation Statistics, U.S. Department of Transportation, Washington, D.C. (June 1974).

3-8 Summary of National Transportation Statistics, U.S. Department of Transportation, Washington, D.C. (June 1975).

3-9 Norman J. Weinstein, Waste Oil Recycling and Disposal, EPA-670/2-74-052, U. S. Environmental Protection Agency, Washington, D.C. (August 1974): prepared by Recon Systems, Inc., Princeton, New Jersey.

3-10 Highway Statistics - 1974, U.S. Department of Transportation, Washington, D.C.

3-11 Waste Automotive Lubricating Oil Reuse As A Fuel, EPA-600/5-74-032, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C. (September 1974).

3-12 A Technical and Economic Study of Waste Oil Recovery, Part II: An Investigation of Dispersed Sources of Used Crankcase Oils, EEED 102, Teknekron, Inc., Berkeley, California (October 1973).

3-13 Report to Congress, U.S. Environmental Protection Agency, Washington, D.C. (April 1974).

3-14 Personal communication: R. Humphrey and S. Humphrey, Nelco Oil Refining Company, National City, California (6 October 1976).

3-15 Personal communication: C. S. McAuley, McAuley Oil Company, Long Beach, California (1 October 1976).

3-16 Personal communication: B. Horton, Dearborn Refining Company, Dearborn, Michigan (21 October 1976).

3-17 R. L. Johnson, Energy Recovery from Municipal Solid Waste, An Environmental and Safety Mini-Overview, ATR-76(7518)-7, The Aerospace Corporation, El Segundo, California (June 1976).

# SECTION 4

# BACKGROUND OF THE RE-REFINING INDUSTRY

## 4.1 INDUSTRY DEVELOPMENT AND CURRENT STATUS

### 4.1.1 Industry Development

Although the earliest patent examined for this report was dated 1933, the lube oil re-refining industry was started in 1915. The initial process used at that time involved simple heating to remove volatile components and the use of a coagulent, followed by settling and centrifugation. While primitive by today's standards, the resulting oil quality was perfectly adequate even for the lubrication requirements of aircraft engines of that time. In fact, in 1932, American Airlines initiated a "closed-cycle" re-refining system in which lubricating oil from company planes was treated to remove contaminants and returned to service (Ref. 4-1). A 20 percent net dollar saving stimulated use of re-refined oil by other industries.

The subsequent growth and decline of the oil re-refining business is shown in Table 4-1.

Table 4-1. Estimated Production of Re-refined Oil In the United States (Ref. 4-1)

| Calendar Year | Volume, Gal. |
|---|---|
| 1939 | 11,250,000 |
| 1948 | 45,000,000 |
| 1950 | 50,000,000 |
| 1954 | 75,000,000 |
| 1960 | 300,000,000 |
| 1966 | 225,000,000 |
| 1971 | 120,000,000 |
| 1972 | 100,000,000 |
| 1975 | 50,000,000 |

During World War II, the desire to conserve strategic lube oil resources focused attention on the advantages associated with re-refining. The Army Air Corp instituted a closed-cycle system similar to that of American Airlines. The program actually continued up to 1949 at which time 1.1 million gallons of oil per year were reprocessed at an annual savings of nearly $500,000. During this period, the oil was used without restriction within the continental United States. No detrimental effects were observed during 29 million hours of flight time. When the program was phased out, about one-fourth of all Air Force aircraft oil was re-refined.

Following World War II, the civilian use of re-refined oil also grew. At its peak in 1960, it represented approximately 14 percent of the total domestic lube oil market. In 1975, it had declined to about 2 percent. This reduction in market share is even more dramatic when viewed in the context that, during the same period, total demand for lube oil grew by 31 percent. Between 1960 and 1973, the number of re-refiners decreased from 150 to 44 (Ref. 4-3). Based on information from the re-refiners contacted for this study, it is evident that some of those 44 have since gone out of business. Since the 1973 oil embargo, prices of all types of virgin oil have risen significantly. At the same time, sales of virgin lube oils (the source of used oil) have declined steadily from the 1973 peak, at an annual rate of about 6 percent at least through 1975 and apparently into 1976.

### 4.1.2 Current Status of the Re-Refining Industry

The general current status of the industry was spot checked in the course of this study; it was indicated that a general shortage of fuel oil combined with high prices caused many industry segments to burn used motor oil, blended with fuel oil. During the second half of 1976, fuel oil prices increased to 28-1/2 cents per gallon, causing used motor oil for fuel purposes to be bid above its value as lube re-refining feedstock. Large industries in the Los Angeles area were reportedly paying 17 cents per gallon, with smaller users paying even more.

It appears that while used automotive oil re-refining is relatively stagnant because of its use as a fuel, the trend of the price/cost situation on new industrial oil is favorable to an increase in industrial oil re-refining volume, and several re-refining plants are planning near-term expansions. Unfortunately, total re-refined oil sales data are not segregated into automotive and industrial categories; hence, the relative shift in emphasis is not verifiable. An inference might be made from the Bureau of the Census (BOC) data (Ref. 4-4), which show a decline in sales of new industrial oil of 7.9 percent annually or 149 million gallons between 1973 and 1975. However, the net reduction cannot be wholly assigned to a shift to re-refining because of the generally reduced national economic and industrial activity during this same period. Re-refining of industrial oil, by its nature, does not present supply problems as the customer usually supplies his own oil.

## 4.2 INDUSTRY FEATURES AND STRUCTURE

In 1950, the re-refiners formed the Association of Petroleum Re-Refiners (APR), headquartered in Washington, D. C. The purpose of this organization is to promote market and technical interchange among its members and foster growth of the industry through annual meetings. Currently, most of the larger re-refiners are members of this organization, which is also open to international membership.

Until recently, the industry, at least in the United States, has not exhibited the typical trend of growth by consolidation and subsequent product diversification. Bonus Oil Company of Salt Lake City may have signaled the beginning of such a movement with its recent acquisitions of Fabian Oil Company of Oakland, California, and Bayside Oil Corporation of San Carlos, California. The re-refining industry has been, and to a large extent remains, composed of a fragmented, strongly independent group of businessmen. Although the composition is changing, the typical current re-refinery is owned by a single person or partnership. The chemical processes which they use were devised by trial and error from years of experience. In general, their facilities lack sophisticated process or quality control instrumentation. Actual processing conditions, such as temperatures, pressures, and flow rates, are frequently guarded as trade secrets.

Although the used oil collected consists of a mixture of various grades, weights, and viscosities, no attempt is made to separate the oil into the different original weight categories (such as 10, 20, or 30 weight). To do so would increase the complexity of re-refining and is technically unnecessary. Instead, re-refiners use the collected mixed oils to produce what may be called a "broad-cut". The resulting single product is usually a 20-weight oil. Blending stock and additives may then be incorporated to produce different weights, as well as multiviscosity oils, and to improve lubricant performance.

Of several possible chemical processes available for re-refining used oil, the acid-clay process has been almost universally applied. Concentrated sulfuric acid is an effective treating agent and produces lube oils of good quality (Ref. 4-5). The sulfuric acid treatment is a simple process which consists of mixing the oil with acid and separating the sludge formed in the process from the refined oil. It is an adaptation of a process once used extensively in the production of virgin lube oil from crude. A detailed description of this process and alternative methods of re-refining are presented in Section 6. Recently, disposal of the acid sludge and clay residue, both of which contain oil products, has become a subject of environmental concern. In the course of this study, it was found that re-refiners were disposing of these waste products in local dumps in ways acceptable to administrative agencies, although at a considerable economic penalty. Other general pollution control measures in effect, such as stack controls (odor and particulates) and waste water treatment, were not considered a severe financial burden. However, the possible future depletion of municipal waste dumpsites presents a potential industry problem. Consideration of alternative processes that reduce or eliminate undesirable by-products is therefore in order.

## 4.3 INDUSTRY PRODUCTS AND MARKETS

The re-refining industry has not confined itself exclusively to automotive lube oils. Through the years, re-refiners have proven remarkably adaptive in devising alternative uses for spent motor oils and, in a more limited way, to other types of lube oils. Lubricants may be loosely classified under two categories: oil and grease. No known attempts have been made to salvage used grease. While it could be processed, it is difficult to recover; most grease therefore is lost to the environment directly after use.

### 4.3.1 Products

Used oil has been processed for use in road oiling, as a fuel-oil blend for burning, and as a plasticizer for use in paint and plastic manufacture. In addition, used oil has been re-refined for use in its originally intended application; e.g., as a lubricant in railroad journal boxes, diesel engines, reciprocating aircraft engines, automobiles, and for various industrial machining applications. In this report, attention is focused primarily on automotive crankcase oil. Other re-refining activities are discussed only for completeness in understanding the industry and its economic analysis. The two principal products of re-refiners today are automotive crankcase oil and industrial oils. The problems, processing, and market relationships are different for each oil.

Industrial oil has different contaminants than automotive oil (Section 2), is generally easier to process (except for possibly more stringent cleanliness requirements), and does not involve supply problems. Customers are developed principally through personal trust in the re-refiner's integrity and ability. The contaminated oil is furnished at regular intervals to the re-refiner who essentially does custom processing, including blending of customer-specified additives. The reprocessed oil returned to the customer is generally not mixed with that of others.

Motor oil processing, on the other hand, is considerably more involved. As further discussed in Section 7, the oil is collected in smaller individual quantities and from diverse sources. The trucks used for collection often belong to re-refiners but are more frequently those of independent collectors. Sources for the oil are more unstable because of a lesser dependence on a single re-refiner. Independent collectors may sell to different processors or to none, depending strictly on price. Also, as described in Section 2, the contaminants in motor oil are more severe than in industrial oils, which makes re-refining of these oils more expensive. Improved segregation of feedstocks from source to re-refiner, that prevents comingling of highly contaminated oils with those that are less contaminated, helps to reduce processing costs. Toward this end, one large midwestern re-refiner segregates railroad diesel oil from truck diesel oil. Finally, the product is generally marketed rather than merely returned to a source.

### 4.3.2 Markets

Historically, the re-refining industry has served the economy-conscious consumer. As can be inferred from military and civilian aviation experience, quality of products was proven in service and accepted by the public at large, at least into the early 1960s. The generally lower operating costs of re-refiners, the fact that they were paid to collect waste oil, and the more centralized sources of crankcase oil in the pre-1960 time period have all contributed to the ability of the re-refiner to sell oil at a price lower than virgin oil. Industrial oils were not a large market at that time. Beginning in the mid-1950s, cutting speeds of machine tools started to rise and demanded the use of highly compounded cooling/cutting/hydraulic oils. Throughout this period, as prices and costs shifted in the market, re-refiners gradually began processing industrial as well as crankcase oil.

Initially, re-refined crankcase oil was sold in bulk. As individual packaging for lube oil became popular, re-refiners adopted this technique in spite of the additional cost. Industrial oil is always handled in bulk. The cost of oil additives is another significant manufacturing expense. Of course, costs vary among re-refiners and, as shown later, are dependent on the refining processes used.

## 4.4 SUMMARY OF INDUSTRY PROBLEMS

In the course of its development, a number of problems have plagued the re-refining industry. For example, government regulations, indirect restrictions by private industries, and financial pressures of the commercial market have served to restrict the ability of re-refiners to respond positively. While the list is not exhaustive, major current problems are (1) Treasury Department tax rulings, (2) Federal Trade Commission labeling requirements, (3) changes in oil marketing methods, (4) oil specifications and engine sequence testing, (5) product quality image, and (6) capitalization and financial support. These items are further discussed in the following subsections and in Section 9.

### 4.4.1 Treasury Department Tax Rulings

Prior to 1965, all virgin lube oil was taxed at a rate of 6 cents per gallon. Because most re-refined oil products are blended with some virgin oil before selling, re-refiners effectively paid a tax in proportion to the blended ratio of virgin and re-refined used oil. The Federal Excise Tax Reduction Act of 1965 exempted those virgin oils which were used in applications other than highway motor vehicles. Subsequently, however, the Treasury Department held (Ruling 68-108) that virgin oil blended with re-refined non-highway oil was not exempt. In effect this gave virgin non-highway oils a tax (price) advantage over re-refined products. Under this adverse Treasury ruling, the more virgin oil a re-refiner added to his product, the greater his price disadvantage became relative to a 100 percent virgin oil. This was not only unreasonable but imposed an economic hardship on the re-refining industry.

### 4.4.2 Federal Trade Commission Labeling Requirements

In 1958, the Federal Trade Commission ruled that specific labeling was required for re-refined crankcase lube oil. In 1963, it stipulated that a statement regarding previous use be placed in a conspicuous location on the front of the container. The specific choice of words to describe the oil is claimed to be a psychological deterrent to potential customers (Refs. 4-1 and 4-6). The consensus seems to be that a negative connotation does exist, but its cumulative effect on sales can not be readily quantified. Details on the current status are further addressed in Section 9.

### 4.4.3 Changes in Oil Marketing Methods

The method of crankcase oil sales has shifted dramatically since about 1960. Whereas used crankcase oil was once accumulated at auto sales and service centers, the advent of discount stores with significant price differentials apparently caused consumers to begin changing their own oil. By 1973, sales of lube oil in service stations had declined from 70 percent of the market share to 45 percent. As sales plummeted, so did the waste oil available at individual service stations. The re-refiner (or used oil collector) was forced to cover a wider and wider area to collect the same amount of oil, which resulted in higher collection costs. Gasoline and oil price increases since 1973 have further compounded the collection expense. Further discussion of the impact of these factors on the re-refining industry is included in Section 7.

### 4.4.4 Oil Classifications and Engine Sequence Testing

Over a period of years, the American Petroleum Institute (API) has evolved a series of lubricating oil service classifications. This organization, together with the Society of Automotive Engineers (SAE) and the American Society for Testing and Materials (ASTM), with major inputs from Ford Motor Company and General Motors Corporation, devised a series of engine sequence tests to ensure the ability of a motor oil to perform acceptably under various operating conditions (Ref. 4-7). It should be emphasized that the API engine service classification does not exclude re-refined oil.

Unlike these specifications, the military specifications MIL-L-46152 and MIL-L-2104C contain specific exclusions for re-refined oil, which are claimed to adversely reflect on the marketability of re-refined oil. In a 1964 letter to the Federal Trade Commission, the U. S. Army Material Command stated that re-refined oil failed to pass engine tests conducted by the U. S. Army (Ref. 4-1). While no test identification or details are provided, the Army subsequently prohibited use of re-refined products in all its procurements, fearing that base stock characteristics would be constantly changing with used oil drainings. Since Army specifications are used throughout government services, it became a government-wide prohibition. The contention is that each collection of used crankcase oil comes from a different source and, therefore, possesses different physical characteristics and quality even after re-refining. However, no evidence has been published which supports this contention. In fact, recent limited work by DOE's Bartlesville Energy Research Center reveals no substantial variation in the physical composition of crankcase drainings, either geographically or seasonally (Refs. 4-8 and 4-9).

A compounded crankcase oil consists of both a base stock oil and an additive package. No known crankcase oil can meet current engine test performance requirements without chemical additives containing rust inhibitors, antifoam agents, etc. It has been estimated that nearly 17 percent of a quart of multiviscosity motor oil is composed of additives (Ref. 4-1). When a virgin oil fails engine testing, it is routine procedure to modify the additive package, not the base stock. Both virgin lube manufacturers and re-refiners contacted during this study acknowledged their dependence on additives to meet engine sequence test requirements.

### 4.4.5 Product Quality Image

Re-refined lube oil is marketed in various quality levels. In the past, re-refiners have not seriously attempted, on an industry-wide basis, to compete with premium or super-premium motor oils. Their principal market competition is a virgin oil which is also of less than premium quality. Importantly, to be termed a "standard quality oil" does not imply that the product does not meet engine test requirements. It is the API/SAE service designation that defines ability to meet service conditions. Premium quality oils, in general, exceed minimum engine performance requirements. Unfortunately, either because of confusion over the meaning of the API/SAE designators or by clever advertising, the general public appears to believe that less than premium is less than adequate quality. As a result, about 98 percent of the public purchases according to factors other than the API/SAE service designation, such as brand name, and nearly 70 percent may purchase oil of higher quality than recommended by the vehicle manufacturer (Ref. 4-1).

Major oil companies, government agencies, and testing laboratories contacted in the course of this study indicate no credible challenge to the belief that re-refined oil of quality equivalent to virgin lube can be made. Lubrication engineers universally agree that oil does not wear out--it becomes contaminated. Three current efforts are expected to contribute data to resolve some of the questions surrounding re-refined oil. The first is work being done by the National Bureau of Standards to establish "substantial equivalence" under direction of the Energy Policy and Conservation Act of 1975. A second unrelated effort by the Army Fuels Laboratory is devoted to evaluating 15 different re-refined oils. Although directed to synthetic oil, work being conducted by the Air Force through Wright Patterson Air Force Base will hopefully also supply pertinent evidence (Ref. 4-10).

### 4.4.6 Capitalization and Financial Support

Most re-refinery facilities are 30 or more years old. By contrast, Exxon stated that the average age of their facilities is 15 years. Capital for renovation, conversion, or expansion of re-refining facilities has been difficult to obtain. In general, most lending institutions are wary of the industry because it has a negative image; its source of raw materials is uncertain, and it has a declining sales history. As a result, the industry may find it difficult to exploit new, more efficient, and environmentally acceptable process technologies.

## 4.5 REFERENCES

4-1 P. M. Cukor, M. J. Keaton, and G. Wilcox, A Technical and Economic Study of Waste Oil Recovery, Part III: Economic, Technical and Institutional Barriers to Waste Oil Recovery, Teknekron, Inc., and The Institute of Public Administration, Berkeley, California (October 1973).

4-2 S. Chansky, et al., Waste Automotive Lubricating Oil Re-Use as a Fuel, EPA-600/5-74-032, U.S. Environmental Protection Agency, Washington, D.C. (September 1974).

4-3 N. J. Weinstein, *Waste Oil Recycling and Disposal*, EPA-670/2-74-052, U.S. Environmental Protection Agency, Washington, D.C. (August 1974); prepared by Recon Systems, Inc., Princeton, New Jersey.

4-4 "Sales of Lubricating and Industrial Oils and Greases," *Current Industrial Reports*, MA-29C(75)-2, Bureau of the Census, Washington, D.C. (September 1976).

4-5 "Lube Oils - Processing Specifications Re-refining," *Hydrocarbon Processing* (December 1974).

4-6 *Waste Oil Recovery Practices -- State of the Art (1972)*, U. S. Environmental Protection Agency, NTIS No. PB 229801(December 1972); prepared by Environmental Quality Systems, Inc., Washington, D. C.

4-7 *Multi-Cylinder Test Sequences for Evaluating Automotive Engine Oils*, ASTM 315F, 04-315060-12, American Society for Testing and Materials, Philadelphia, Pennsylvania (January 1973).

4-8 M. L. Whisman, et al, *Waste Lubricating Oil Research*, BERC/RI-75/3, Bartlesville Energy Research Center, Bartlesville, Oklahoma (June 1975).

4-9 M. L. Whisman, et al, *Waste Lubricating Oil Research*, BERC/RI-75/11, Bartlesville Energy Research Center, Bartlesville, Oklahoma (December 1975).

4-10 "Reclamation of Synthetic Turbine Engine Oil Mixtures," Contract F33615-76-C-203, Monsanto Research Laboratory, St. Louis, Missouri.

# SECTION 5

# RE-REFINING PROCESSES

## 5.1 GENERAL

The processes employed in current re-refineries or described in the patent literature are based almost entirely on petroleum refining or chemical production experience. These processes include techniques ranging from acid contacting, now almost obsolete in the petroleum industry, to various severities of hydrogen treatment. In attempting to achieve economical removal of solid and liquid contaminants from used crankcase or industrial oil, investigators have explored a variety of physical separation processes and chemical treatments. The additional emphasis in recent years on environmental quality and energy conservation has introduced new evaluation criteria in process selection.

The acid-clay process is the most widely used re-refining process in the United States. Although it can produce a high-quality product when properly operated, it does not appear to be as economically feasible for today's high additive lubricants as some of the newer alternatives. Furthermore, disposal of the acid sludge and oily clay is becoming more difficult and expensive. This section describes the acid-clay process in some detail and, in lesser depth, several of the more recent options that are either in commercial operation or under study for hardware implementation. In addition, an extensive review of applicable United States patents dating back to 1957 has been included.

## 5.2 EXISTING PRODUCTION PROCESSES

Four processes that are currently in use include the following: acid-clay, clay, caustic, and solvent extraction (propane). Although the acid-clay process is meeting with disfavor on economic and environmental grounds, it is still widely used and is described in greater detail than the others.

### 5.2.1 Acid-Clay Process

The treatment of virgin lubricating oil with concentrated sulfuric acid to remove contaminants and color bodies has been practiced in petroleum refining for many years. Its application is now generally limited to the production of specialty products, such as medicinal and transformer oils, because refineries have had difficulty disposing of the acid sludge and newer processes based on solvent extraction and hydrogen treatment have been developed.

Acid treatment was used in the re-refining industry prior to World War II but was universally adopted after the war when additives became widespread in motor oils. Concentrated sulfuric acid is capable of removing these additives, as well as other contaminants, from the used oil. Despite environmental pressures and attendant economic disadvantages of the process today, the industry has been slow to change its technology because of a lack of capital for plant conversion and a limited number of proven alternatives. The acid-clay process thus remains the predominant approach in the re-refining industry.

### 5.2.1.1 Process Description

#### 5.2.1.1.1 Chemistry

Paraffin and naphthene hydrocarbons are only slightly attacked by 93 percent sulfuric acid at room temperature. However, toluene and xylene are more readily attacked while olefins, diolefins, and acetylenes are attacked by even 75 percent acid. Sulfuric acid also removes resinous or asphaltic substances that may be present, as well as oxygen compounds, such as naphthenic acids, ketones, alcohols, and aldehydes. Other compounds that are removed include nitrogen bases and alkyl sulfides, disulfides, and sulfates. Finally, metals such as lead and barium are removed as insoluble sulfates in the sludge.

Following acid treatment, the oil is invariably given a clay treatment. Finely suspended clay is mixed with the oil at elevated temperatures to accomplish two tasks. Color bodies of asphaltic or resinous material are readily adsorbed on the particle surface, resulting in a significant improvement in color of the base stock. At the same time, any residual acid is neutralized by the clay, which provides a less troublesome operation than caustic neutralization which may form an unwanted emulsion (Ref. 5-1).

Hydrocarbons are adsorbed in the following decreasing order: unsaturates, aromatics, naphthenes, and paraffins. In each series, the high molecular weight compounds are adsorbed more readily, undoubtedly accounting for most of the decolorizing action; materials containing nitrogen, oxygen, and sulfur generally are colored and, being polar in nature, are selectively adsorbed by clay.

#### 5.2.1.1.2 Feedstock

The most prevalent feedstocks for acid-clay treatment in the re-refining industry are automotive crankcase drainings. However, many other used oils may be effectively treated by this process, including highway and railroad diesel oils, hydraulic and transformer oils, aircraft piston engine oil, and various unemulsified metal working oils. Acid treatment is not always required, particularly in the case of low solids content industrial lubricants; dehydration, filtration, and possibly clay treatment may be all that is needed. Also, acid treatment may be avoided by cascading the used lube oil; i.e., re-refining only to the degree necessary to have the product meet the requirements of less demanding use.

#### 5.2.1.1.3 Flowsheet and Operating Conditions

Figure 5-1 illustrates the sequence of steps in the acid-clay process from used oil feedstock to a re-refined base stock motor or industrial oil product. Individual plants may depart from this typical process description because of feedstock variations, product desired, equipment

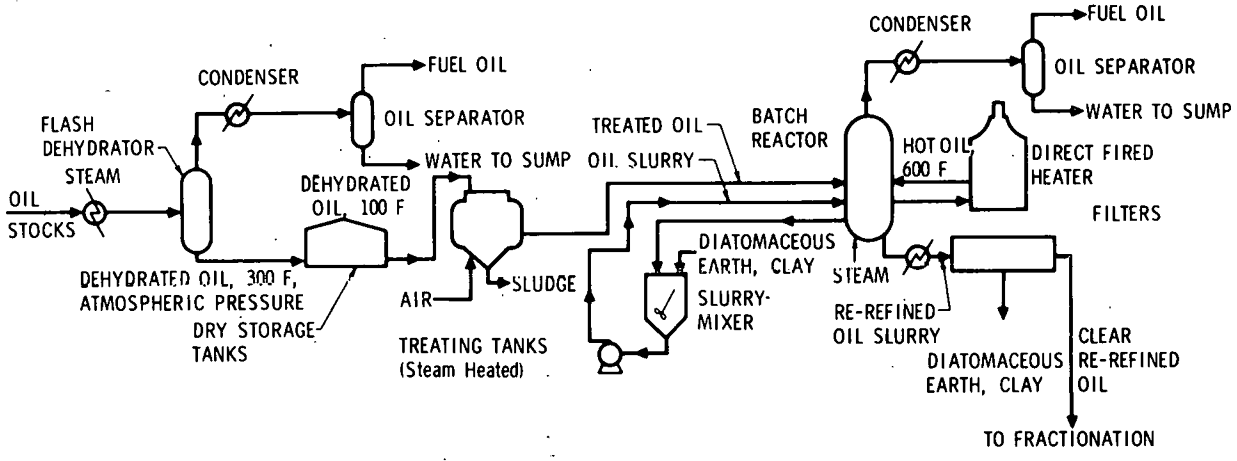


Figure 5-1. Schematic of Acid-Clay Type Re-refinery (Ref. 5-2)

differences, chemicals and fuels used, or operating experience of the owner. Also, the plant may include compounding of the base stock with additives and a canning operation.

The feedstock arrives at the re-refinery in collection tank trucks or railroad tank cars. Feedstock volume is not sufficiently large to make use of bulk carriers, such as ships or barges. Free water may be drained from the incoming vehicle before the oil is dumped into an underground receiving tank or the water may be periodically removed from the bottom of the tank later. A screen over the inlet of the receiving tank removes the coarse debris invariably found in used oils. Feed storage capacity is generally sized to hold a week or more of feedstock volume to allow for fluctuations in deliveries or plant shutdowns. The tank is fitted with a steam coil to enable the viscous feed to be pumped out in cold weather. In those re-refineries handling several types of feedstocks, segregation is of prime importance in successful processing.

The oil is first pumped to a flash dehydrator to remove bound water (e.g., emulsified) and light hydrocarbons. The flowsheet indicates a temperature of 300°F and atmospheric pressure, but conditions vary widely in the industry. Low-temperature dehydration covers a range of from 250° to 350°F, at atmospheric pressure or under vacuum. However, several re-refiners visited during the study said they had to dehydrate at 600° to 650°F and atmospheric pressure because of the high additive content in current motor oils. Either a steam heat exchanger or a direct fired heater is used for low-temperature dehydration, while the latter is invariably used for high-temperature operation. Typical of almost all the re-refineries, the heat in the dehydrated oil is not recovered, the expense of a heat exchanger not being justified.

The overhead mixture of water and oil is condensed and separated. The light oil is usually stored for use as plant fuel but several re-refiners indicated that it is sometimes more profitable to sell this oil and burn natural gas when the market demand for the oil is high. The water is sent to a waste water disposal system (Section 5.2.1.4.2).

The dehydrated oil is allowed to cool by natural convection in storage tanks to about 100°F if low-temperature dehydration is used. Water cooling is also employed if the dehydration step is carried out at high temperature. The oil is pumped to a vertical tank with a conical bottom, and 2 to 6 volume percent (depending on the type of feedstock) of 93 percent (66° Baume) sulfuric acid is added. Plant air is used to mix the tank contents, while a steam jacket or steam coil is used to maintain the temperature at near 100°F. After agitation for an hour or more, the sludge is allowed to settle in the conical bottom for one to three days. The sludge, containing unreacted acid and most of the contaminants in the waste oil, is drained from the reactor bottom outlet for disposal. Disposal of the sludge is discussed in Section 5.2.1.4.1.

The partially processed oil is then pumped to an atmospheric tower where steam stripping and clay neutralization and decolorization are carried out next in the processing sequence. The oil is circulated through an external, direct-fired pipestill heater, which raises its temperature to about 500° to 600°F. Steam is introduced to remove acidic and odorous compounds as well as additional light ends. The latter also brings the product oil to the desired viscosity. The steam-stripped overheads are condensed and separated as from the dehydration tower.

At this point, heating is discontinued, and finely powdered clay is added to the hot oil for final color improvement and acid neutralization. From 0.2 to 0.6 pounds of clay are generally used for each gallon of oil treated. Diatomaceous earth filter aid, amounting to 50 to 100 percent of the clay used, may be mixed with the clay to facilitate subsequent filtration. The oil and clay mix, now cooled to less than 300°F, is pumped through a plate and frame filter press for clay removal. Often two filters are used, in series, the second being a polishing filter for final clarification. One plant visited used a Sweetland circular leaf filter for the first stage and a plate and frame filter press for the second stage. Canvas and/or paper is the filtering medium. The filter cake, composed of clay, diatomaceous earth, impurities, and oil, is discarded along with the used filter paper.

Plants are operated batch-wise, often only one or two shifts per day, five days per week, because of limited feedstock. Most plants can be operated by one man but usually more people work on the day shift performing maintenance, packaging, and shipping tasks.

### 5.2.1.1.4 Plant Products

The product from automotive crankcase drainings treated as described above is generally an SAE 20-weight oil with a viscosity of 56 to 58 Saybolt universal seconds (SUS) at 210°F. Occasionally, an SAE 10-weight oil is made if the light ends are not completely removed. Diesel oil drainings produce a heavier SAE 40-weight oil, with a viscosity in the 80 to 85 SUS range. The oil is an ashless, neutral base stock that can be sold to a jobber for blending and compounding. Alternatively, these operations can be done in-plant by the re-refiner; many re-refiners also have the capability to package the product; e.g., in cans.

For production of an SAE 30-weight oil, the viscosity of the plant product must be increased to over 58 SUS either by blending in virgin bright stock or a chemical additive, such as polyisobutylene. The latter approach is not only less expensive but also improves the viscosity index (VI) of the oil, which usually is in the 90 to 100 range without any additive.

The base stock may be further compounded into a wide variety of engine oils and greases, as well as industrial lubricants. However, only a few re-refiners make, or are planning to make, greases as they involve additional processing technology. All of the products designed for specific end uses incorporate additive or performance packages (Section 2.2.2). The amount of additives employed is frequently in excess of the minimum requirement, a so-called "fat package," in an attempt to ensure satisfactory end-use performance; this approach is followed particularly for engine oils.

The list of products marketed by the re-refiners is extensive and dependent, of course, on the type of feedstock processed. From conventional automotive crankcase drainings, one company lists four grades of single-viscosity motor oil, one multigrade oil, a hydraulic oil, an automatic transmission fluid, a compounded and noncompounded aircraft engine oil, several greases and gear oils, several solvents, and a sweeping compound.

Waste products from the re-refining plant; i.e., the acid sludge and oily clay, have not been, heretofore, sources of revenue. In fact, their disposal in an environmentally acceptable manner has been an important cost item for acid-clay processors.

#### 5.2.1.2 Plant Equipment and Maintenance

Any description of re-refining process hardware, as typified by the current industry, must start with the realization that most plants are over 20 years old and many date back to the 1930s. Even when originally built, much of the equipment was second-hand. In the interim, corrosion and wear have forced repair and replacement of tanks, pumps, furnaces, and piping to the extent that little is often left of the original equipment. It is indeed surprising that some items were observed that have been in continuous use for 40 years or more. When replacements have to be made, used equipment is generally purchased, inasmuch as plant owners are generally small entrepreneurs operating on minimum profit margins and with limited capital funds. Consequently, it should not be surprising that the equipment is not always optimum for the process or plant throughput, while leaks, defects, and patchwork repairs are widely evident. Maintenance is generally done in-plant, often by the owner. One re-refiner indicated that maintenance was the largest labor cost item.

Not evident at most re-refineries are heat exchangers, control instrumentation, and laboratory analytical equipment. Undoubtedly, an opportunity for considerable energy conservation is present in most re-refineries, but thus far it has not been worth the capital investment in heat recovery equipment. Process control is mostly based on the experience of the plant owner or head operator, using a few temperature and pressure gages. The appearance of a sample is often the key indicator of adequate residence time, acid usage, etc. Sometimes a quick field test is used; e.g., running a reactor sample through a piece of filter paper to see if the batch is "done."

The equipment that is evident in most United States facilities is typical of small chemical processing plants. Because only concentrated acid is used for treatment, mild steel can be used for everything except a few overhead lines and condensers, where dilute acids (which may form) can cause rapid corrosion. Pumps are generally centrifugal and motor-driven although an old steam pump can be seen occasionally. Some plants report wear problems in the hot waste oil pumps used for circulation through the furnace. They are repaired if possible, as is the case with most of the other equipment, not only because it is usually cheaper to do so but delivery times of replacement pumps may be quite long and it is too costly to stock spares. Equipment tends to be tightly packed because the facility grounds are usually small.

It should be noted in concluding this description that the plant of the largest re-refiner in the United States, Motor Oils Refining Company, a division of Esmark, Inc., is significantly different from the industry average. A tour of the plant revealed heat exchangers, temperature and pressure recorders, modernized equipment, and an impressive control laboratory.

### 5.2.1.3 Process Chemical and Water Requirements

The chemicals used in the acid-clay process are predominantly those indicated by its name; i.e., acid and clay. The acid is generally purchased in tank truck or railroad tank car quantities. Clay is purchased in 50-pound bags and brought into the plant by truck or freight car. It is usually Filtrol grade 20, an acid-activated montmorillonite clay of about 200 mesh.

Diatomaceous earth is frequently added to the clay as a filter precoat material. No other chemicals are consumed directly in making a re-refined base stock. Water usage for steam generation, cooling, and cleaning varies with plant design, location, and local ordinances. In addition to separation of oil residues from waste water, the water is often neutralized with sodium hydroxide before discharge to the sewer. The quantity of caustic used could not be reliably ascertained, but is small.

### 5.2.1.4 Environmental Considerations

The environmental problems associated with the acid-clay process center around disposal of the acid sludge and, to a lesser degree, the spent clay. Other difficulties related to odorous emissions and contaminated water disposal to the sewer system are relatively minor by comparison and more amenable to solution. These problems are briefly discussed.

#### 5.2.1.4.1 Waste Product Disposal

Acid sludge contains from 18 to 28 percent sulfuric acid by volume (Ref. 5-3). It also has a high metal content, particularly lead, and is combustible. Therefore, it cannot be disposed of indiscriminately. Most United States re-refiners truck the sludge to a Class I-type* landfill, which can accept such hazardous material. According to the re-refiners contacted during this study, costs at the dump range from 4 cents to 16 cents per gallon. To this must be added the transportation costs for hauling the sludge as much as 50 miles one way. Also, it usually has to be heated prior to loading. One re-refiner visited pays 6 cents per gallon to have the sludge neutralized so that it will be accepted at the city dump (Ref. 5-4). Although the magnitude of the sludge disposal problem varies with the locality, it can be a significant cost item for some re-refiners. Several re-refiners indicated that they were

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*A classification applied in California to designate a disposal facility which has no possibility of discharge to usable waters and therefore can receive all types of waste.

working on processes to convert the sludge to a useful, saleable product. A road-base material was mentioned at one facility as the objective. Low treatment cost is one hurdle, and another is that the product must be environmentally acceptable; e.g., acidity neutralized, with metallic contaminants prevented from leaching out.

Disposal of the spent clay is a somewhat easier problem. The principal component of concern is oil, which amounts to about 20 percent by weight. The clay is usually sent along with sludge to the landfill, but it need not be neutralized. Also, there are some uses for it. Several re-refiners are saving transportation and dump charges by giving the black, oily powder away for dust control.

### 5.2.1.4.2 Effluent and Emission Control

Several re-refiners indicated that they had encountered some environmental problems a few years ago, but pollution control equipment had since been added to bring their plants into compliance with applicable regulations. They also stated that they are under continual surveillance by local authorities as they represent an obvious source of pollution. Sanitary district personnel periodically sample the waste water discharged, while air pollution inspectors make frequent visits to check visible and odorous emissions.

Waste water containing oil originates from several points in the re-refinery, including the incoming waste oil itself, stripping steam, and plant runoff. The oil content and acidity is too high to run the water directly into the sewer. The usual treatment is to pass the waste water through an American Petroleum Institute (API) type separator, which effectively separates the oil globules from the water phase. One plant had to meet a maximum allowable hydrocarbon concentration in the discharge water of 100 parts per million hexane soluble, a typical value in many municipalities (Ref. 5-3); the water usually ran about 40 parts per million. To meet pH requirements, caustic has to be added to the waste water at most acid-clay plants.

Air pollution is currently not a major re-refiner problem. Venting of off-gases to a process furnace or special incinerator has essentially eliminated odorous compounds. Steam is generally injected into the firebox to ensure a clean flue gas when the light overheads are burned. In the several re-refineries visited during this study, air pollution was not evident to the casual observer.

### 5.2.2 Clay Treatment

This process is a predecessor of the acid-clay treatment, being used in the days before automotive lubricating oils were highly compounded with additives. Generally using somewhat higher concentrations of clay than employed with acid, the clay process is capable of producing an acceptable product oil. It is still used by re-refiners who treat only industrial oils (Ref. 5-5) or mixed industrial and crankcase oils (Ref. 5-6). The advantage of clay treatment, of course, is the avoidance of acid sludge with the attendant difficulty and expense of disposal.

The processing of industrial oils, including hydraulic press oil, air compressor oil, and lubricating oils, is relatively simple (Ref. 5-5). The oil is first heated to about 200° to 300°F to remove water; then the clay is added at a rate of about 0.5 pound per gallon of oil. After being agitated for good contact, the oil is passed through primary and polishing filters. The viscosity is checked, and an additive, e.g., for antiwear, may be added. The yield is said to be near 90 percent.

Of greater interest is the application of clay treatment to crankcase oil. According to the mode of operation described in Ref. 5-6, industrial and crankcase oils are mixed before processing. The mixture is heated to about 560°F for 2 hours to dehydrate and recover the light ends. A mixture of Attapulgas clay and Filtrol-20 is added at the rate of approximately 1.5 pounds per gallon of oil. The amount used is based on experience. If the mixture filters with difficulty insufficient clay has been used, whereas if the oil is overbleached too much has been added. The oil and clay mixture is held overnight at 250°F and then is passed through three filter presses. The first one removes 95 percent of the clay, while the last one acts as a polishing press. The finished base oil is an SAE 20 product. For higher viscosity (SAE 30 or 40), virgin bright stock is added, while cold test neutral oil is used to lower viscosity (SAE 10). About one-third of the product goes to motor oil and the balance to industrial oils. Additives are blended with the base oils, depending upon the final product requirements. Most of the motor oil is sold as a nondetergent oil.

### 5.2.3 Caustic Treatment

Caustic (sodium hydroxide) washing or caustic and sodium silicate treating has been used in several ways in crankcase oil re-refining.

As the only processing step, it does not produce a satisfactory motor oil although the product is claimed to be an excellent cutting oil base stock (Ref. 5-7). It has been followed by clay treatment to improve quality, but, according to Reference 5-8, the yield is even less than for the acid-clay process. Furthermore, the quality is apparently questionable even with clay treatment inasmuch as Reference 5-9 states that the advent of large percentages of additives in compounded motor oil made it necessary for re-refiners to switch to sulfuric acid treatment to produce a usable product. Finally, Reference 5-10 describes a process using caustic soda as a pretreatment to make a good motor oil or railroad car journal oil. This process, however, includes a complete dehydration, acid, and clay treatment sequence after the caustic wash, leaving some question as to why the latter was used at all.

Two re-refiners who use caustic treatment were contacted during the course of this study. Berk Associates, of Pottstown, Pennsylvania, uses caustic as a pretreatment step prior to distillation (Ref. 5-11) and Diamond Head Refinery of Kearny, New Jersey, uses caustic in conjunction with silicate, followed by clay contacting (Ref. 5-12). Both produce automotive lube oil. The first process is discussed in Section 5.3.1, while the other is briefly described in the following paragraphs.

According to the mode of operation described in Reference 5-12 and shown in Figure 5-2, undehydrated oil is brought up to 160°F, while a

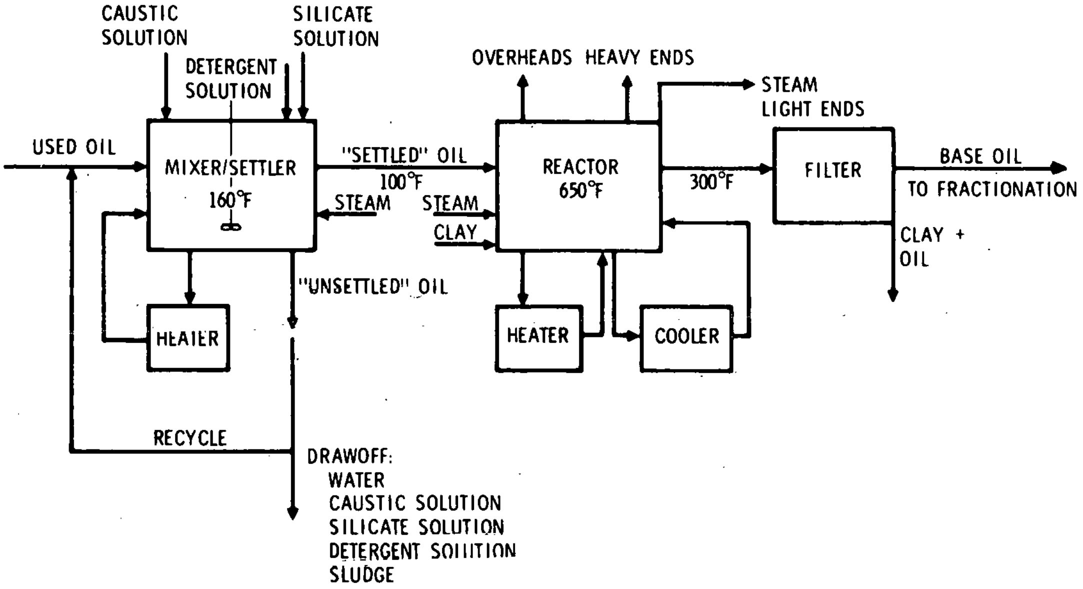


Figure 5-2. Schematic for the Caustic Clay Process (Ref. 5-12)

50 percent caustic solution and a 50 percent silicate solution are added at the appropriate temperature points in the amount of 2 percent each. A small amount of detergent solution, 0.1 percent of Richonate 60 B, which is a 60 percent slurry of sodium dodecylbenzene sulfonate in water, is also added to facilitate the process. Steam is injected to provide additional heat and to increase the moisture level. After thorough mixing in insulated, unheated tanks, the mixture is allowed to settle for 18 to 36 hours. The settled oil is then decanted and sent to an atmosphetic reactor, where steam stripping and clay neutralization and decolorization are carried out, with 0.35 pounds of clay used per pound of oil. The oil and clay mixture is heated to 650°F for removal of the light ends and what is claimed to be two subsequent cuts: an overhead which is comparable to a No. 2 fuel oil and a low-viscosity lube oil equivalent to an SAE 10-weight. The remaining oil and clay mixture is then allowed to cool before being pumped through a plate and frame press for clay removal.

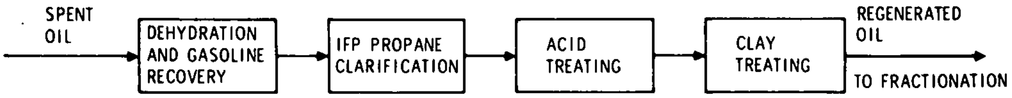
In an effort to increase oil recovery rate and to minimize chemical costs, the "bottoms" from the settling tanks are blended back with incoming used oil. When finally spent, these bottoms are removed for use as a road oil and as a coal dust palliative.

This process, as currently used, appears unique among the various other processes since it takes a heavy fuel cut from the used lube oil being processed.

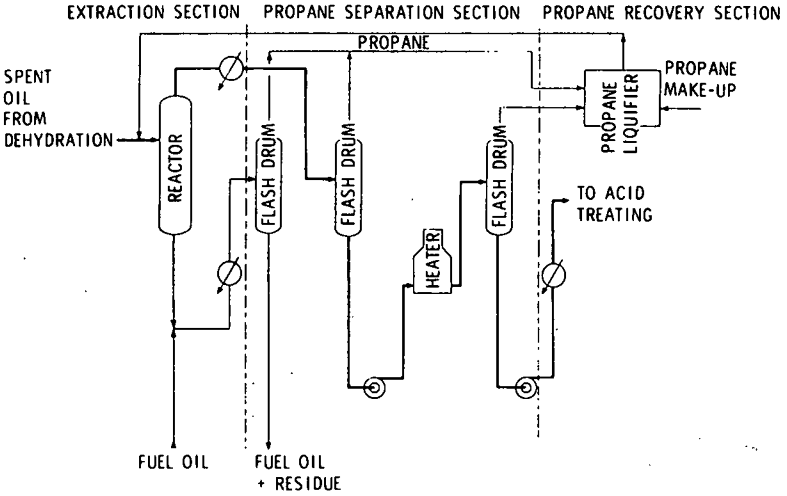
### 5.2.4 Propane Solvent Extraction Process

Although the application of solvent extraction in re-refining has been studied for many years (Section 5.4), only one process is now in operation at a commercial level. This process was developed by the Institute Francais du Petrole and is known as the IFP or Selectopropane process (Ref. 5-13). It is available for licensing; two plants are in operation in Italy, and one is being engineered for Yugoslavia. As indicated in Figure 5-3, the IFP process does not totally replace acid-clay treatment but is intended to reduce the quantity of these materials required and, consequently, the amount of waste to be disposed of.

Only the propane extraction portion of the process is described. As shown in Figure 5-3, the dehydrated and preheated spent oil is mixed with recycled liquid propane and sent to a specially designed reactor operating at several hundred pounds per square inch pressure. The propane and oil mixture is taken off the top, while the insoluble residue is drawn from the reactor bottom. A small amount of fuel oil is added to the bottoms to improve flow properties and is flashed (pressure-reduced) to recover the propane. The remaining residue and fuel oil mixture is then burned in a rotary furnace. The propane and oil solution from the top of the reactor is flashed in two stages to recover the propane, which is compressed and condensed for recycling. The clarified oil is then sent to the acid-clay treating equipment.



a. IFP PROPANE CLARIFICATION OF USED CRANKCASE OIL



b. IFP PROPANE CLARIFICATION SECTION

Figure 5-3. Schematics for the Propane Solvent Extraction Process (Ref. 5-14)

As noted in Ref. 5-3, disposal is still a problem despite the reduction in acid sludge and spent clay produced. Burning the fuel and residue mixture, containing most of the hazardous constituents in the original used oil, poses essentially the same environmental problem. In discussing the combustion of the residue, Reference 5-14 mentions that a special rotary incinerator is used which allows only a low level of particulate matter to escape. It is noted though, that an 80-meter stack is used, which may cause wide dispersal of contaminants and result in a lessening notice of their presence (Ref. 5-15). However, neither operating details nor quantitative performance data are presented.

## 5.3 PROPOSED PROCESSES

The processes covered in this section are in various stages of development or implementation, ranging from laboratory testing to full-scale plant construction. At the time this study was performed, none of these processes was operating commercially.

### 5.3.1 Distillation Processes

Distillation is the basis for numerous re-refining processes that have appeared in the patent and technical literature during recent years. There are several variations in the processing schemes depending upon such factors as (1) the type of pretreatment used, (2) the nature of the finishing step, (3) the feedstock accepted, and (4) the kind of oil produced. Since many processing approaches employ a distillation step for secondary contamination separation and/or product fractionation, the distillation category tends to be ill-defined. In this report, the term is reserved for those processes which depend upon distillation for a major portion of contaminant removal, notwithstanding the fact that there may be a comparatively simple pretreatment step and subsequent finishing with clay or hydrogen.

Among the advantages claimed for the distillation approach are suitability for continuous operation, excellent yields, highly stable product oil, freedom from pollution, and economy. According to Weinstein, only the distillation-hydrotreating process, which is under development, holds promise as an economically attractive process, producing no waste products (Ref. 5-16).

The statement that distillation processes are pollution-free requires some caveats. As this re-refining approach must still separate out the used oil contaminants, the residues, which contain lead, other metals, and asphaltic compounds, appear in the distillation column bottoms and/or pretreatment waste. If clay treatment is used for the finishing step rather than hydrotreating, an additional waste product must be disposed of. It is true that, compared with the acid-clay process, the sludge volume is much reduced, the acid contamination is avoided, and the residue may have economic value as an asphalt component or for metal recovery. Therefore, while distillation processes are certainly more environmentally attractive than present industry practice, proper disposition of the waste by-products must be considered in plant operations.

A flowsheet for a distillation and hydrotreating process is shown in Figure 5-4 (Ref. 5-17). The box labeled "Dehydration and Gasoline Recovery" is a special pretreatment system whereby a major part of the contaminants, such as lead, is also recovered. This points to an inherent difficulty in applying distillation to the re-refining of used oil; namely, the inherent tendency of distillation columns to foul and eventually clog (Refs. 5-18 and 5-19). The nature of the pretreatment system applied in the Kinetics Technology International (KTI) process depicted in Figure 5-4 is not known, but various mechanical, thermal, and chemical techniques have been suggested in the literature. Several organizations are attempting to eliminate such costly pretreatment steps, as is mentioned later. Another approach to minimize fouling would be to take a narrower boiling point cut, which would reduce lube yield, but could be economically satisfactory because of the increased production of fuel products.

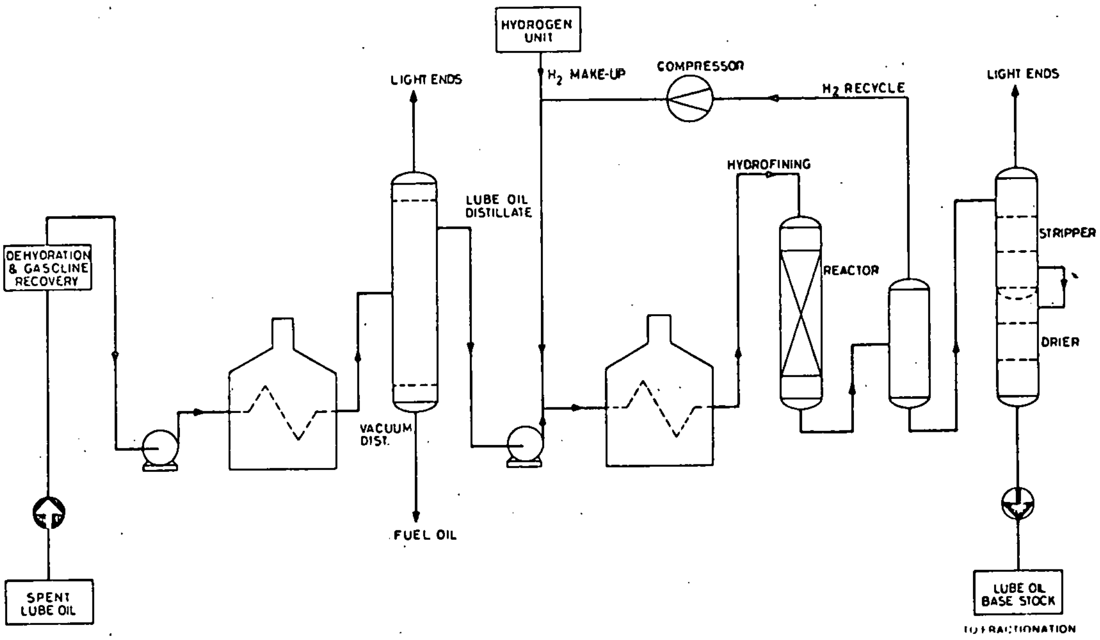


Figure 5-4. Distillation-Hydrotreating (Ref. 5-17)

As shown in Figure 5-4, the pretreated oil is heated further in a furnace and sent to the high-vacuum distillation tower to produce a distillate in the desired lube base stock range. Special proprietary design features are applied to produce a distillate of maximum yield and to minimize any entrainment of residue-containing asphaltic compounds. The latter point is important in order to avoid an increase in hydrotreating costs resulting from catalyst poisoning and coke formation. The light ends and bottoms are presumably suitable for use as fuel although some attention must be paid to the metal composition of the bottoms to ensure that combustion products are environmentally safe. The distillation step can be also used to fractionate the oil into several lube cuts to be further processed separately.

In the hydrotreating end of the process, the distillate oil is mixed with hydrogen, heated in a furnace, and passed through a fixed catalyst bed in the reactor under pressure. Catalyst activity and operating conditions are such that little or no cracking occurs in the process. The reactor products are sent to a flash drum, where the hydrogen-rich gas is separated and compressed for recycling. The oil is steam-stripped to obtain a product with the desired viscosity, then dried in a vacuum column. Alternatively, fractionated lube oil products can be made by a modified final step.

The process described was slated for implementation in the Netherlands, but plans were subsequently dropped when that country passed a law allowing burning of waste oil, thereby periling an assured supply of feedstock (Refs. 5-10 and 5-20). However, KTI has a demonstration plant under construction in West Germany for Haberland and Company, which is scheduled for completion in early 1978 (Ref. 5-21). In addition, it has a letter of intent from Haberland to start construction of a 2500 BPSD commercial plant in the second half of 1978. This capacity, which is equivalent to about 25 million gallons per year, will be approximately twice that of the largest existing plant in the United States.

Other processes employing distillation, in various stages of implementation, were investigated during the course of this study. One plant was under construction by NORCO in Bayonne, New Jersey (Ref. 5-22). The process consists of dehydration, vacuum distillation, and hydrotreating. No chemical pretreatment of the feed was contemplated at that time as it was considered to be too expensive. The base stock to be produced in this plant would be sold for compounding as a cutting oil, bearing oil, or grease; no motor oils would be made. Recent attempts to contact NORCO as to the status of its plant were unsuccessful. According to recent reports, NORCO is experiencing financial troubles and has terminated the project (Refs. 5-15 and 5-23).

The Gladieux Refining Company of Ft. Wayne, Indiana, a small crude oil refiner, is well along in engineering design and cost estimating for an industrial oil re-refinery; a pilot plant is concurrently gathering data on the critical process steps (Ref. 5-24). The sequence involves dehydration, hydrotreating, and vacuum distillation. The process appears to be unique in that hydrotreating precedes rather than follows distillation. Also, the hydrogen treatment is severe, whereas only a mild treatment is generally considered necessary. Since industrial oils will comprise the feedstock, distillation column-fouling may not be as severe a problem as it would be if crankcase oil were being processed. Nevertheless, a prefiltration step is being considered if the solids content gets too high.

An interesting variation of the distillation process was observed during a visit to the development laboratory of ECO-Separator, a division of A. Johnson & Company, a Swedish-based corporation (Ref. 5-25). The process steps investigated thus far are dehydration of crankcase oil, followed by distillation, with both operations conducted under vacuum. The uniqueness of this process resides in the thin film heat exchangers and evaporators used for the separations. Advantages of such units include excellent heat transfer, high throughputs in small equipment, and little fluid holdup. On the other hand, the narrow passages that provide the thin film are prone to plugging in the absence of a preseparation step for the used oil. In the pilot plant, two of the compact units are piped in parallel and operate alternately. After about 18 hours running time on one of the units, flow is switched and the fouled unit is cleaned for 1 to 2 hours with a small quantity of chromic acid solution; the acid is then neutralized and sent to the sewer. Acceptability of discharging this waste product into the sewer system has not been determined.

Although laboratory data indicate that substantially all of the metal contaminants have been removed, the product (at the time of the visit) was dark and had an undesirable odor. While steam-stripping successfully removed the odor and clay treatment improved the color, attempts are being made to avoid these final steps. Currently, no attempt is being made to market the product of this experimental operation as lube oil: all product produced is disposed of as burner fuel (Ref. 5-15).

Berks Associates of Pottstown, Pennsylvania had used a straight distillation process for 7 years prior to incorporating a caustic pretreatment. The caustic pretreatment has been in use for the past 8 years, and is based on their patent, which is described in Section 5.4.2.4.

Used oil is first dehydrated and then diluted with a light solvent oil in the ratio of 1/2 part solvent to 4 parts oil. After dehydration and dilution, a 50 percent caustic solution is added at the rate of 0.5 percent, and the mixture is then held for about 12 hours in a settling tank at a temperature below 212°F. After decantation, the treated oil goes to a vacuum distillation tower which produces two lube oil cuts in addition to the overheads and bottoms. The lube oil fraction is then clay-treated at the rate of 0.25 to 0.50 pounds per gallon. The product is marketed both as a base oil for use as a railroad journal oil, and is compounded as a "Series 3" oil for use in diesel truck engines.

Both the bottoms and sludge are marketed to a roof coating manufacturer. The bottoms are acceptable in untreated form, but the sludge requires drying and screening.

Even with the caustic pretreatment step, column-fouling occurs, requiring shutdown for cleaning approximately every 6 months. A bubble cap column is used, with 140 caps per tray and 21 trays in the column. These caps and trays are removed for cleaning, then scraped and washed in solvent. The cleaning procedure requires about 7 workers and takes 1 to 2 weeks.

Another variation of the distillation process is in use at Coral Refining of Kansas City, Kansas. The process used in this plant was developed at Coral Refining and is owned by the Vacsol Corporation, also of Kansas City; it is called the O'Blasny process after its developer (Ref. 5-26). The process has a patent pending and as such is currently considered proprietary.

Apparently, the process employs no pretreatment prior to distillation, except for a conventional dehydration step. After dehydration, the used oil is subjected to the proprietary distillation process. Currently, the lube oil product is sold as a base oil, both with and without clay-treating, to railroads as a journal oil and to other users, such as grease manufacturers. The overhead distillate and bottoms are also sold. According to Coral Refining, these bottoms could be used in asphaltic products, as rubber plasticizers, and even as traction motor lubricants (Ref. 5-26).

Although current use of the lube oil produced is limited to nondemanding applications, the intent is to produce automotive lube oils. Base oil quality, as determined by spectrographic analysis of metals remaining, is claimed to be good. Engine sequence tests to fully evaluate the quality of the oil are said to be in process.

The current plant started operation in February of 1977 and is sized to process 5 million gallons per year of used oil. Recent processing rates have been around 350,000 gallons per month. Claims have been made by the operator that, because of the unique distillation process, no shutdowns will ever be required for cleaning the distillation equipment.

### 5.3.2 BERC Solvent Extraction Process

The Bartlesville Energy Research Center (BERC), a part of the Department of Energy (DOE), has been involved in a research project on re-refining used crankcase oil for several years. Papers have been published on the comparative compositions of collected oils (Ref. 5-27), laboratory evaluation of several re-refining processes (Ref. 5-28), and pilot plant studies of an in-house process (Ref. 5-29). The latter aspect of the BERC work is described in this section.

The process shown schematically in Figure 5-5 is covered by two patent applications (No. S-46,037 and G-48,107), both of which have been allowed. The major steps are dehydration to remove water and light ends; solvent extraction, including solvent recovery from the extract and raffinate; fractional vacuum distillation for additional contaminant removal and base stock production; and clay treatment for color improvement and stabilization, although other finishing processes have been investigated, such as hydrotreating. The solvent consists of a mixture of 1 part (by volume) isopropyl alcohol, 1 part methyl ethyl ketone, and 2 parts butyl alcohol. The combination is used in a solvent to oil ratio of 3:1. The various steps in the process are similar to refining operations described elsewhere in this report for used or virgin lube oil.

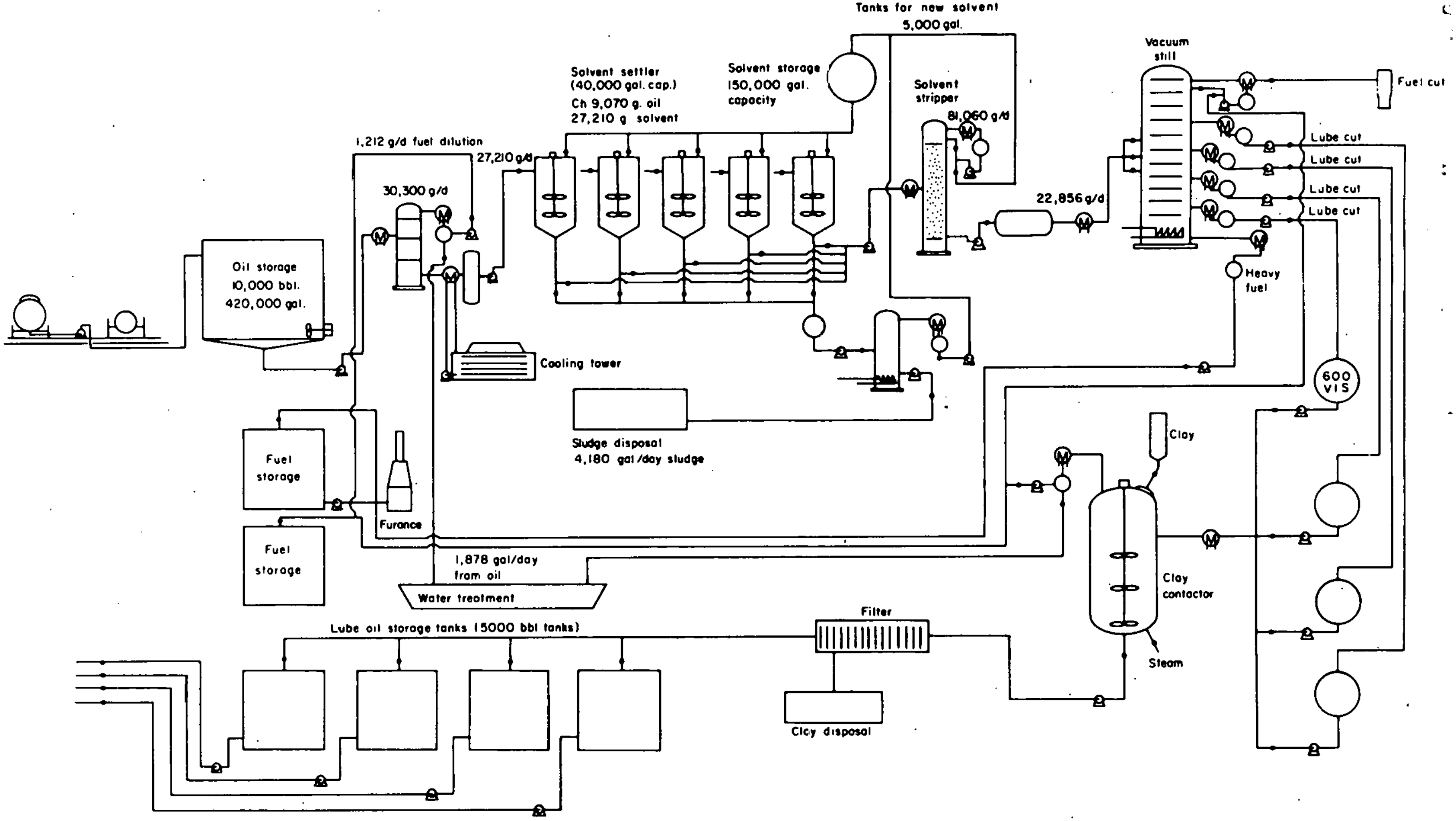


Figure 5-5. BERC/DOE Re-Refining Process; $10 \times 10^6$ Gal Per Year Capacity (Ref. 5-30)

The BERC process has been run in pilot plant scale equipment, and enough material has been prepared to obtain engine performance data (Ref. 5-31). Two BERC process oils were tested, one finished by clay contacting and one by hydrotreating. In addition, a commercial re-refined motor oil provided by Motor Oils Refining of McCook, Illinois was tested concurrently. All three oils were compounded for SE service. The commercial oil passed the IIC, IIIC, VC, and the L-38 engine test evaluations (Section 9) that are established for SE service, and which are also specified by the military to meet the major requirements set forth in the MIL-L-46152 specification. The hydrogen-finished BERC oil passed both IIIC and VC sequence tests but failed the IIC marginally. The clay-treated sample successfully passed the IIC and IIIC tests but failed the VC marginally (Ref. 5-32). Both oils passed the L-38 test. Fleet testing of oil produced by BERC technology is currently being conducted in the State of Iowa, showing satisfactory service after 15 months of use (Ref. 5-15).

### 5.3.3 MZF Solvent Extraction Process

As an example of an advanced process, the MZF process was chosen for evaluation in this study. This process is based on two solvent extraction techniques which were patented by Dr. M. Fainman and Mr. C. McAuley. These techniques require aqueous isopropyl alcohol solutions in conjunction with small amounts of alkali (Ref. 5-33) or acid (Ref. 5-34) to remove contaminants from the used oil. The alkali technique is favored by Dr. Fainman and has been further improved (patent pending). Information was primarily available from the existing patents and was supplemented by additional data provided by the inventor. Claims for the process have not been verified and are based on a limited amount of small-scale laboratory experimentation.

A process schematic is shown in Figure 5-6. In an initial step, the used oil is diluted with recycled naphtha, in a volume ratio of 1:1, to reduce the oil viscosity and facilitate the extraction process. Aqueous isopropyl alcohol plus sodium carbonate are added and thoroughly mixed with the oil. According to the patent, an unstable emulsion is formed which is physically separated into a top layer consisting of oil-naphtha and a bottom alcohol-water layer containing the sludge. The phases are stripped to recover the naphtha and alcohol for recycling, the latter as an alcohol-rich azeotrope. The oil so obtained is ready for further finishing, such as distillation and/or clay treatment.

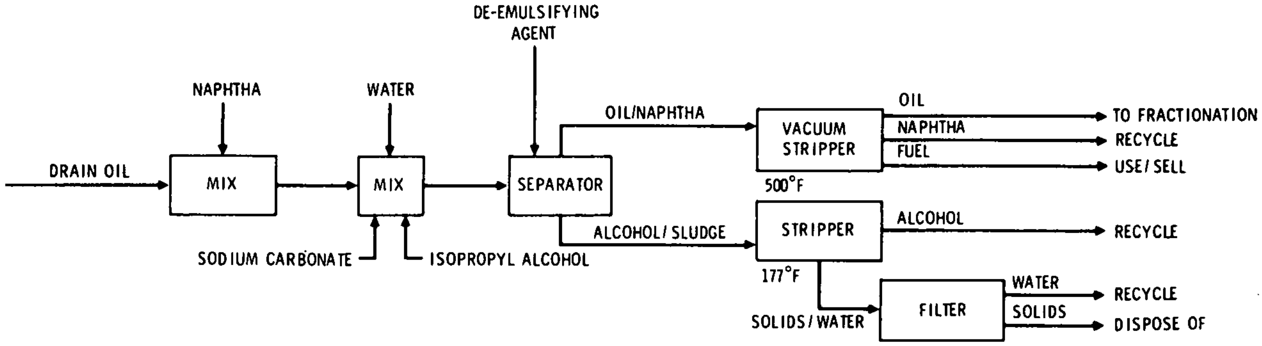


Figure 5-6. MZF Re-refining Process
(Based on Refs. 5-35 and 5-36)

The physical separation technique described in the patent uses centrifugation, which is expensive in terms of both equipment cost and operating energy. According to Dr. Fainman, the improved process is based on an alternative method which does not require the expenditure of energy. However, it was stated that the process employed a small amount of a low-cost and abundant chemical deemulsifier (Ref. 5-35). Since the procedure is being patented, no descriptive material could be made available.

### 5.3.4 Phillips Re-refined Oil Process (PROP)

In August of 1977, the Phillips Petroleum Company announced a new re-refining process and signed a contract with the State of North Carolina to build a 2 million gallon per year plant for 1.4 million dollars (Ref. 5-37). The plant, which is scheduled to go into operation in mid-1978, is designed to operate continuously but could be operated on a single-shift, 5-day week basis. Throughput capacity would then drop to 500,000 gallons per year. Phillips (Ref. 5-38) considers the process proprietary and is unwilling even to discuss it in relation to its patented processes (Sections 5.4.5.3 and 5.4.7.1), which make use of aqueous solutions of ammonium sulfate or bisulfate and ammonium phosphate. It is noted though, that their purchase agreement with the State of North Carolina mentions both these patents and a patent application, Serial No. 797,212. The State of North Carolina (Ref. 5-39) could not offer any technical assistance since it has entered into a secrecy arrangement with Phillips for the purpose of evaluating the process at the School of Chemical Engineering, North Carolina State University. However, a limited amount of nonconfidential economic data was provided.

Phillips marketing approach for the process is to offer a prefabricated, skid-mounted quick-connect plant, sized to meet specific volume requirements. It is a fixed-price turnkey arrangement that includes training of operators. Product quality and yield are guaranteed. To meet these guarantees, Phillips specifies that the feedstock be normal crankcase drainings and exclude other types, such as industrial oils. Process claims include (1) high lube oil yields, (2) rapid startup and shutdown, (3) environmental acceptability through elimination of acids, sludges, solvents, harmful air and water effluents, and generation of a neutral solid waste that can be processed into useful by-products, (4) production of a diesel fuel side stream, and (5) a process time of 3 hours from used oil feedstock input to finished product output (Ref. 5-40).

The following description is taken from Reference 5-40:

> ... The oil reclamation process is a continuous process that can be operated on a "batch" type basis. The reclamation equipment will require approximately 1 to 2 hours to bring equipment and oil up to operating temperature and 1 hour at the end of the day to shut down and remove sludge. Thus, for a production rate of 2000 gallons daily, the operation time for personnel will be 11 hours daily. Spent oil will be accumulated in a 6000-gallon tank (3-day supply). Pumps are provided to remove oil from drums or tankers.
>
> The reclamation process (confidential) terminates in an 8000-gallon tank where the additives are blended with the processed oil. No storage facilities have been provided for additives since roughly only 160 gallons are added daily. Additives would be stored in drums and added manually. Sludge is removed twice daily, requiring an estimated 45 minutes for one man. One sludge removal is planned at the end of operations. No interruption of production is required. Maintenance downtime is estimated at 8 percent of operation time or about 14 hours/month. This routine maintenance should be scheduled for Saturday to permit continuous production.
>
> Upon adding the additive package and mixing, the finished product will be stored in two 8000-gallon tanks. Oil can be pumped into either tank trucks or 55-gallon drums from these storage tanks.

## 5.4 OTHER PROCESSES AS DESCRIBED IN THE PATENT LITERATURE

### 5.4.1 General

The patent literature was reviewed for processes applicable to re-refining used oils. This review, which covered patents issued within the past 20 years, was conducted in accordance with the ordering system used in the Patent Classification Manual. Class 208 contains patents related to "Mineral Oils: Processes and Products." Under this class are the subclassifications "Refining" and "Purifying Used Oil." The latter subclassification is subdivided in the classification manual according to the method used to purify the used oil. The following paragraphs present these patents as entitled and follow the same organization as the classification manual. Data within a subclassification is then presented in order of grant, with the earliest patents presented first.

### 5.4.2 Purifying Used Oil: Basic (Subclassification 179)

This category represents the initial and major patent subclassification which covers those processes applicable to re-refining used oils. The succeeding breakdowns under this subclassification are by the particular type of process employed, such as the addition of organic material.

### 5.4.2.1 Refining Used Lubricating Oils with Sulfuric Acid and Hydrogenation (Ref. 5-41)

This process for re-refining used engine and industrial oils consists of a prepurifying step using sulfuric acid, followed by a catalytic hydrogenation treatment. Patent emphasis appears to be on the hydrogenation step, detailing pressures, temperatures, space velocity, and catalysts used in the process.

The used lubricating oil, assumed to have 7 percent water, is treated with 5 weight percent concentrated sulfuric acid. According to the patent description, this treatment causes a loss of 17.5 percent (sludge), yielding 82.5 percent prepurified oil, which is then hydrogenated at a pressure of 40 atmospheres and a temperature of 360°C, with a space velocity of 0.5 $\text{hour}^{-1}$. The gas and liquid ratio is 0.1 cubic meter per liter, with a 75/25 percent hydrogen/nitrogen gas mixture. The catalyst is composed of a mixture containing nickel oxide, molybdenum trioxide, silica, and iron oxide, all carried on a gamma aluminum oxide base. After hydrogenation, the oil is subjected to vacuum distillation to separate out fractions. The product yield is 48.2 percent re-refined engine oil, 32.5 percent re-refined gas oil and industrial oil, 17.5 percent acid treatment loss, and 1.8 percent hydrogenation and distillation losses.

It is claimed in the patent that the yield and quality of products are better than achieved in "conventional" re-refining processes. The amount of sludge that precipitates out with the 5 percent acid treatment appears quite low and inconsistent with that obtained from current acid-clay re-refining processes. It is conceivable, however, that in the patentee's home country (Hungary), motor oils were not compounded with additives at the time of patent filing.

### 5.4.2.2 Reclamation of Used Lubricating Oils by Sulfuric Acid Treatment (Ref. 5-42)

This process for re-refining used motor oils appears to be based on the use of an aqueous solution of sulfuric acid rather than the concentrated form commonly employed in the acid-clay process. The process, which is intended for motor oils containing ashless polymeric dispersants, consists of adding 20 to 40 pounds of an 80 to 95 percent aqueous concentration of sulfuric acid to each barrel of used oil. The treated oil, at 100° to 140°F, is permitted to settle for about 20 hours prior to decanting the purified oil.

Although not specifically stated in the patent, the purified oil is subjected to a clay treatment. For an acid strength of 90 percent, a dose of 30 pounds per barrel, and a settling time of 20 hours, the process yield is claimed to be 65 percent oil, 13.1 percent overheads, 10.5 percent sludge, and 11.4 percent filtering losses.

The patent states that the use of concentrated sulfuric acid on motor oils containing ashless dispersants tends to hinder the removal of sludge.

### 5.4.2.3 Re-refining of Waste Crankcase and Like Oils (Ref. 5-43)

This process treats used oil with chemical compounds generating free hydroxyl radicals, which precipitate out contaminants without harming the detergents and additives in the oil. Compounds to be added are selected from the peroxides, such as hydrogen peroxide, and metal halides, such as aluminum chloride.

The used oil is heated to 120°F and 0.2 percent of a 50 percent concentration of aqueous sodium hydroxide is added, followed by further heating to 130°F and the addition of 0.1 percent of a 30 percent solution of hydrogen peroxide. The treated oil is then thoroughly mixed, heated to 150°F, allowed to cool to room temperature, and settle for 24 hours. The clear oil is then decanted. For a used oil with a 7 percent bottom sediment and water to start with, a 90 percent yield is claimed in the patent. The purified oil may be further treated or distilled and fractionated. No details regarding the latter operations are provided.

### 5.4.2.4 Crankcase Oil Refining (Ref. 5-44)

This process makes use of an alkali metal hydroxide, such as sodium or potassium hydroxide, in conjunction with a heads oil (which is a light hydrocarbon fraction with an American Society for Testing and Materials (ASTM) boiling range of 150° to 250°F) to precipitate out carbonaceous materials.

The waste oil is first dehydrated at about 400°F, which is below the coking point. After cooling to 200° to 300°F, about 0.2 to 2.0 percent of a concentrated aqueous alkali metal hydroxide solution is added. The mixture is then blended with heads oil, with a heads oil to dehydrated oils volume ratio between 1 to 5.7 and 1 to 4.1, causing the formation of a precipitate. The precipitate is then separated centrifugally. The separated liquid mixture is then subjected to a distillation process to obtain the desired lube cuts, to remove water, and to recover the heads oil and other overheads.

The patent contains a detailed description of the process and equipment employed. Much of this description is related to the specifics required to place the invention into practice and to the distillation process performed after the waste oil is treated. No details as to product yield or quality are provided.

### 5.4.2.5 Process for Re-refining Used Petroleum Products (Ref. 5-45)

This process is essentially a multistage vacuum distillation. The first stage of the process is a combination of flash distillation and multistage stripping. Waste oil heated to 300° to 450°F is expanded from about 90 to 130 pounds per square inch, gage (psig), down to atmospheric pressure to remove water and volatile hydrocarbons. The less volatile liquid bottoms then flow through a multistage stripping column counter-current to superheated steam of 400° to 500°F. If the used oil is acidic, a small amount of alkali is introduced along with the steam injected into the first-stage stripping column. This neutralization step is intended to protect the equipment, which is made from plain carbon steel. The overheads from this stripping operation are condensed to separate out water and light hydrocarbons. The bottoms are then subjected to a one- or two-step vacuum distillation process using temperatures of 600° to 700°F and a vacuum of 1 to 40 torr. The two-stage vacuum distillation process is preferred as it gives a wider range of product yields. The product yield for the three-stage (one atmospheric stage and two vacuum stages) process is claimed to consist of approximately 30 to 50 percent light lube oil, 10 to 30 percent heavy lube oil, and 10 to 20 percent asphaltic bottoms.

No details were noted regarding measures to prevent clogging of the distillation units, which is the basic problem in distillation of waste oil. The patent is for the process and not the hardware. In fact, the patent states that any suitable column may be employed, but a Baird disc and tube column is preferred since it is not subject to clogging by dirt, sludge, oxidation products, mixed oil additives, and the like. Also, it is claimed that residence time in the first-stage stripper is only 2 to 5 seconds. In the second- and third-stage distillation evaporators, the residence time is 1 to 3 seconds.

### 5.4.2.6 Removal of Lead and Other Suspended Solids from Used Hydrocarbon Lubricating Oil (Ref. 5-46)

This process uses heat and residence time to agglomerate lead and other dispersed solids in waste oil. First, the used oil is dehydrated to remove water and the light ends. This portion of the process is carried out at temperatures of 500° to 700°F and pressures ranging from a mild vacuum of 2.5 up to 150 pounds per square inch, absolute (psia). The oil is then heat-treated at 500° to 700°F for 1 to 12 hours, depending upon the geometry of the equipment and the degree of particulate removal desired. The agglomerated metals are then removed by one of the many standard procedures available, such as gravity settling, filtration, or centrifugation.

Depending upon the design of equipment used, the process can be either of the batch or continuous type. Also, the heat-treating and gravity-settling zones can be unitized such that the oil is settled at the end of the heat treatment period. While process details are not known, it is believed that thermal decomposition of the peptizing agents which hold the dispersed solids in colloidal suspension takes place as a result of the high process temperatures.

No data on product yield and quality are provided in the patent. However, the statement is made that over 90 percent of the dispersed lead and other solids can be removed.

### 5.4.2.7 Process for Cleaning Used Oils (Ref. 5-47)

This process purifies oil by heat treatment. In the process, used oil is heated in a reactor to about 610° to 750°F, using a pressure of 1 to 6 atmospheres and a residence time of 15 to 30 minutes. The oil is then filtered and/or centrifuged.

The process as described in the patent calls for a continuous withdrawal of oil from the reactor. This oil is then divided into two parts, with one part going to the filtration unit and the other back to the reactor. A recycling ratio of 5 to 20 (the entering used oil flow rate is 1/5 to 1/20 of the flow rate of the recycle loop) is used to ensure the proper residence time of the oil in the reactor. The residues removed from the oil, along with overheads from the reactor, are fed to the furnace heating the oil.

Selected product yield and quality data provided in the patent disclosure are presented in Table 5-1 for two runs.

### 5.4.3 Purifying Used Oil with Added Organic Material (Subclassification 180)

The patents listed under Subclassification 180 are based on the addition of organic material as a means of used oil purification.

### 5.4.3.1 Reclaiming Used Lubricating Oil (Ref. 5-48)

This process uses a small amount of hydrazine to precipitate out impurities contained in the used oil. The oil is treated at a temperature of 50° to 150°F with 0.5 to 10 percent of hydrazine. The mixture is thoroughly agitated to ensure complete contact. Sludge is then separated by conventional means such as gravity or centrifugation. A final clay treatment is used to improve color. To remove dissolved hydrazine, it may be necessary to water-wash the oil or treat with acid.

Table 5-1. Product Yield and Quality Data for Troesch Used Oil Cleaning Process (Ref. 5-47)

| Parameter | Run 1 | Run 2 |
|---|---|---|
| **Reactor Condition** | | |
| Temperature, °F | 617 | 617 |
| Pressure, atm | 4 | 2 |
| Time, min | 30 | 25 |
| **Yield** | | |
| Treated Oil, % | 88.7 | 89.0 |
| Light Distillates, % | 1.8 | 2.9 |
| Water, % | 4.0 | 2.7 |
| Residue, % | 5.1 | 4.9 |
| Losses, % | 0.4 | 0.5 |
| **Quality: Before and After Conditions** | | |
| Gravity | 0.900 to 0.884 | 0.898 to 0.887 |
| Viscosity, centistokes at 122°F | 38.7 to 33.5 | 49.4 to 45.9 |
| Acid Index | 0.85 to 0.70 | 0.90 to 0.72 |
| Ash, % | 1.15 to 0.12 | 1.25 to 0.17 |
| Flash Point, °F | 275 to 315 | 257 to 320 |

A comparison of the properties of new oil, used oil, and treated used crankcase oil as provided in the patent is shown in Table 5-2.

Table 5-2. Comparison of Oil Properties (Ref. 5-48)

| Property | New Oil | Used Oil | Treated Oil, Hydrazine Used | |
|---|---|---|---|---|
| | | | 10% | 5% |
| Viscosity at 210°F, SUS | 64.9 | - | 59.6 | 60.0 |
| Viscosity Index | 99 | - | 99 | 99 |
| Neutralization Number | 0.21 | 0.48 | 0.12 | 0.12 |
| Ash | 0.23 | 1.86 | 0.09 | 0.12 |
| Ramsbottom Carbon Residue | 0.24 | 6.98 | 0.32 | 0.12 |
| NPA Color | 2.5 | - | >8 | >8 |
| API Gravity | 28.5 | - | 27.6 | 27.3 |

Criteria for selecting the exact amount of hydrazine are not given. However, the data indicate that the final product is not very sensitive to the selected hydrazine treatment volumes.

### 5.4.3.2 Process for Purifying Oil with Monoisopropanolamine (Ref. 5-49)

This process purifies oil by the addition of an oil-soluble, acid-reducing chemical compound of the amine type. In this process, the oil is pretreated with 0.5 weight percent sulfuric or hydrochloric acid to form an electrolytic solution. The mixture is then treated with 0.25 percent of an ammonia-bearing amine compound, such as mono- or iso-propanolamine, forming a sludge which is then separated out by conventional techniques. No data relative to product yields and quality are provided in the patent.

### 5.4.3.3 Method of Neutralizing Oil with Diazomethane (Ref. 5-50)

This patent neutralizes oil acidity by the addition of diazomethane. While the primary usage of this process is in refining crude oil, it is also applicable for the treatment of used oil. A 3 percent solution of diazomethane in hexane is added to used oil, after it has been percolated through Fuller's earth for purification purposes, in an amount proportional to the acid present. All acids present are thus converted to methyl esters. A neutralization number of 0 is obtained, and the color is improved by an amount of about 0.5 on the ASTM color scale. Except for improvements in acid number and color, no other purification of the used oil results from this process.

### 5.4.3.4 Process for Removing Engine Produced Contaminants from Used Lubricating Oil (Ref. 5-51)

In principle, this process represents solvent (generally propane) extraction of lube oil from the contaminating materials. A selected solvent comprised of approximately 90 percent propane, 8 percent butane, and 2 percent ammonia is mixed with the waste oil in a solvent tower, using a solvent to oil ratio varying from 1:1 to as high as 20:1, with an average ratio of about 5:1. The higher solvent oil ratios tend to produce better separation of the lube oil from the impurities and improve color. The solvent tower is operated at 100° to 170°F, with sufficient pressure (400 to 600 psig) to maintain the solvent as a liquid.

Oil impurities, including water, are precipitated out in the solvent tower. The solvent and oil mixture is then further processed in a solvent stripping (flash) tower which operates at 250 to 350 psig and 250° to 500°F. The solvent is recycled, and the oil is then subjected to final treatment in a catalytic reactor, consisting of an activated bauxite, marketed under the trade name Porocel and operating at 350° to 700°F and 0 to 50 psig. This step removes the remaining 10 percent of the total impurities contained in the used oil, with the initial 90 percent removed in the solvent extraction step. The catalyst may be regenerated by a steam and air treatment. The light ends are then removed in a conventional reactor, operating at 400° to 600°F, followed by clay treatment to improve color.

The yields for this process as claimed by the inventor are shown in Table 5-3 for a solvent mixture consisting of butane plus 2 percent ammonia.

Table 5-3. Process Yields (Ref. 5-51)

| Product | Yield, % |
|---|---|
| Water | 1.65 |
| Overheads | 8.10 |
| Cracked Products | 0.00 |
| Lube Oil | 87.85 |
| Bottoms | 1.40 |
| Sludge | 0.00 |
| Loss to Clay | 1.00 |

#### 5.4.3.5 Process for Removing Naphthenic Acids from Mineral Oils (Ref. 5-52)

This process reduces the acidity of used crankcase oil by the addition of an aqueous alkali and a compound selected from the group consisting of aliphatic sulfones, carbyl sulfates, ethylene sulfates, etc. The intent of this patent disclosure is similar to that described in Section 5.4.3.3. In place of the diazomethane, 2 percent of a 3 percent concentrated solution of sodium hydroxide and 0.15 percent of ethylene sulfate are added to the used oil. This results in a reduction in the neutralization number and an improvement in color.

### 5.4.3.6 Re-refining of Lubricating Oils (Ref. 5-53)

This process purifies oil by the addition of surface-active agents possessing high detergency at room temperature, but none at elevated temperatures. In this process, an aqueous cleansing agent is added to the used oil at room temperature using a ratio of 1:3. The mixture is then agitated to form an emulsion, followed by an increase in temperature to about 150° to 200°F, to break the emulsion and to permit separation of the clean oil from the spent cleansing agent by means of a centrifuge. Typically, 1 gallon of surface-active cleansing agent contains 43 grams of a conjugated polyoxyalkylene compound, 48 grams of trisodium phosphate, 7 grams of dodecyl benzene sulfonate, and water.

No product yield information is provided in the patent. Product quality data indicate reduction in the bottom sediment and water content of the oil from 1.1 to 0.8 percent and in the ash content from 1.4 to 0.1 percent. The purified oil may undergo further treatment, such as distillation or filtration. Use of this process as a pretreatment step prevents clogging of the distillation units and reduces the amount of clay required in subsequent finishing processes.

### 5.4.3.7 Process for Re-refining Used Oil (Ref. 5-54)

This process precipitates sludge from used oil by the addition of diethylenetriamine (DETA). The used oil is heated to 120° to 190°F and 0.1 to 12 percent of DETA is added. The flocculent precipitate formed is allowed to settle out. After settling and decanting, the purified oil is then subjected to a clay treatment step, using a temperature of 350°F and about 10 percent clay to improve color. The amount of clay to be used as well as the specific temperatures is similar to the practices employed in the common acid-clay process. Product quality data based on using 1 percent DETA are shown in Table 5-4.

### 5.4.3.8 Purifying Used Metal-Working Lubricating Oils (Ref. 5-55)

Contaminated metal-working oils are cleansed by the addition of a small amount of a trimerized polycarboxylic acid. Metal-working oils, including rolling, cutting, and grinding oils, are usually of the emulsified

Table 5-4. Product Quality Data (Ref. 5-54)

| Parameter | Treated Oil | Used Oil | New Oil |
|---|---|---|---|
| API Gravity | 30.5 | 27.2 | 28.5 |
| Viscosity at 210°F | 55.4 | 55.9 | 56.6 |
| Viscosity Index | 104 | 104 | 104 |
| Acid Number | 0.056 | 2.805 | - |
| Flash Point | 436 | 403 | 455 |
| Ash | 0.4 | - | 1.0 |

type. They become contaminated with fine metal particles and oxides. The contaminated oil mixture is allowed to stand so that the oil layer may be skimmed off. This oil is then heated to about 100°F or slightly higher, and 50 to 1000 parts per million of a trimerized polycarboxylic acid is added, which is produced by polymerization of a polyolefinic acid containing at least 10 carbon atoms in an aliphatic chain. An acid of this type, called Empol 1040, is marketed by Emery Industries. Particle agglomeration occurs within 20 minutes. The particles are then filtered out, centrifuged, or magnetically separated, and the oil is reemulsified and returned to use.

### 5.4.3.9 Removal of Dispersed Solids from a Liquid (Ref. 5-56)

Nondissolved particles are removed from organic liquids by the addition of ultrahigh molecular weight polethylene (UHMW PE). While no specific application is stated in the patent disclosure, it might be suitable for cleaning metal-working oils of the type described in the preceding patent. The process is rather straightforward and requires only that the organic liquid is capable of dissolving polyethylene. The type of polyethylene required is one with a molecular weight in the range of 1,500,000 to 6,000,000. These polyethylenes melt at about 266°F and are stable up to about 750°F, whereupon thermal degradation begins. The contaminated oil is heated above the polyethylene's melting point and a small amount, about 0.03 to 0.3 percent of the UHMW PE is added. After stirring and cooling, the UHMW PE containing the contaminants precipitates out. The cleansed oil may be decanted and reused.

### 5.4.3.10 Method of Reducing the Lead Content of a Used Hydrocarbon Lubricating Oil by Adding Methyl Ethyl Ketone to Separate the Resulting Mixture into a Coagulated Insoluble Phase (Ref. 5-57)

Methyl ethyl ketone (MEK) is used to extract lube oil from lead-containing crankcase drainings. The process requires anhydrous used oil having less than 0.5 weight percent water. In the process, which takes place between 65° and 95°F, 2 parts of MEK are added to each part of used oil. The mixture is left undisturbed for about 6 to 24 hours to facilitate coagulation and separation. The separated insolubles amount to about 10 percent of the total mixture volume.

The clarified MEK-oil solution is then fed to a distillation unit to recover the MEK, which is recycled in the process. The oil, which is dark in color, can be lightened by an appropriate cleaning technique, such as clay-contacting. The sludge formed in the process is then deoiled by solvent extraction to yield a dry product which contains about 20 to 40 percent lead. This product is disposed of by reprocessing for metals recovery or is sent to a dump. Product quality data as provided in the patent are listed in Table 5-5.

Table 5-5. Product Quality (Ref. 5-57)

| Parameter | Used Oil | MEK-treated Oil |
|---|---|---|
| SUS Viscosity, 210°F | 61.6 | 55.4 |
| Viscosity Index | 158 | 133 |
| Pour Point, °F | -35 | -40 |
| Sulfated Ash, % | 2.95 | 0.64 |
| Lead, % | 1.25 | 0.02 |
| Chlorine, % | 0.95 | 0.07 |
| Bromine, % | 0.30 | 0.05 |

### 5.4.3.11 Process for Regenerating Used Lubricating Oils (Ref. 5-58)

This is the IPF propane extraction process, which is discussed in detail in Section 5.2.4.

### 5.4.3.12 Treating Muddy-like Waste Oily Material (Ref. 5-59)

This is a 5-step process for reclaiming fuel oil and asphalt from the oily sludges that are generated by industrial waste water treating plants. Step 1 involves settling of the mixture at about 120° to 160°F to separate out water. In Step 2, the pH value of the oily material is adjusted at about 2 to 4. Step 3 involves solvent extraction of the fuel oil content by use of a paraffin-base hydrocarbon whose boiling point range is about 76° to 480°F. An extraction tower is used, with temperatures maintained between 40° and 77°F. Step 4 involves centrifuging to separate the fuel-solvent mixture from the asphaltic base material, which is then dry-distilled at about 930° to 1100°F. In Step 5, distillation of the fuel-solvent mixture is performed to recover the solvent and the fuel oil component.

### 5.4.3.13 Process and Equipment for the De-asphalting of Residues from Vacuum Distillation of Petroleum, and Application to the Remaining of Lubricant Oil (Ref. 5-60)

The objective of this invention is to purify drain oils on a small scale through the use of simple, inexpensive equipment. The process devised is based on a technique for improving the contact between the mineral oil being treated and the propane solvent. The used oil is pulse-sprayed into liquid propane in an extraction tower. The excellent contact afforded causes the asphalts and insoluble particles to precipitate out. The final scrubbing of the dissolved lubricant takes place in a series of three columns, in which separation of the liquid propane occurs. A reflux system is set up between these towers, which also make use of pulsed injections counter to the flow of material. This pulsed reflux system causes a rapid precipitation of all impurities. The oil-propane mixture then flows through an evaporator coil and a heat exchanger to separate the propane from the oil. A compressor is then used to liquefy the propane, which is recycled for further use. No data as to product yield or quality are provided in the patent disclosure.

### 5.4.3.14 Process for Regenerating Used Lubricating Oils (Ref. 5-61)

An ultrafiltration membrane permeable to hydrocarbons is used in this patent to purify used lubricating oils containing soluble metal compounds. This process is particularly applicable to crankcase drainings which contain large amounts of additives. The process is intended as a replacement for the sulfuric acid treatment process.

Used oil, after being stripped of water, is dissolved in a light hydrocarbon to reduce its viscosity. Propane, butane, pentane, hexane, and other such solvents are suitable and are used in a solvent-to-oil ratio of about 2:1. The oil-solvent mixture is circulated against the face of the ultrafiltration membrane. Purified oil and solvent pass through the membrane, leaving impurities behind. The solvent is then stripped from the oil and recycled. Ultrafiltration membranes having a cut zone of 5000 to 300,000 may be used. A cut zone is defined as the approximate limit between the molecular weights retained by the membrane to those not retained. The membranes are fabricated from various materials, including cellulose, cellulose esters, polytetrafluoroethylene, sulfonated polystyrene, and ionically cross-linked complex polyelectrolytes. The patent description cites numerous physical arrangements of these membranes as well as typical operating pressures (0 to 10 atmospheres), temperatures (70° to 86°F), and circulation velocities of 1 meter per second. The velocity should be sufficiently high to prevent buildup of an impurity-rich polarization zone on the face of the membrane.

Product yields of 80 percent are reported in the patent disclosure. Mass spectrometry data indicate large reductions in metal content. Typical membrane efficiency is reported to be about 9 to 10 kilograms per hour per square meter.

### 5.4.4 Purifying Used Oil-Plural Treating Agents: Sequential or Simultaneous (Subclassification 181)

Patents covered in the following subsections are those contained in the patent Subclassification 181, entitled "Plural Treating Agents."

#### 5.4.4.1 Method of Regenerating Used Lubricating Oil (Ref. 5-62)

The objective of this patent is to convert undesired components and impurities from colloidal suspension into crystalline macromolecules that can be removed by mechanical processes. The used oil is purified by bringing it into contact, in an acidulated environment, with a halogen derivate and monatomic oxygen. The principal agents used in the process are sulfuric acid, zinc chloride, and inorganic acid salts. The acid is used in a weak aqueous form so as to introduce water into the oil. Apparently, the process does work without the presence of water. Zinc chloride is used to provide halogen derivatives. The monatomic oxygen required in the process is generated from inorganic salts such as perborates, persulfates, and permanganates of sodium or potassium. An example of the process is as follows: Typically, 0.5 percent of a 25 percent aqueous solution of sulfuric acid, 1.0 percent of zinc chloride, and 0.2 percent of sodium perborate is added to the used oil. The mixture is then stirred and heated initially to 226°F under atmospheric pressure, followed by further heating to 536°F with the application of a vacuum. The treated oil is cooled, settled for 12 hours, decanted, and treated with 6 percent activated clay. The product yields claimed in the patent are 84 percent lube oil, 9.7 percent light ends, 5.2 percent sludge, and 1.1 percent unaccounted materials. No data are included in the patent relative to the quality of the oil produced.

### 5.4.4.2 Re-refined Waste Crankcase Oils and Method (Ref. 5-63)

This process is primarily intended to remove contaminants from used crankcase oil so that it is readily suitable for distillation. The used oil is treated with a combination of sulfuric acid, nitric acid, and a compound such as dimethyl sulfoxide to precipitate out contaminants.

At room temperature, an acid mixture consisting of 70 percent of a 70 percent solution of nitric acid and 30 percent of a 98 percent solution of sulfuric acid is added to the used oil at the rate of 0.6 percent. After thorough mixing, approximately 0.6 percent of dimethyl sulfoxide is added. The treated oil is then heated, with continuous stirring, to about 180°F until a waxy, semisolid flocculent precipitate is formed. Upon completion of the settling process, the clear oil is decanted. The oil, which is medium to dark brown in color and essentially neutral, is then ready for distillation.

### 5.4.4.3 Refining of Used Lubricating Oils (Ref. 5-64)

This process uses a $C_4$ or $C_5$ aliphatic alcohol, such as butanol, to precipitate out polar additives and oxidation products. The desludged oil is then subjected to conventional lubricating oil refining steps and may even be included as part of the normal feed-stream used in virgin lube oil refineries. The preferred $C_4$ or $C_5$ aliphatic alcohol is normally butanol. However, other alcohols or alcohol mixtures such as secondary butanol, isobutyl, and isoamyl could be used. The precipitation process can be enhanced by adding hexane or pentane to the alcohol mixture at the rate of 25 percent of the amount of alcohol used.

For this process the used oil, which is first steam-stripped of water and light ends, is treated with one-third to twice its volume of the selected alcohol. The process is carried out at room temperature. Precipitation should be completed within 12 to 24 hours. Initially, the used oil (100 volume units) is stripped at 375°F to remove water and light ends, yielding about 97 volume units. Impurities are precipitated out by the addition of 78 volume units of butyl alcohol and 19 volume units of pentane. Three layers result: a sludge layer, a viscous layer, and an oily layer. The oily layer is then distilled to recover the butyl alcohol and pentane, leaving 92 volume units of oil for further processing. Acid treatment is then applied to the extracted oil by the addition of 14 volume units of fuming sulfuric acid. Typically, this produces 25 volume units of sludge and 70 volume units of oil. The acid-treated oil is separated from the sludge and treated with 50 volume units of a 10 percent solution of sodium carbonate to neutralize the acidity. Any residual acidity is neutralized by the addition of 8 volume units of isopropyl alcohol. This step also removes the sodium sulfonates which were formed in the neutralization step. Upon settling, three layers are formed, with the bottom layer containing inorganic salts dissolved in water, the middle layer containing sodium sulfonates dissolved in alcohol, and the top layer containing neutralized oil diluted with alcohol and some water. The top layer is then stripped, at 275°F and 15 mm Hg vacuum. The reclaimed oil amounts to 61 volume units and has an ASTM color rating of 3.5. Further improvement is made by the addition of 5 percent Attapulgus clay, maintaining a temperature of 270°F and then filtering out the clay.

#### 5.4.4.4 Method of Purifying Oils Containing Liquid and Solid Impurities (Ref. 5-65)

This process is intended to purify industrial oils by the sequential addition of an alkali and an acid. The oil to be purified is heated so as to decrease its viscosity and reduce the time for the solids to settle to the bottom. A temperature of 140° to 180°F is preferred. A small amount of caustic, such as 0.4 to 5 percent by volume of a 50 percent concentration of sodium hydroxide, is added and mixed in with the oil. Approximately 30 minutes later, a small amount of an acid, such as 0.1 to 5 percent of a 19 percent concentration of sulfuric acid, is added. After thorough mixing, a

10 to 96 hour settling period is added to facilitate contaminant removal. The purified oil is then decanted and reused.

### 5.4.5 Purifying Lube Oil - Plural Treating Agents: One is a Solid Contact Material (Subclassification 182)

Patents contained in the subsequent paragraphs are those contained in patent Subclassification 182. This subclassification is a subclass of the preceding section, where one of the plural treating agents is specified as a solid contact material.

### 5.4.5.1 Method and Apparatus for Reclaiming Waste Industrial Oils (Ref. 5-66)

This patent involves the purification of industrial oils by heating the oil to 150°F and filtering it through a bed of activated earth, such as fuller's earth, bauxite, or alumina. The filtered oil is then treated in a vacuum still to remove the light ends.

The main feature of the invention, which makes it economical and avoids certain disposal problems, is the provision for reactivating the spent filter earth. The spent earth is removed periodically and discharged into the upper end of an inclined rotary incinerator to burn out carbonaceous materials. The incinerator is operated at temperatures of at least 1000°F in order to completely burn out carbonaceous materials. The upper temperature limit is set by the type of earth used. Fuller's earth can be heated to 1100°F without being destroyed and bauxite to 1600°F.

### 5.4.5.2 Method for Reclaiming Used Crankcase Oil (Ref. 5-67)

This process reacts used motor oil with anhydrous zinc chloride to precipitate out impurities. An activated clay treatment follows. In the process, anhydrous zinc chloride is added to the used motor oil in amounts of 3 to 10 percent. The mixture is rapidly heated, under vacuum, to about 480°F. This temperature is maintained for about 20 minutes to drive off the light ends and to form a sludge. As the mixture is allowed to cool, the sludge settles out and is removed. The partly purified oil is then decanted, followed by the addition of about 10 percent activated clay and a 20-minute settling period at 365°F. The clay is then filtered out by conventional means such as a plate and frame press.

Product quality, as presented in the patent, is presented in Table 5-6. The process yield is reported to be 55 percent.

Table 5-6. Product Quality of Clark Process (Ref. 5-67)

| Parameter | Value |
|---|---|
| Neutralization No. | 0.29 |
| Flash Point, °F | 395 |
| Viscosity, centistokes at 210°F | 7.9 |
| Viscosity Index | 103 |
| Sulfated Ash, % | 0.15 |
| Conradsom Carbon Residue, % | 0.027 |
| Color (ASTM No.) | 4 |

### 5.4.5.3 Reclaiming Used Motor Oil (Ref. 5-68)

The basic intent of this process is to remove metallic contaminants from used motor oils in an efficient, economical, and non-polluting manner. This is accomplished by reacting the used motor oil and the aqueous solution of ammonium sulfate or bisulfate at appropriate temperatures, pressures, and time. Typically, the oil is reacted for 60 minutes with an equal volume of a 20 percent concentration of a 50-50 mixture of ammonium sulfate and bisulfate at 350°F using an operating pressure of 90 to 350 psig.

As the reaction takes place, a separated water-oil phase is formed. The oil is decanted and subjected to further treatment, consisting of a flash dehydration step to remove water and light ends, followed by clay contacting and hydrotreating. The last two steps are only performed if a lube oil base stock is desired. The treated oil, after dehydration, would be sutiable for use as a fuel oil. The water layer is filtered to remove the precipitated metals. These metals may be sent on to be recovered by standard smelter techniques, The filtered water is brought back to strength with an additional ammonium sulfate and bisulfate mixture and recycled back into the process.

The procedures for clay-contacting and hydrotreating are described in detail in the patent. Clay-contacting is done at temperatures of 300° to 760°F and at pressures of 0 to 1000 psig. Hydrotreating is accomplished at temperatures of 500° to 800°F, 150 to 3000 psig, a hydrogen concentration of 500 to 2500 cubic feet per barrel, using a suitable catalyst such as a nickel-molybdenum sulfide on alumina. Based on data provided in the patent, the process reduces the sulfated ash content to 0.08 percent and the lead content to 0.008 percent from the respective pretreatment levels of 2.46 and 1.15 percent.

### 5.4.6 Purifying Used Oil with Acid or Alkali (Subclassification 183)

This grouping of patents, which has the patent manual subclassification number 183, is a subset of the two preceding classifications. Only one pertinent patent was found under this heading.

#### 5.4.6.1 Method of Converting Crankcase Oil to Usable Oil (Ref. 5-69)

This patent involves the purification of crankcase oil in a series of multiple steps, consisting basically of dehydration, followed by an 11-step acid-clay process. The dehydration step consists of heating the used oil up to 219°F, then cooling it down to 212°F, and repeating the process 2 to 6 times. The acid treating process involves a number of heating, cooling, settling, sludge removal, and filtration steps. In this process, the oil is cooled below 50°F, preferably below 32°F, compared with conventional acid treatment temperatures of about 100°F.

### 5.4.7 Purifying Used Oil by Distillation (Subclassification 184)

Patent manual subclassification 184, distillation, was found to have only one patent related to purifying used oil, which is described in the following paragraph. Both the patent title and the process as described appear to be inconsistent with the classification.

#### 5.4.7.1 Reclaiming Used Motor Oil by Chemical Treatment with Ammonium Phosphate (Ref. 5-70)

In this process, used motor oil is contacted with an aqueous solution of an ammonium phosphate in order to reduce the lead and ash content. The patent is similar to that described in Section 5.4.5.3 and is issued to the same inventor. The difference between the two patents is that an ammonium phosphate is used here in place of ammonium sulfate. Acceptable ammonium phosphates are diammonium hydrogen phosphate or ammonium dihydrogen phosphate.

### 5.4.8 Purifying Used Oil by Distillation, with Solid-Liquid Separation (Subclassification 186)

One applicable patent has been identified in patent Subclassification 186.

#### 5.4.8.1 Process and Apparatus for Re-refining Used Petroleum Products (Ref. 5-71)

This patent tries to overcome the difficulties associated with distilling used crankcase oil. Impurities in the used oil tend to clog, collect, and otherwise interfere with the operation of multistage distillation columns. The process features flash vaporization, using as many as four flash evaporators to provide different end products. Mechanical filtration is provided subsequent to the first evaporator.

The preferred configuration is to use a series of four evaporators, where each succeeding one operates at a higher temperature and vacuum. Typically, the first evaporator is operated at temperatures between 210° and 240°F and at atmospheric pressure. The fourth evaporator has a temperature of 630° to 680°F and a pressure of about 0.06 to 0.12 psig. Mechanical filtration is provided between the first two evaporators. This filter consists of a 40 to 45 micron vibratory filter, feeding cartridge filters that work down to 3 microns. While product yield fractions are not itemized in the patent disclosure, it is stated that all of the useful petroleum products in the used crankcase oil are recovered in some form, ranging from kerosene to a residual fuel oil.

### 5.4.9 Patent Summary

A summary presentation of patents related to used oil re-refining and treated in this report is provided in Table 5-7. The table lists patent numbers, inventors, assignments, and issue dates, and provides a brief description of the individual processes.

## Table 5-7. Summary of Patents Researched

| Sub-classification | Patent No. | Inventor | Assignment | Date | Process Description | Comments |
|---|---|---|---|---|---|---|
| 179 | 3,346,483 | Somogy, et al | None | 10 Oct 67 | Sulfuric acid, hydrotreating, distillation. | Patent emphasis on hydrotreat details. |
| | 3,376,216 | Carlos, et al | Sinclair | 2 Apr 68 | Aquous sulfuric acid, clay | Says that concentrated acid hinders sludge removal. |
| | 3,620,967 | Gulick | Quvoe Chemical | 1 May 68 | Free hydroxyle radicals generated in situ. | Purified oil may be treated further (ie distillation) if desired. |
| | 3,625,881 | Chambers | Berks Assoc. | 7 Dec 71 | Alkali metal hydroxide, heads oil. | Distillation required to remove heads oil. |
| | 3,791,965 | Fitzsimons, et al | Petrocon | 12 Feb 74 | Multi-stage distillation. | Prefers a Baird disc and tube column. |
| | 3,923,643 | Lewis, et al | Shell Oil | 2 Dec 75 | Heat and residence time. | Intended to remove metallic components (ie lead). |
| | 3,954,602 | Troesch, et al | SPLN (France) | 4 May 76 | Heat treatment. | Overheads and residues recycled back to furnace as fuel. |
| 180 | 2,822,320 | Mitacek | Phillips Petroleum | 4 Feb 58 | Hydrazine, clay. | Water wash or acid treatment may be needed to remove dissolved hydrazine. |
| | 2,951,031 | Barclay | None | 30 Aug 60 | Monoisopropanolamine | Acid pretreatment required. |
| | 3,123,549 | Ayers, et al | Pure Oil | 3 Mar 64 | Diazomethane | Intended for neutralization of acidity (primarily for use on crude). |
| | 3,169,917 | Kahan | Ulrich Process | 16 Feb 65 | Solvent (principly propane) extraction. | Catalytic reactor, clay treatment as finishing steps. |
| | 3,222,275 | Krewer, et al | Union Oil | 7 Dec 65 | Aquous alkali and aliphatic sultones. | See 3,123,549 above. |

## Table 5-7. Summary of Patents Researched (Continued)

| Sub-classification | Patent No. | Inventor | Assignment | Date | Process Description | Comments |
|---|---|---|---|---|---|---|
| 180 (cont) | 3,282,827 | Grysiak | Norvel Co. | 1 Nov 66 | Special surface active agents. | Agents lose detergent powers at elevated temperatures. |
| | 3,305,478 | Gilson, et al | Dow Chemical | 21 Feb 67 | Diethylenetriamine | Clay treatment to improve color, if desired. |
| | 3,450,627 | Johnson | Nalco Chemical | 17 Jun 69 | Trimerized polycarboxylic acid, filtration. | Intended for metal rolling oils. |
| | 3,563,885 | Talbot | Sun Oil | 16 Feb 71 | Ultra high molecular weight polyethylene. | Intended to remove non dissolved particulants. |
| | 3,763,036 | Jordan, et al | Texaco | 2 Oct 73 | Methyl ethyl ketone extraction. | Intended to remove lead, further processing may be required. |
| | 3,773,658 | Dang Vu, et al | IFP (France) | 20 Nov 73 | Propane extraction. | Discussed in detail in Paragraph 5.2.4. |
| | 3,819,508 | Fainman, et al. | None | 25 Jun 74 | Water-miscible alcohol, alkali. | Discussed in detail in Paragraph 5.3.3. |
| | 3,864,242 | Watanabe | KKIS (Japan) | 4 Feb 75 | Paraffin base hydrocarbon extraction. | Treats industrial slops to provide fuel and asphalt. |
| | 3,870,625 | Wielezynski | None | 11 Mar 75 | Propane extraction using pulsating injection technique. | Pulsating technique enhances solvent extraction process. |
| | 3,919,075 | Parc, et al | IFP (France) | 11 Nov 75 | Ultrafiltration | Mechanical separation of soluble metal compounds. |
| 181 | 3,417,012 | Morace | None | 17 Dec 68 | Acid, halogen derivatives, monatomic oxygen. | Only works in the presence of water, final dehydration, clay treatment required. |
| | 3,607,731 | Gulic | Quvoe Chemical | 21 Sept 71 | Sulfuric acid, nitric acid, dimethyl sulfoxid. | Intended as a pretreatment before distillation. |

## Table 5-7. Summary of Patents Researched (Continued)

| | Patent No. | Inventor | Assignment | Date | Process Description | Comments |
|---|---|---|---|---|---|---|
| 181 (cont) | 3,639,229 | Brownawell | Esso Research | 1 Feb 72 | Aliphatic alcohol. | Normal lube oil refining steps required on the extracted oil. (a) |
| | 3,790,474 | Moffitt | None | 5 Feb 74 | Caustic, acid (sequentially added). | Intended for industrial oils. |
| | 3,835,035 | Fainman, et al | None | 10 Sept 74 | Water miscible alcohol, acid. | Discussed in detail in Paragraph 5.3.3. |
| 182 | 3,527,696 | Wallover | Wallover Oil Co. | 8 Sept 70 | Filtration thru activated earth. | Intended for industrial oil. |
| | 3,904,512 | Clark | Brit. Col. Res. Council | 9 Sept 75 | Anhydrous zinc chloride, clay. | Temperature and vacuum conditions during treatment result in simultaneous removal of light ends. |
| | 3,930,988 | Johnson | Phillips Petroleum | 6 Jan 76 | Aqueous ammonium sulfate. | Intended to remove soluble metals, further processing may be required. |
| 183 | 2,922,758 | Kostyreff | Guller (1/2) | 26 Jan 60 | Dehydration, acid, clay. | Process steps repeated and performed under specific conditions. |
| 184 | 3,879,282 | Johnson | Phillips Petroleum | 22 Apr 75 | Aqueous ammonium phosphate. | Intended to remove soluble metals, further processing may be required. |
| 186 | 3,923,644 | Hindman | Petrocon Corp. | 2 Dec 75 | Flash evaporators operated in series. | A distillation scheme designed to overcome clogging problems experienced in distillation columns. |

(a) May be added to virgin lube oil plant feed stream.

## 5.5 REFERENCES

5-1 W. L. Nelson, Petroleum Refinery Engineering, McGraw-Hill Book Company, New York (1958).

5-2 Waste Oil Recycling -- Issue Paper, U. S. Bureau of Mines, Washington, D. C. (circa 1973).

5-3 N. J. Weinstein, Waste Oil Recycling and Disposal, EPA-670/2-74-052, U. S. Environmental Protection Agency, Washington, D. C., prepared by Recon Systems, Inc., Princeton, New Jersey (August 1974).

5-4 Personal communication: B. Horton during visit to Dearborn Refinery Company, Dearborn, Michigan (21 October 1976).

5-5 Personal communication: R. Wiggins, Talley Bros., Inc., Huntington Park, California (27 September 1976).

5-6 Personal communication: A. Warden, Warden Oil Company, Minneapolis, Minnesota (5 May 1977).

5-7 J. W. Swain, Jr., Paper presented at the New York City Section of the American Society of Lubrication Engineers (4 March 1970).

5-8 M. H. Chiogioji, "Waste Oil: A Resource to be Conserved," SAE Paper No. 740684, Society of Automotive Engineers, Inc., New York (1974).

5-9 Waste Oil Recovery Practices -- State of the Art (1972), Environmental Quality Systems, Inc., Washington, D. C., NTIS No. PB-229,801 (December 1972).

5-10 Personal communication: R. Kern, Gulf Science & Technology Company, Pittsburgh, Pennsylvania (4 October 1976).

5-11 Personal communication: Mr. L. Schurr, Berks Associates, Pottstown, Pennsylvania (11 October 1977).

5-12 Personal communication: Mr. R. Mahler, Diamond Head Oil Refinery, Kearny, New Jersey (9 November 1977).

5-13 "Spent Lube Reclamation," Hydrocarbon Processing, p. 213 (September 1976).

5-14 D. V. Quang, et al., "Experience with the French Petroleum Institute Propane Clarification Process in Re-Refining Spent Crankcase Oils," The Journal of Environmental Sciences, pp. 18-20 (May/June 1975).

5-15 Personal communication: Mr. M. L. Whisman, Bartlesville Energy Research Center, Bartlesville, Oklahoma (8 November 1977)

5-16 N. J. Weinstein, "Re-Refining Schemes Compared," Hydrocarbon Processing, pp. 74-76 (December 1976).

5-17 KTI Technology in Refining of Spent Lubricating Oils, Brochure supplied by Kinetics Technology International Corporation, San Marino, California (8 October 1976).

5-18 H. R. Emmerson, "Problems Facing the Re-Refiner," Hydrocarbon Processing, pp. 145-148 (September 1975).

5-19 J. C. Davis, "New Technology Revitalizes Waste-Lube Oil Re-Refining," Chemical Engineering, pp. 62-68 (22 July 1974).

5-20 "News Item," Chemical Engineering, p. 39 (5 July 1976).

5-21 Personal communication between Dr. R. F. Westerduin, KTI, Zoetermeer, Netherlands, and Mr. M. L. Whisman, Bartlesville Research Center, Bartlesville, Oklahoma (25 August 1977).

5-22 Personal communication: S. H. Ismail during visit to NORCO, Bayonne, New Jersey (8 November 1976).

5-23 Personal communication: Mr. J. W. Swain, Consultant, Wellesley, Massachusetts (18 October 1977).

5-24 Personal communication: R. Marshall during visit to Gladieux Refining Company, Ft. Wayne, Indiana (11 November 1976).

5-25 Personal communication: E. H. Palmason during visit to ECO-Separator Division of A. Johnson & Company, Ventura, California (21 December 1976).

5-26 Personal communication: Mr. T. Tierney, Vacsol Corporation, Kansas City, Kansas (19, 20 October 1977).

5-27 M. L. Whisman, et al., Waste Lubricating Oil Research: Part 4, BERC/RI-76/4, Bartlesville Energy Research Center, Bartlesville, Oklahoma (October 1976).

5-28 M. L. Whisman, et al., An Investigation of Several Re-refining Methods, BERC/RI 7884, Bartlesville Energy Research Center, Bartlesville, Oklahoma (1974).

5-29 J. S. Corlew and R. J. Sluski, Treatment of Waste Lubricating Oil Using BERC/ERDA Solvent, BERC/RI-76/11, Bartlesville Energy Research Center, Bartlesville, Oklahoma (October 1976); prepared by Custom Refining Company, Denver, Colorado.

5-30 R. J. Bigda, Predesign Cost Estimate for Re-Refined Lube Oil Plant, BERC/RI-77/11, Bartlesville Energy Research Center, Bartlesville, Oklahoma (June 1977).

5-31 C. J. Thompson and M. L. Whisman, *Waste Oil Recycling -- An Idea Whose Time Has Come*, BERC/OP-76/38, Bartlesville Energy Research Center, Bartlesville, Oklahoma (December 1976).

5-32 C. J. Thompson, et al., *Engine Sequence Testing of Re-Refined Lubricating Oils*, BERC/OP-76/29, Bartlesville Energy Research Center, Bartlesville, Oklahoma (8 October 1976).

5-33 M. Fainman and C. McAuley, "Method of Purifying Lubricating Oils," U. S. Patent No. 3,819,508 (25 June 1974).

5-34 M. Fainman and C. McAuley, "Method of Purifying Lubricating Oils," U. S. Patent No. 3,835,035 (10 September 1974).

5-35 Personal communication: Dr. M. Z. Fainman, MZF Associates, Los Angeles, California (10 October 1977).

5-36 Personal communication: Letter from MZF Associates, Los Angeles, California (9 February 1977).

5-37 "Phillips Announces Process for Recycling Waste Motor Oils," *News Release*, Phillips Petroleum Company, Bartlesville, Oklahoma (26 August 1977).

5-38 Personal communication: Mr. E. A. Malik, Phillips Petroleum Company, Bartlesville, Oklahoma (21 October 1977).

5-39 Personal communication: Ms. S. Bass, The Governor's Office, Raleigh, North Carolina (26 October 1977).

5-40 R. K. Clegg, et al., *Economic Feasibility Study -- Motor Oil Reclamation*, Office of Administrative Analysis, State of North Carolina (1 August 1977).

5-41 L. Somogyi, et al., U. S. Patent No. 3,346,483 (10 October 1967).

5-42 D. Carlos, et al., U. S. Patent No. 3,376,216 (2 April 1968); assigned to Sinclair Research, Inc.

5-43 G. Gulick, U. S. Patent No. 3,620,967 (1 May 1971); assigned to Quvoe Chemical Industries.

5-44 J. M. Chambers, U. S. Patent No. 3,625,881 (7 December 1971); assigned to Berks Associates.

5-45 O. Fitzsimons, et al., U. S. Patent No. 3,791,965 (12 February 1974); assigned to Petrocon Corporation.

5-46 R. Lewis, et al., U. S. Patent No. 3,923,643 (2 December 1975); assigned to Shell Oil Company.

5-47 A. Troesch, et al., U. S. Patent No. 3,954,602 (4 May 1976); assigned to Societe Parisienne des Lubrifliants Nationaux et des Entrepots d'Hydrocarbures.

5-48 B. Mitacek, U. S. Patent No. 2,822,320 (4 February 1958); assigned to Phillips Petroleum.

5-49 S. Barclay, U. S. Patent No. 2,951,031 (30 August 1960).

5-50 G. Ayers, et al., U. S. Patent No. 3,123,549 (3 March 1964); assigned to the Pure Oil Corporation.

5-51 U. Kahan, U. S. Patent No. 3,169,917 (16 February 1965); assigned to Ulrich Process Company.

5-52 W. Krewer, et al., U. S. Patent No. 3,222,275 (7 December 1965); assigned to Union Oil Company.

5-53 M. Grysiak, U. S. Patent No. 3,282,827 (1 November 1966); assigned to Norvel Company.

5-54 J. Gilson, et al., U. S. Patent No. 3,305,478 (21 February 1967); assigned to the Dow Chemical Company.

5-55 C. Johnson, U. S. Patent No. 3,450,627 (17 June 1969); assigned to Nalco Chemical Company.

5-56 A. Talbot, U. S. Patent No. 3,563,885 (16 February 1971); assigned to Sun Oil Company.

5-57 T. Jordan and W. McDonald, U. S. Patent No. 3,763,036 (2 October 1973); assigned to Texaco, Inc.

5-58 Q. D. Vu, et al., U. S. Patent No. 3,773,658 (20 November 1973); assigned to Institute Francais du Petrole, des Carburants et Lubrifiants.

5-59 S. Watanabe, U. S. Patent No. 3,864,242 (4 February 1975); assigned to Kabushiki Kaisha Imamura Seisakusho.

5-60 L. Wielezynski, U. S. Patent No. 3,870,625 (11 March 1975).

5-61 G. Parc, et al., U. S. Patent No. 3,919,075 (11 November 1975); assigned to Institute Francais du Petrole.

5-62 M. Morace, U. S. Patent No. 3,417,012 (17 December 1968).

5-63 G. Gulick, U. S. Patent No. 3,607,731 (21 September 1971); assigned to Quvoe Chemical Industries.

5-64 D. Brownawell, U. S. Patent No. 3,639,229 (1 February 1972); assigned to Esso Research and Engineering Company.

5-65 J. Moffitt, U. S. Patent No. 3,790,474 (5 February 1974).

5-66 J. Wallover, U. S. Patent No. 3,527,696 (8 September 1970); assigned to Wallover Oil Company.

5-67 T. Clark, U. S. Patent No. 3,904,512 (9 September 1975); assigned to British Columbia Research Council.

5-68 M. Johnson, U. S. Patent No. 3,930,988 (6 January 1976); assigned to Phillips Petroleum Company.

5-69 G. Kostyreff, U. S. Patent No. 2,922,758 (26 January 1960); assigned (1/2) to I. Guller.

5-70 M. Johnson, U. S. Patent No. 3,879,282 (22 April 1975); assigned to Phillips Petroleum Company.

5-71 G. Hindman, U. S. Patent No. 3,923,644 (2 December 1975); assigned to Petrocon Corporation.

# SECTION 6

# REFINING PROCESSES FOR VIRGIN LUBE OIL

## 6.1 GENERAL

Refinery processes for the production of mineral oil lubricants are described in this section. Mention is made of historical developments, but emphasis is on modern refinery practice. Although disturbing to the reader, it is nevertheless necessary to point out that there is no single processing sequence that is universally descriptive of all lubricating oil plants; indeed, it is doubtful that any two are substantially identical. The reasons for this variability range from differences in crude stocks and product slates to refinery size and age, degree of modernization, patent situation, and company economics.

At best, this brief description can only present typical, generic processing steps for virgin lube oil, particularly for lubes intended for automotive service. Many specialty oils require additional treatment or different process conditions. Furthermore, many patented processes employ specific catalysts or solvent combinations, often uniquely combining several treatment steps for improved yield, more favorable economics, better flexibility, or reduced energy consumption.

The primary objective of this section is to illustrate the close relationship between virgin lube oil processes and those used or being investigated for re-refining plants. A secondary objective is to show the size, number, and capacity of virgin lube facilities in the United States for comparative purposes.

## 6.2 VIRGIN LUBE FACILITIES IN THE UNITED STATES

According to Ref. 6-1, there were 47 lube oil production plants in the United States as of 1 January 1977, with a total capacity of 232,977 barrels per stream day (b/sd). Texas has by far the largest capacity, 99,222 b/sd, over three times that of its nearest rival, Pennsylvania. In all, 14 states produce lube oil products, ranging down to Wyoming with a total capacity of 1470 b/sd.

Specific plant sizes also vary widely. Three are listed at under 1000 b/sd, (200, 500, and 800 b/sd), while the 44 remaining plants range from

1100 to 33,800 b/sd. Most lube plants are generally a part of larger refinery installations processing crude for many other products. For comparison, most present re-refineries have capacities near 200 b/sd; the largest in the country is slightly under 1000 b/sd.

## 6.3 OVERALL LUBE PLANT FLOWSHEET

A flowsheet for a petroleum refinery producing lubricating oils is shown in Figure 6-1.

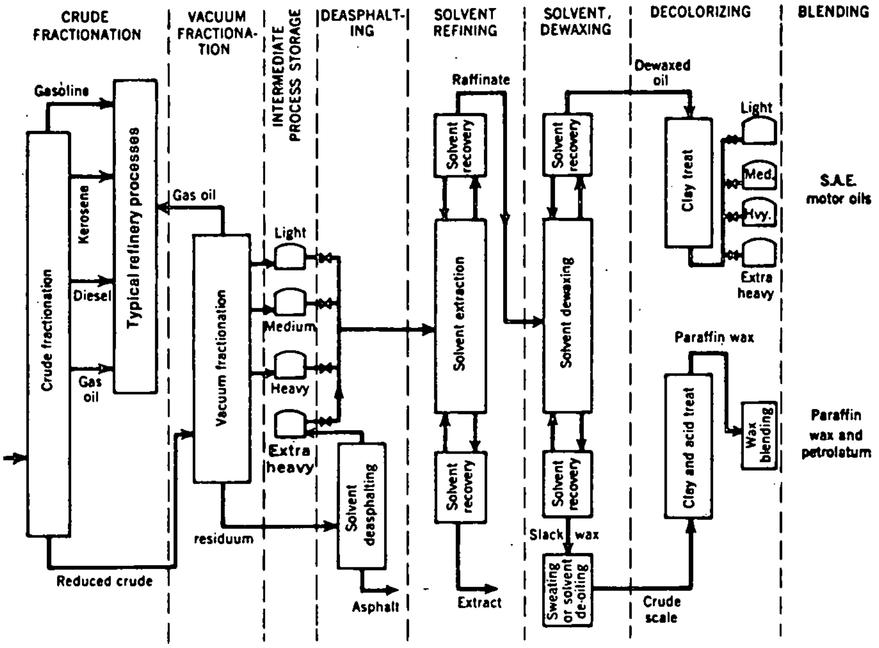


Figure 6-1. Schematic Diagram of a Refinery for Producing Lubricating Oils (Ref. 6-2).

The first step, crude fractionation, is not a part of the lube plant, per se, but indicates the source of the plant feed, namely, the reduced crude from the bottom of the (atmospheric) crude fractionation column. Although solvent deasphalting, solvent extraction, and solvent dewaxing are representative of current plant practice, the clay or acid-clay decolorizing step is to a great extent obsolete. Not shown in this 1958 schematic is the increased use of hydrogen treatment for decolorization and product stabilization. Disposal of the spent clay adsorbent gradually became extremely difficult, and clay contacting is now seldom used in large-scale lube oil manufacturing (Ref. 6-3).

Occasionally, the several raw lube fractions from vacuum fractionation are each sent through its own solvent-refining and solvent-dewaxing units. Historically, however, most plants have operated on a semibatch type of processing, by which a single solvent extraction and dewaxing plant is used first for one stock and then for another. While one of the stocks is being treated and dewaxed, further raw lube stocks are collected and stored in intermediate storage tanks (Ref. 6-4). The problem in this approach is that many intermediate storage tanks are required; the tank farm becomes costly and uses a large plot area. Other difficulties relate to degradation in storage and changeover in feedstocks.

The new trend (Ref. 6-2) is, first, to use high efficiency processing equipment, with reduced holding times, e.g., a rotating disc contactor (RDC) or a Podbielniak centrifugal extractor. The new lube oil refineries are now designed as fully integrated plants. The raw lube oil fractions from the vacuum tower are separately but simultaneously treated in the extraction units. The raffinate and extract phases are combined, and all of the downstream equipment and units process the combined raffinate. A rerun unit, as the last part of the lube oil train, fractionates the finished wide-cut lube oil into three or four base stocks which can be blended into the final lube products. Another approach to integration (Ref. 6-5) is to combine processes, such as phenol extraction and hydrotreating, into one unit, called in this case a "phenolfiner". This approach reduces the amount of equipment required, improves energy conservation, and minimizes investment costs. Theoretically, the operation of an integrated lube oil refinery does not require intermediate storage tanks, but refiners usually provide a few between some units to facilitate startup and to offset short operating upsets.

The following subsections briefly describe the processing steps comprising an automotive lube oil refinery.

## 6.4 PROCESSING DESCRIPTION

### 6.4.1 Vacuum Distillation

A vacuum distillation unit is a basic component of any, however simple, lube oil production plant. The reduced crude from atmospheric distillation, which is the feed to the lube plant, has a boiling point range of about $700^{\circ}$ to $1000^{\circ}$F, too high to be distilled at atmospheric pressure without decomposition. Therefore, it is distilled at reduced pressure, either by using vacuum or steam or by a combination of the two. The reduced crude charge is heated by heat exchange and then by a furnace before introduction into the vacuum tower in an atmosphere of superheated steam. Typical pressure in the tower is in the neighborhood of 100 mm Hg or less. Such pressures allow everything but the asphalt and very heavy lube stocks to be vaporized and fractionated. Several products are taken off as side-stream products and are often steam-stripped for improvement of their flash points.

A vacuum distillation unit can either be integrated with a crude oil atmospheric unit or designed as an independent unit fed from atmospheric residue storage tanks. The integrated approach has advantages in heat conservation and elimination of storage tanks. However, there are several reasons why it is not often done, including physical separation of the lube oil plant in the refinery and increased flexibility in handling different crudes and lube plant feeds.

Sharp separation between the vacuum residue and the heaviest lube oil distillate is one of the most important objectives of vacuum unit design. Asphaltenes, entrained into the lube oil fraction, have an adverse effect on the operation of downstream units due to discoloration, coking, high clay usage, emulsions, etc. On the other hand, heavy lube oil is a desirable component of many engine and industrial lubricating oils, and refiners are naturally interested in cutting deep into the vacuum residue to maximize this fraction. One solution is to include a propane deasphalting unit in the lube oil refinery, removing the need to aim at a high true boiling point (TBP) cut point in the tower. A so-called long residue is produced by leaving some heavy oil in the bottom product. This oil plus a very heavy oil fraction are recovered in the deasphalting unit described in the following subsection.

### 6.4.2 Propane Deasphalting

Prior to 1933, effective methods of recovering solvents had not been developed (Ref. 6-2). The flashing, distilling, and stripping of solvents from the treated oils and the purification of the solvent are actually the major parts of a solvent treating system. The purpose of a solvent process is to separate a general group of unwanted materials or hydrocarbons from the oil more efficiently and/or at less cost than by other methods, such as acid treatment. The solvent processes tend to erase the old crude oil marketing system by which only a few crude oils were considered satisfactory for lubricant manufacture. By solvent methods, the original properties of the oil can be changed so that a uniform grade of oil can be manufactured from a wide variety of crude oils, although yields and costs will vary with the type of feedstock.

Propane is a selective solvent with some extraordinary properties (Ref. 6-3). At low temperatures, from -40° to +70°F, it does not dissolve paraffinic hydrocarbons. At higher temperatures, from 100° to 140°F, paraffins are quite soluble in propane, but high molecular weight asphaltic and resinous compounds precipitate. Other advantageous properties of propane as a solvent are (1) its low boiling point, which facilitates its separation from high-boiling oils and furnishes refrigeration for dewaxing operations; (2) its fluidity, simplifying contact and equipment design; and (3) its relatively low cost.

Propane is a solvent used universally for production of very heavy oils from vacuum residues. As mentioned in Reference 6-3, it is surprising that a relatively light color oil can be produced from a black residue which is otherwise used as road asphalt. In the early days of lube oil refining, this oil was given the name "brightstock," and this term is still used for heavy base stock.

Propane deasphalting is an unusual extraction process for several reasons. First, the desired oil product is an extract and not a raffinate. The oil is dissolved in propane in a concentration of 15 to 20 percent, indicating that a relatively large quantity of propane has to be circulated in order to produce commercial quantities of heavy lube oil. Secondly, the raffinate phase is not a homogeneous solution but rather a colloid or emulsion of precipitated asphalt in propane. Thirdly, the solubility of hydrocarbons in propane decreases with temperature; near its critical temperature (206°F), propane does not dissolve hydrocarbons of any type. Finally, increasing operating pressure increases solubility, whereas normally this variable has little effect on extraction operations; this also relates to critical point operation.

Figure 6-2 shows a flowsheet for a propane deasphalting unit. The deasphalting tower operates somewhere in the range of 100° to 175°F and 400 to 550 psi. Solvent ratios run between 5:1 and 13:1 by volume (Ref. 6-5). Extraction takes place countercurrently in a tower equipped with specially designed contacting trays. A unique feature is the internal steam heater at the feed end of the tower to maintain a higher temperature at the extract than at the raffinate end. The purpose is to control selectivity of separation based on solubility changes near the critical point.

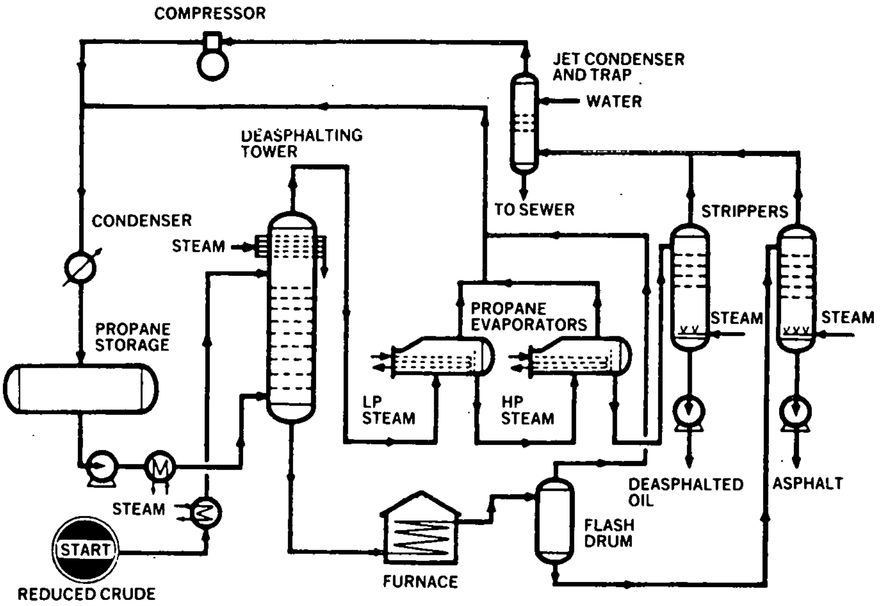


Figure 6-2. Propane Deasphalting (Ref. 6-5)

As indicated in Figure 6-2, a two-stage propane recovery system is used. The first stage operates at elevated pressure, which permits condensation of the recovered propane by air or water cooling. In the second stage, propane is stripped from the oil and asphalt streams at atmospheric pressure in order to accomplish complete removal from the products. After condensing the stripping steam, the propane vapor is compressed and condensed.

Propane may also be used as a dewaxing solvent, in which case the deasphalting operation may be neatly integrated with dewaxing by not evaporating the propane from the extract. As is discussed later, although many propane dewaxing units are still operating in lube oil refineries, it is no longer the most popular dewaxing solvent, having been replaced by methyl ethyl ketone.

### 6.4.3 Solvent Refining

Solvent refining processes are used to improve the viscosity index and paraffinicity of lube oil stocks. The extracts obtained in solvent refining are relatively rich in naphthenic, aromatic, and unsaturated hydrocarbons and they contain relatively large amounts of the sulfur and other inorganic elements found in petroleum.

Many solvents have been employed, including (1) furfural, phenol, cresylic acid and propane (Duo-Sol process); (2) liquid sulfur dioxide (Edeleanu process); and (3) sulfur dioxide/benzene. The oil and solvent are contacted countercurrently, frequently in a packed column, and then the refined oil and extract layers are separated. Recovery of solvent from the oil and extract solutions constitutes a major part of every solvent refining process; the recovery system design depends on the physical properties of the solvent, particularly the boiling point. The complexity of this process is illustrated by the furfural unit shown in Figure 6-3. Only a few major features are discussed here.

Furfural is a good selective solvent for aromatics and resins, but asphaltenes interfere with furfural extraction, promoting the formation of emulsions. Furfural boils at 324°F under atmospheric pressure and is therefore readily separated from the heavier lube oil fractions. Furfural and water form an azeotrope rich in furfural which boils at 208°F, permitting a convenient method of removing stripping steam condensate from the system. Extraction temperatures lie in the range of 86° to 266°F, with solvent ratios normally between 1.5 and 3.5. Furfural is unstable at high temperatures and, therefore, in order to prevent the formation of carbonaceous deposits and acidic components, should not be heated above 450°F in the solvent recovery section of the plant (Ref. 6-5).

As shown in Figure 6-3, furfural enters at the top of the extraction tower, and the oil charge enters closer to the middle. The refined oil mixture rises to the top, and the extract settles to the bottom. Each of these solutions is heated in a furnace coil and fractionated, then finally stripped for the removal of the furfural. Most of the furfural, nearly pure, is distilled from the extract solution, but the rest is associated with large amounts of water from the stripping steam. Upon condensation, two immiscible solutions are formed, one rich in furfural and the other rich in water. The wet furfural from all sources is collected, condensed, and delivered to a settling drum at the top of the furfural stripper shown at the right of the diagram. The furfural-rich

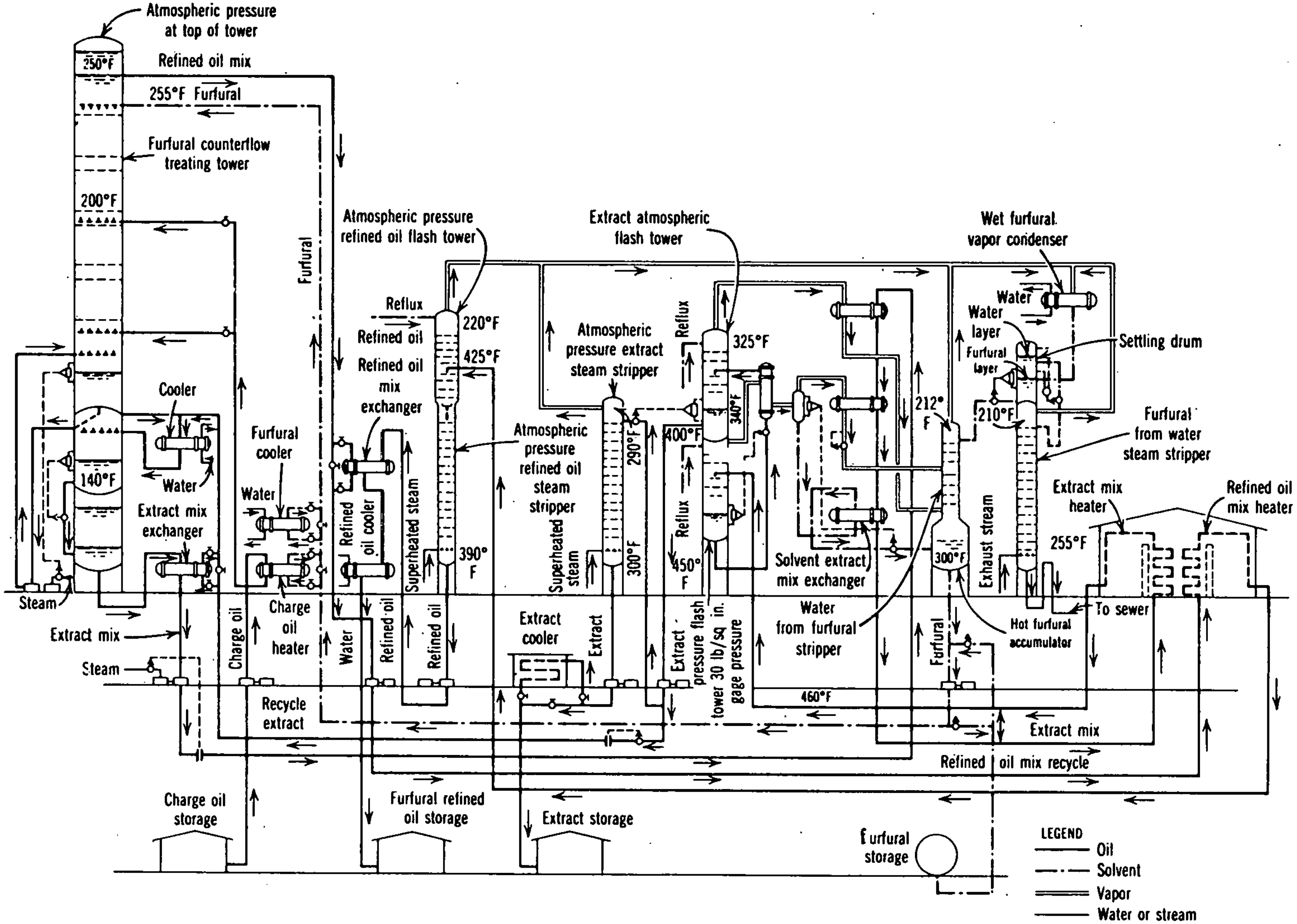


Figure 6-3. Solvent Extraction of Lubricating Oils by Furfural (Ref. 6-4)

solution from the drum is distilled for the removal of water, as the constant-boiling azeotrope, leaving the furfural. Likewise, the water-rich solution is fractionated for recovery of the azeotrope, which is returned to the drum (Ref. 6-4).

Furfural is a reactive chemical compound. It can be easily oxidized and, therefore, some furfural treating units have been designed with charge stock deaerators to prevent air from entering the system. Furfural also tends to polymerize, but polymers are continuously removed from the process with the extract product. For these reasons, furfural loss can be higher than that for solvents in other processes, e.g., phenol in the phenol extraction process (Ref. 6-3).

The complexity of the furfural treating and solvent recovery system is generally typical of solvent refining operations. Nevertheless, the improvement in viscosity index and the elimination of colored materials justify the cost. Before proceeding to a discussion of the solvent dewaxing step, the older, but now largely obsolete, acid treating process is briefly covered because of its widespread contemporary use in re-refining.

### 6.4.4 Acid Treatment

Acid treatment is normally carried out with 98 percent sulfuric acid, although the manufacture of special products, such as transformer oil and medicinal mineral oil, may require the use of oleum. A centrifugal pump may be used as the mixing device, but, however done, agitation to promote intimate contact is necessary. The sludge may be allowed to settle by gravity or sent through a centrifuge for separation. This treatment removes unsaturated, asphaltic, and unstable compounds which cause the oil to darken when exposed to air (Ref. 6-4).

Acid-treated lubricating oils are usually given a clay treatment to remove reaction products, neutralize residual acid, and remove traces of sludge by adsorption. Clay treating is usually carried out at 200° to 215°F, followed by filtration to remove the spent clay.

Concentrated sulfuric acid is a good treating agent and produces lube oils of outstanding quality. It is not used much anymore for refining lube oils because of the sludge disposal problem. In addition, treatment of heavy oils poses serious operating difficulties. At the moderate temperatures employed, efficient separation of the acid sludge from a relatively viscous oil, on a commercial scale, is difficult (Ref. 6-3).

### 6.4.5 Solvent Dewaxing

The dewaxing of lubricating oils is the most difficult process in lube oil manufacturing; it is also the most expensive (Ref. 6-3). Paraffinic hydrocarbons from light lube oil fractions tend to grow large crystals which do not trap much oil during filtration. However, wax formed from the heavier fractions tends to be in little crystals, termed microcrystalline wax, which occlude a high percentage of oil. Dewaxing cannot be effected by distillation since the waxy materials boil over the entire lube oil range. The oldest process was straightforward, chilling down to the required pour point temperature, followed by filtration at this temperature to remove the wax. This process is little used now because of high labor costs to operate the filter press and the difficulty in low-temperature filtration of heavy oils (Ref. 6-5).

In recent years, solvent dewaxing has been widely adopted in lube oil refineries. Solvents serve to precipitate hydrocarbons with a high melting point, reduce viscosity of the oil fraction at the crystallization temperature, and facilitate filtration of the wax. Propane was once the most popular dewaxing solvent, but it has been replaced by a mixture of methyl ethyl ketone (MEK) with benzene and/or toluene. MEK precipitates wax efficiently and selectively but is a poor solvent for oil-type hydrocarbons. Thus, up to 20 percent benzene and 20 percent toluene are added to MEK to improve solubility.

A flowsheet for a typical MEK unit is depicted in Figure 6-4. The solvent and oil charge is heated to ensure complete solution of the wax carried over in the solvent; any wax nuclei present may subsequently lead to crystals that are difficult to filter. The mixture is then chilled to about -5°F, using scraped-surface exchangers to remove wax crystals from the walls and thus maintain a good heat transfer coefficient. The wax is removed by filtration under vacuum in rotary filters. The cake collected on the filter drum is washed with chilled solvent, blown off with inert gas, and transferred by a conveyor to the wax-mix flow tank and thence to the solvent recovery system.

Solvent is recovered from both the dewaxed filtrate and the separated wax by evaporation. A double-effect flash evaporator is used to obtain good thermal efficiency. Water enters the plant primarily in the stripping steam used in the final stages of solvent recovery. It is removed from the solvent as a bottom stream from the ketone fractionator. Solvent ratios normally

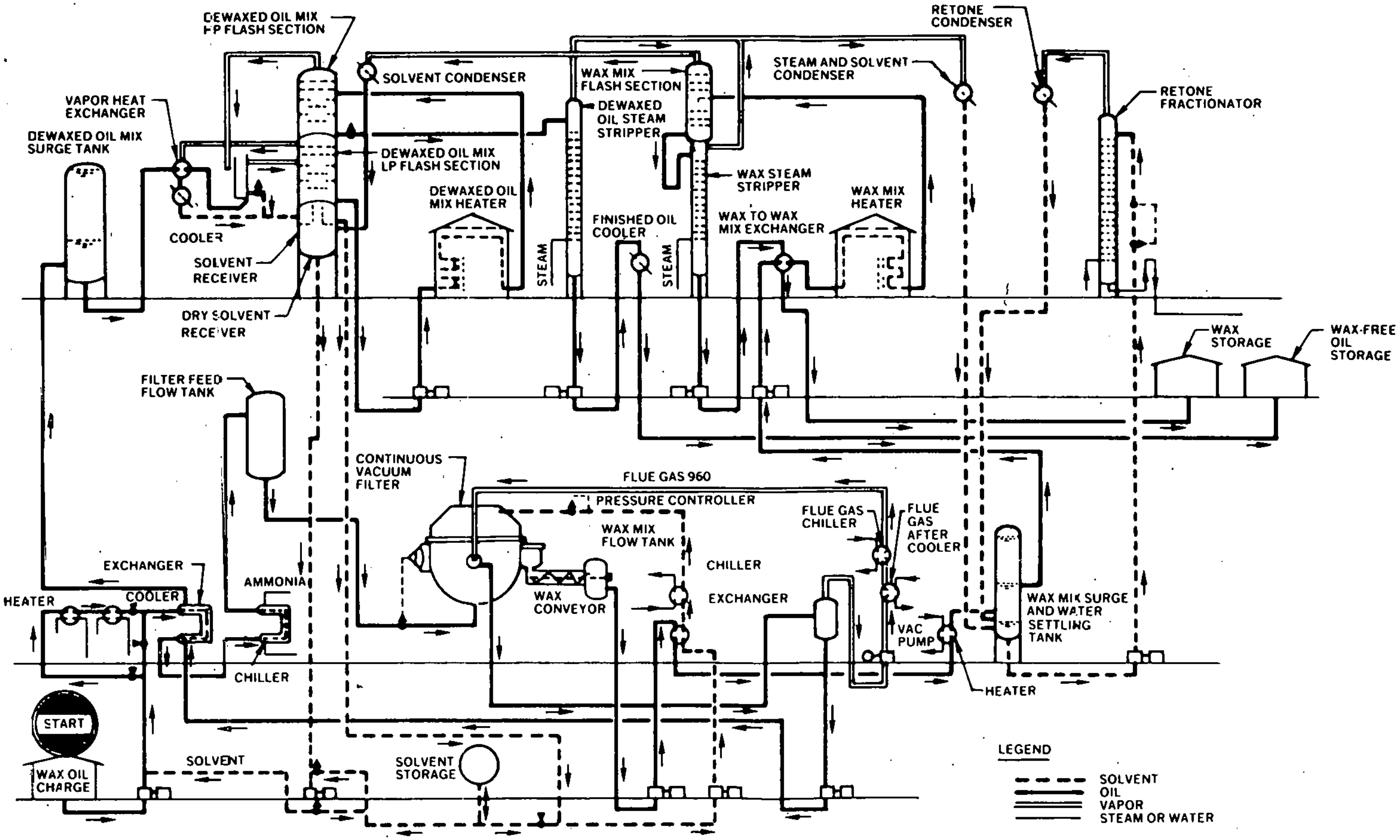


Figure 6-4. MEK/Benzene Dewaxing Process (Ref. 6-5)

lie between 1:1 and 4:1. There are no high pressures in the process.

The oil content of the wax, called "slack wax", is generally too high to meet the marketing specification for commercial grades of wax and must be further treated by "deoiling". The modern method involves addition of solvent and refiltration; the process is then repeated.

### 6.4.6 Finishing

Traces of resinous materials and chemically active compounds can form organic acids and cause quick deterioration of the color of the lube oil product and also the petroleum wax. These compounds can be removed by contacting the oil with clay, using either percolation through a long column packed with the adsorbent or mixing the oil with powdered clay at high temperature, followed by filtration. Problems with disposal of the spent adsorbent and loss of oil on the clay led to the abandonment of clay contacting when hydrogen treating (hydrotreating) became available.

The success of hydrotreating light and middle distillates fostered research aimed at improving the properties of lube oil fractions. Special catalysts have been developed, and hydrotreating units (also termed hydrofinishing, hydrofining, and various proprietary names) are now widely used for this purpose. Organic nitrogen compounds are the principal contributors to color instability; thus, the main objective of hydrotreating is removal of nitrogen. In so doing, oxygen also is removed efficiently. Inevitably, the sulfur content of the oil is reduced, too, but this is often no credit because some of the sulfur compounds which are destroyed act as natural inhibitors (Ref. 6-3).

Treating oils with hydrogen is considerably more difficult than treating distillates. The chemistry of oil treating is quite different from that for lighter distillates. Also, lube oils are heavy fractions, which do not vaporize at the reactor pressure and tend to lay down coke on the catalyst. On the other hand, hydrotreating can measurably improve the viscosity index of the product oil by control of process conditions. Hydrotreating can be used for production of special oils, including white oils, which, as previously mentioned, are usually treated with concentrated acid. It is also employed to finish waxes in place of the acid-clay treatment shown on Figure 6-1.

The flowsheet for the hydrotreating process is quite simple, as indicated in Figure 6-5.

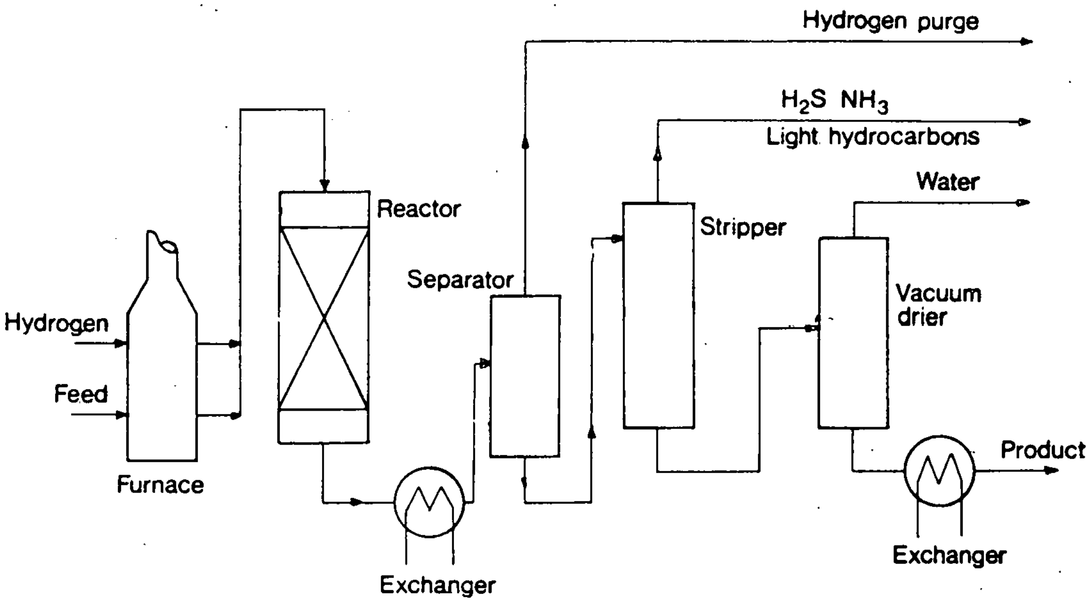


Figure 6-5. Hydrotreating Process (Ref. 6-5)

The feed is combined with hydrogen gas, heated in a furnace and passed through a catalytic reactor. The reactor effluent is cooled, followed by high-pressure separation of liquid and gas. The hydrogen gas is recycled, and the liquid is sent first to a stripper for removal of $H_2S$, $NH_3$, and light hydrocarbons, followed by drying. These operations are necessary to correct the flash point and remove traces of moisture, which makes the oil hazy. The process usually involves only a mild hydrogenation conducted at a relatively low pressure (250 to 900 psi) and a relatively low temperature (500° to 760°F), with the consumption of only small amounts of hydrogen (25 to 100 cubic feet per barrel) (Ref. 6-4).

## 6.5 REFERENCES

6-1 A. Cantrell, "Annual Refining Survey," Oil and Gas Journal, Vol. 75, No. 13, pp. 97 - 123 (March 28, 1977).

6-2 W. L. Nelson, Petroleum Refinery Engineering, McGraw-Hill Book Company, New York (1958).

6-3 M. Soudek, "What Lube Oil Processes to Use," Hydrocarbon Processing, pp. 59-66 (December 1974).

6-4 Kirk-Othmer, *Encyclopedia of Chemical Technology*, Vol. 15, pp. 54 - 61.

6-5 G. D. Hobson and W. Pohl (Editors), *Modern Petroleum Technology*, John Wiley and Sons, New York, N. Y. (1973).

# SECTION 7

# ECONOMICS OF USED OIL COLLECTION

## 7.1 GENERAL

The economics of secondary (salvage) material operations have been traditionally marginal. This has been particularly true when the virgin supply source is both plentiful and cheap. Under these conditions, recovery and recycling operations are replaced by disposal operations wherein a fee is paid to have the unwanted product removed. Used oil collecting had been operating in this mode until the Organization of Petroleum Exporting Countries (OPEC) imposed its petroleum price increase. Used oil is now an eagerly sought after commodity.

## 7.2 AVAILABILITY

Re-refiners contacted during the course of this study indicated a lack of sufficient quantities of used oil feedstock. Most re-refineries were not running at full capacity even though demand for the finished product existed. However, as discussed in a subsequent section, the nonavailability of used oil is related to price competition and the amount of money that re-refiners are willing to pay.

Used oil tends to accumulate at places related to the type of user. For automotive lubes, accumulation points reflect a broad spectrum of vehicle service habits including the "do-it-yourself" home garage, service stations, auto dealers, and fleet garages. Generally, the more oil accumulated at a single point, the greater the potential that it will be available for collection. This is reflected in an EPA-funded study estimate of only 22 percent availability from the do-it-yourselfer and 90 percent from auto dealers (Ref. 7-1). However, some of these used oil sources are utilizing it in-house, which then makes it unavailable for collection. The American Petroleum Institute (API) reported several installations, such as a New Jersey truck stop, that burns self-generated crankcase drainings to provide heat (Ref. 7-2).

Industrial oils generated in manufacturing plants may not be available for collection because of a lack of proper segregation of all waste products (Ref. 7-3). Used oil may become mixed with water, chemicals, solids, and other wastes such that the most practical course is to dispose of it in a landfill. Also, most industrial plants generate large amounts of power, which provides a convenient means of utilizing used oil. As reported in Reference 7-3, only a small proportion of industrial oil is burned, while over one-third of the used oil generated is disposed of in an unknown manner.

### 7.2.1 Sources

Estimates of recoverable used oil were provided in Section 3 of this report. These estimates show approximately 51 percent of all recoverable used oil coming from the automotive sector and 49 percent from industrial sources. Data shown in Tables 3-3 and 3-4 of Section 3 have been adapted in the form of percentiles of totals; Tables 7-1 and 7-2 provide a breakdown of sources within each major category.

Table 7-1. Available Used Oil from Automotive Sources

| Source | Percent of Total |
|---|---|
| Service Stations and Garages | 33.7 |
| Commercial Engine and Fleets | 25.7 |
| Car Dealers | 15.0 |
| Automotive Fleets | 11.0 |
| Factory Fills | 8.6 |
| Discount Stores | 6.0 |
| Total | 100.0 |

Table 7-2. Available Used Oil from Industrial Sources

| Source | Percent of Total |
|---|---|
| Hydraulic Oils | 32.9 |
| Metal Working Oils | 25.2 |
| Stationary Engine Oils | 13.4 |
| Electrical and Refrigeration | 13.4 |
| Railroad Locomotives | 7.7 |
| Process Oils | 7.4 |
| Total | 100.0 |

Some re-refining operations are located relatively close to a readily available source of supply. For instance, Motor Oils Refining is located in the Chicago area, which is a major rail and trucking center. Motor Oils Refining obtains used oil from 500 truck fleets and 20 railroads and re-refines it on a closed-loop basis (Ref. 7-4). It also deals with many industrial plants in the area. Conversely, other areas appear to be generating large quantities of used oil without any re-refiner close by. This situation prompted Gladieux Refining of Fort Wayne, Indiana, into taking steps to enter the re-refining business (Ref. 7-5). There are large industrial plants within 50 to 60 miles of Fort Wayne, such as a Chrysler transmission plant at Kokomo and a Chevrolet unit at Muncie, which should generate at least 10 million gallons per year of used industrial oil.

### 7.2.2 Price

There are two prices of interest relative to used oil: the price paid at the source and the price paid on delivery to the user. These prices are commonly called street price and delivered price.

The used oil collection market is an unregulated free enterprise operation. Used oil sellers range from small independent service stations, primarily interested in getting their holding tanks emptied; to large corporate giants interested in maximizing profits; and to governmental agencies. Therefore, the street price of oil, even for the same quality of oil in the same area, can fluctuate widely depending on the relative bargaining between seller and buyer. The delivered price of used oil tends to reflect its end use and the price of virgin lube oil, which provides a ceiling. Used oil intended for burning has an effective ceiling price imposed by the price of virgin fuels.

An interesting interference in this free market competition between re-refiners and fuel users, by government regulation, is reported in Reference 7-3. In New Jersey, competition among collectors for used oil for fuel purposes raised the price re-refiners had to pay from about 6 to 8 cents to about 9 to 12 cents per gallon. In New York, which has collector-licensing legislation limiting the number of used oil collectors, the price remained at the 6 to 8 cent level.

Other factors influencing the price of used oil are the quality of a specific oil and regional differences. This study did not attempt to survey prices paid throughout the country, but did query a number of re-refiners about the cost of used oil, indicating a variation in price. Leach Oil Company, Los Angeles, California, reported a street price ranging from 0 to 10 cents per gallon and a delivery price to fuel users of 17 to 20 cents per gallon. For delivered used oil, Leach was paying 14 cents per gallon (Ref. 7-6). Nelco Oil Refining of San Diego has taken a unique approach to used oil pricing. It has its own collection trucks and has established a maximum delivered price of 10 cents per gallon. On the basis of the street price for used oil, its location, and truck operating costs, Nelco determines whether the delivered price will meet its ceiling requirements (Ref. 7-7). Motor Oil Refining, located in the Chicago area, follows another used oil pricing procedure. For oil purchased outright for re-refining, it offers 10 cents per gallon, whereas for oil supplied in exchange for re-refined oil a credit of 5 cents per gallon is allowed (Ref. 7-4). The Williams Refining Company of Denver, Colorado, has abandoned re-refining but maintains a used oil collection operation. Its used oil purchase price is 3 cents per gallon, and its selling price is 13 cents per gallon (Ref. 7-7). In the New York area, the reported street price varies between 2 cents and 5 cents per gallon, with a selling price of 6 cents to 12 cents per gallon.

## 7.3 COLLECTION

The available data on used oil collectors and collecting operations date back to a 1974 EPA study which is based on information obtained by means of a survey (Ref. 7-1). The names of 285 used oil collectors were compiled via the yellow pages and supplemented from other sources, such as those provided by members of the Association of Petroleum Re-Refiners (APR). A telephone survey of 100 collectors was successfully completed. Reference 7-3 provides data obtained from a survey of oil collectors in the New York City area.

### 7.3.1 Pickup Operator

Conclusions and observations reached in the course of the EPA-sponsored study (Ref. 7-1) are as follows:

a. The waste oil industry is highly fragmented, ephemeral, and not easily characterized in terms of the average operator or firm.

b. Many firms, both old and new, seem to run their businesses in a highly informal and flexible manner, often operating out of temporary facilities with no formal address or phone number.

c. Waste oil firms, in general, keep either poor records or no records.

d. Collectors and collector/processors are not cooperative respondents. Many refused to grant an interview, and many of those who did refused to answer many of the questions.

The EPA survey distinguished between collectors and collector/processors. Collectors were categorized, with 38 percent owning a single truck and only 21 percent owning 5 or more trucks. Total capacity of these truck fleets was also categorized, with 36 percent being less than 2500 gallons and only 8 percent over 20,000 gallons. Collector/processor operations tended to be larger, with 41 percent owning 5 or more trucks and 23 percent having more than a 20,000 gallon total truck capacity. The fragmented nature of the used oil collection industry may be due to the fact that it only requires the acquisition of a small tank truck equipped with a suction pump to start in a collection business. Few states have regulations covering used oil collectors that inhibit entrance to the field. During the course of this study, one collector, Fabian Oil Refining Company of Oakland, California, was contacted (Ref. 7-8). The Fabian operation, which is relatively large, using 13 trucks of over 50,000 gallons total capacity, appears to refute the generally negative impressions stated in Reference 7-1.

### 7.3.2 Pickup Operations

The survey reported in Reference 7-1 showed that 64 percent of the collectors operated within a 100-mile radius, 31 percent within 200 miles, and 5 percent over 200 miles. Collector/processors tended to cover a larger area, with 59 percent operating within 100 miles, 10 percent within 200 miles, and 31 percent over 200 miles.

Some interesting operating arrangements were discovered in discussions with re-refiners. For example, Motor Oils Refining has a closed-loop operation with the state of West Virginia. Used oil is hauled to Chicago via truck, and re-refined oil is hauled back with the tank cleaned prior to loading the re-refined oil. A distance of about 500 miles each way is involved (Ref. 7-4). Bayside Oil Corporation of San Carlos, California, purchases re-refined oil from Los Angeles, San Diego, and Salt Lake City, which involves distances of about 400 to 600 miles each way. Used oil is hauled back on the return trip (Ref. 7-9). The Double Eagle Refining Company of Oklahoma City, Oklahoma, also engages in long haul operations, to Albuquerque, New Mexico (about 550 miles one way) and Denver, Colorado (about 650 miles one way) (Ref. 7-10).

Apparently, relatively long-range transport of used and re-refined oil by tank truck is economically feasible. However, no specific costs for these operations are available. Some insight may be provided in the Gladieux Refinery planned price schedule for re-refining. In this case, a charge of 1 cent per gallon is made for every 30 miles of distance between the refinery and the industrial plant (Ref. 7-5). For the Chicago to West Virginia operation, which is about 500 miles one way, about 17 cents per gallon would be added to the cost of re-refined oil. No cost data are available for rail tank shipping operations. Motor Oils Refining of Chicago operates with 60 railroad tank cars. To avoid cleaning costs these cars are segregated as to used oil and re-refined oil, and the cars are returned empty.

According to Reference 7-3, the most common frequency of pickup from service stations is monthly. The amount of oil picked up, on a mean basis, ranges from 200 to 500 gallons per station. For industrial oils, the pickup interval varies from less than a month to yearly. Reported operating costs for collecting used oil from service stations range from 1 to 5 cents per gallon with 3 cents per gallon as the average. Operating costs of about 5 cents per gallon are reported for collecting industrial oils.

A detailed used oil collection plan was developed under EPA sponsorship for the state of Maryland, using computer modeling of feedstock source and several proposed re-refining plant locations (Ref. 7-11). Many factors are considered in the study, including (1) direct hauling from source to plant, (2) use of intermediate storage areas, (3) different plant processing capacity, and (4) system operating conditions involving parameters such as overhead rates, equipment utilization, waiting times, and average driving speeds. Optimization of operations shows a wide spread in the cost of collecting used oil ranging from 1.3 to 7.5 cents per gallon reflecting the assumptions in system operating conditions. Costs are relatively insensitive to the volume of oil generated or to the region of origin.

The Maryland system envisions computer control of the operation, taking over after a used oil source phones in and requests a pickup. The computer dispatches drivers, provides for fee payments, and maintains a data bank. It is interesting to note that the proposed system can collect all of the used oil generated in Maryland with a fleet of 18 to 22 tank trucks. This compares to 171 existing collectors operating in the state of Maryland at that time (Ref. 7-11).

## 7.4 REFERENCES

7-1 N. J. Weinstein, *Waste Oil Recycling and Disposal,* EPA-670/2-74-052, Recon Systems, Inc., Princeton, New Jersey (August 1974).

7-2 *Final Report of the Task Force on Used Oil Disposal,* The American Petroleum Institution, Washington, D. C. (May 1970).

7-3 S. P. Maltezou, *Waste Oil Recycling: The New York Metropolitan Area Case,* Council on the Environment of New York City (March 1976).

7-4 Personal communication: B. Williams, Motor Oils Refining Company, McCook, Illinois (12 November 1976).

7-5 Personal communication: B. Marshall, Gladieux Oil Refinery, Ft. Wayne, Indiana (11 November 1976).

7-6 Personal communication: R. Leach, Leach Oil Corporation, Compton, California (5 October 1976).

7-7 Personal communication: L. Cunningham, Williams Refining Company, Denver, Colorado (12 October 1976).

7-8 Personal communication: B. Fabian, Fabian Oil Refining Company, Oakland, California (29 September 1976).

7-9 Personal communication: R. Banks, Bayside Oil Corporation, San Carlos, California (28 September 1976).

7-10 Personal communication: C. Karran, Double Eagle Refining Company, Oklahoma City, Oklahoma (18 October 1976).

7-11 E. J. Martin, et al., "State of Maryland Waste Oil Recovery and Reuse Programs," NTIS No. PB-234 446, Environmental Quality Systems, Inc., Washington, D. C. (January 1974).

# SECTION 8

# FUTURE MARKET FOR RE-REFINED LUBE OIL

## 8.1 GENERAL

The viability of the re-refining industry rests heavily on market demand for re-refined lube oils. Therefore, the feasibility of expanding re-refining operations is dependent on the ability to market re-refined products in the future. The following subsections address these issues and examine the market for re-refined oil and the factors affecting the development of the re-refining industry.

The lube oil market share captured by re-refined products depends primarily on (1) the availability and price of virgin lube oil, provided that this market is permitted to operate by economic forces alone, and (2) the quality of the lube oil products manufactured from used oil. In case of a virgin lube oil shortage, re-refined products must be used to cover the supply and demand difference. Therefore, the prediction of re-refined oil sales involves projecting total lube oil demand and the ability to satisfy the demand from virgin crude.

The availability of virgin lube oil is dependent on (1) the availability of crude oil, (2) the magnitude of the lube oil cut contained in the crude, and (3) the available refining capacity. However, predictions of the long range availability of crude are clouded by uncertainties in the projections of future consumption. With regard to future refining capacity, historical data are available on actual capacity which can be used as the basis for near to mid-term (1985 to 2000) projections (Refs. 8-1 and 8-2).

If an ample supply of virgin lube oil is available relative to demand, the dominant market penetration factor for re-refined products will be determined by price competition. An important factor impacting price competition is the establishment of equivalency to virgin products because price differentials between virgin and re-refined products would then be viewed as true savings and not as savings associated with the acceptance of lower quality. Other factors affecting market penetration are related to federal, state, and local government legislation which could provide a market for re-refined oil without the need for competition. These factors and their impact on marketing opportunities for re-refined oil have been examined in this study with regard to type of oil and geographical region.

## 8.2 LUBE OIL DEMAND PROJECTIONS

Future lube oil demand may be predicted by projecting historical data. Of course, predictions using this technique are only reliable when the influencing factors impacting the historical data trends remain in force. In the case of petroleum products, severe dislocations were recently experienced as a result of artificially imposed supply restrictions, price increases, and a multitiered structure for foreign oil, old domestic oil, and new domestic oil. These factors are expected to remain effective in the future with additional factors to be added as a result of federal policies and actions relative to energy conservation. Any forecast of future lube oil demand, based on historical data, must be adjusted to reflect these effects.

## 8.3 MARKET ANALYSIS FOR RE-REFINED OILS POSTULATING A SHORTAGE OF VIRGIN LUBE OILS

### 8.3.1 Automotive Lube Oil Demand

In this scenario, the potential market for re-refined lube oils is examined, assuming a shortage of virgin lube oils, with re-refined oils supplying the deficit. Initially, statistical techniques were applied in this study to project the automotive and industrial lube oil demands to the year 2000. A first-order least squares fit of actual sales data for the 1958 to 1975 time frame and a projection to the year 2000 are shown in Figure 8-1.

Historical automotive lube oil demand patterns are currently changing because of (1) new governmental policies and actions, (2) changing economic forces, (3) new technological developments, and (4) changing demographic patterns. These factors affect lube oil consumption because they influence the number of vehicle miles driven, the number of vehicles in use, the size of vehicles, and the oil change intervals. The direction of these changes is toward lowering the historical lube oil growth rate. Therefore, on the basis of a qualitative assessment of these factors, the anticipated demand shown in Figure 8-1 is expected to fall between the projected demand line for compounded oil (extension of the least squares fit line) and a lower line drawn through the projections made by the Atlantic Richfield Company (ARCO) for 1981 (Ref. 8-3) and by Frost and Sullivan for 1985 (Ref. 8-4). Also included in Figure 8-1 is the projection made by The Sun Oil Company for

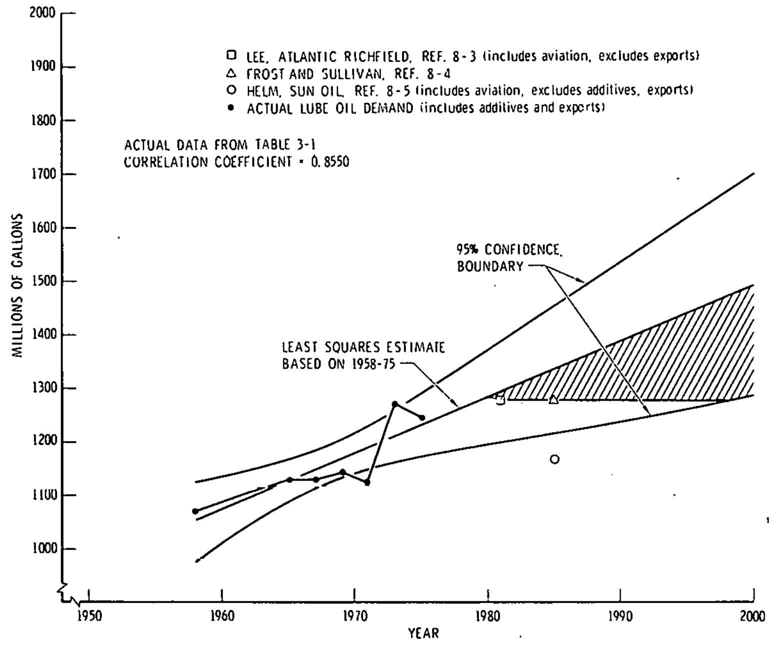


Figure 8-1. Projected Demand for Automotive Lube Oil

1985 (Ref. 8-5). The Sun Oil projection is not used in this anslysis primarily because it represents a base oil rather than a compounded oil. A discussion of the types of oils projected is provided in the following paragraph.

Actual lube oil demand data used in this anslysis (Section 3) are based on Bureau of the Census (BOC) data. These data represent sales of compounded lube oils, including those exported. Compounded lubes are identified by the BOC as to type (automotive, aviation, etc.) and separated as oils and greases. ARCO projections are also based on BOC data. However, they exclude exports and sales to the federal government, which amounted to about 4 percent in 1975 for automotive oils, and include aviation lube oils, which are declining and represented less than 2 percent of automotive oils in 1975.

Conversely, The Sun Oil Company projections are based on Bureau of Mines (BOM) data, which only include total domestic demand of lube oil base stock (not compounded oils). Sun Oil then categorizes this oil as to type (automotive, aviation, etc.) by use of percentiles derived from BOC data by estimating and removing quantities of additives and aromatic process oils. The intent is to arrive at the domestic demand for pure base oil. Also, as was done by ARCO, aviation lubes are included with automotive lube oils. An illustration of the relative change between reported compounded oils and estimated base oils is shown in Table 8-1

Table 8-1. Comparison of Compounded Lubricants to Base Oil for 1973 and 1975

| Data Source | Compounded Lube Oil,[a] million gal<br>BOC (Ref. 8-11) | | Base Oil,[b], [c] million gal<br>Sun Oil (Ref. 8-5) | | Ratio | |
|---|---|---|---|---|---|---|
| Year | 1973 | 1975 | 1973 | 1975 | 1973 | 1975 |
| Automotive[d] | 1224 | 1212 | 1130 | 987 | 1.08 | 1.23 |
| Industrial | 1483 | 1332 | 1348 | 1117 | 1.10 | 1.19 |

[a] Excludes exports and sales to federal government.

[b] Domestic demand.

[c] Includes base oils used for grease, which amounts to 5 percent of total on a compounded basis.

[d] Includes aviation sector.

In comparison to the rather involved methodology of Sun Oil Company, Frost and Sullivan merely presents an estimate of lube oil demand for 1985, with the notation that aviation oils are included with industrial oils. It is presumed that the Frost and Sullivan estimate is for what is normally considered lube oil, the compounded product.

### 8.3.2 Industrial Lube Oil Demand

Industrial lube oil demand projections were made using the methodology previously applied to automotive lube oils. Actual demand data, least squares projections, and estimates by ARCO (Ref. 8-3), Sun Oil Company (Ref. 8-5), and Frost and Sullivan (Ref. 8-4) are shown in Figure 8-2.

Historical industrial lube oil demand patterns are currently changing because of changing economic forces and new technological developments. These factors influence lube oil consumption because of changes in manufacturing operations, changes in material composition, and product design changes. The direction of the total effect of these changes is to reduce the historical growth rate. However, the trend is not the same for all industries or types of oil. For example, a shift from metals to plastics reduces demand for cutting oil but increases the demand for process oils. The anticipated demand, shown in Figure 8-2, is expected to fall between the extrapolated historical demand line and the line drawn through the projections of ARCO (Ref. 8-3) and Frost and Sullivan (Ref. 8-4). This line should be a conservative

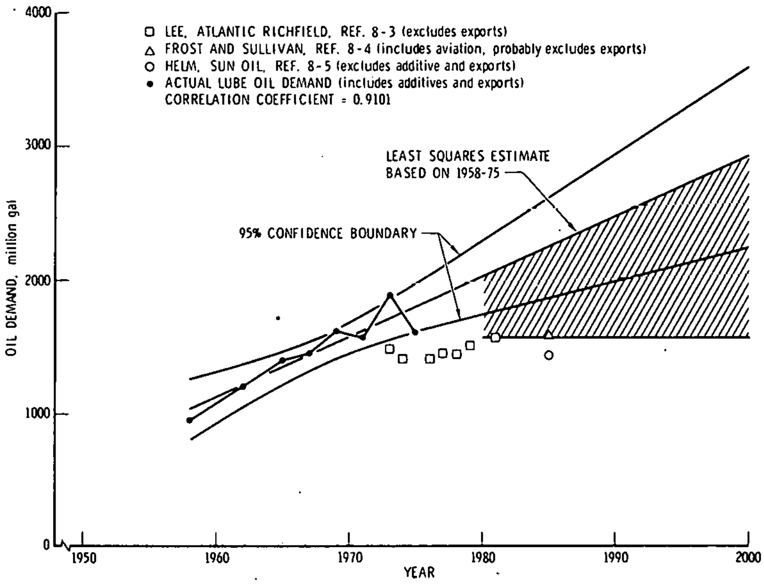


Figure 8-2. Projected Demand For Industrial Lube Oil

lower limit since, unlike automotive lube oil, exported industrial oils, which are not included in the data, represent a significant percentage of the total. In 1975, exports and sales to the federal government (which are also excluded by ARCO) amounted to 16 percent of total production, down from 21 percent in 1973. Although not identified by Frost and Sullivan, it appears that their projection also excludes exports. The Sun Oil projection is not used for the same reasons stated for automotive lube oils.

### 8.3.3 Lube Oil Supply Estimates

The supply of virgin lube oil is dependent upon many factors, including the availability of crude petroleum, the available lube cut from the crude, and the available lube oil refining capacity. These factors and their effects on virgin lube oil supplies are addressed in the following subsections.

### 8.3.3.1 Refining Capacity

Using the 1976 reported domestic capacity and assuming an operating utilization of 92.5 percent, the present yearly total production capability is about 3300 million gallons of lube oil base stock, which is used to produce both oils and greases. Since greases amount to only about 5 percent of the lubricant demand and oil additives are becoming an increasingly greater percentage of compounded oils, it was assumed that these two factors are offsetting. Therefore, production capacity of base oil may be equated to demand for compounded lube oil.

An estimate of lube production capacity in the year 2000 may be obtained by using the historical lube production capacity growth trend shown in Figure 8-3. In the year 2000, a growth rate of 1.26 percent per year relative to the 1976 capacity results in an estimated capacity of about 4300 million gallons.

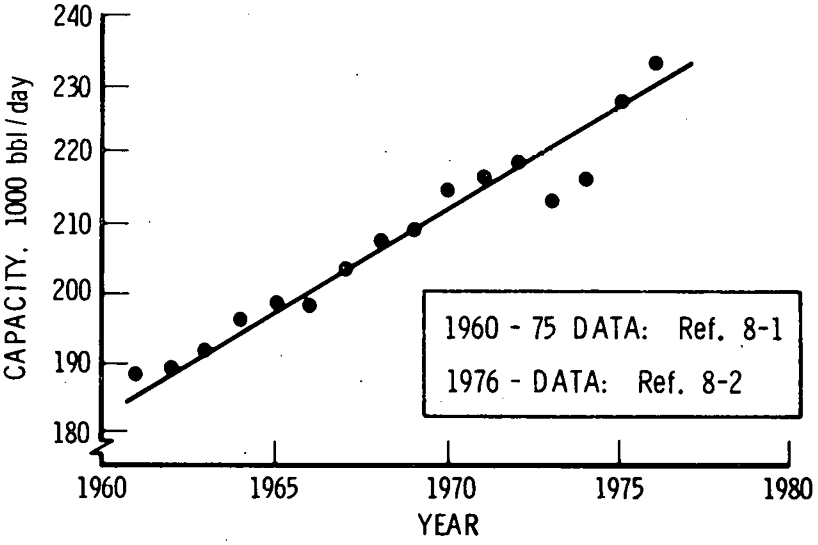


Figure 8-3. Refining Capacity For Virgin Lube Oil

### 8.3.3.2 Petroleum Availability and Lube Cut

The National Energy Plan projects a crude oil consumption of about 24 million barrels per day in 1990 (Ref. 8-7). Extrapolating this quantity to the year 2000 results in a crude demand of about 28 million barrels per day or about 10.3 billion barrels per year. This quantity of crude petroleum permits the manufacture of about 13 billion gallons of lube oil, based on an average lube cut of 3 percent. Using the estimated average lube cut of 1.7 percent for

U.S. crudes (Ref. 8-8), it would permit manufacture of over 7 billion gallons of lube oil. From these data, it is apparent that the available lube oil supply exceeds the refining capacity projected from historical data by a wide margin. However, as discussed in Section 12 of this report, potential shortages of specific types of petroleum, such as naphthenic crude, might occur. As a result, virgin lube oil shortages might develop even though, on an overall basis, sufficient quantities of lube oil products could be made available.

### 8.3.4 Demand and Supply Comparison

As shown in Figure 8-1, a demand in the range of 1290 million to 1500 million gallons is projected for automotive lube oils in the year 2000. For the same year, Figure 8-2 shows a projected demand for all industrial oils in the range of 1570 million to 2920 million gallons. This represents a total combined lube oil demand of 2860 million to 4420 million gallons. The upper limit of this demand projection results in a lube oil shortage of 120 million gallons when compared to the estimated refinery capacity of 4300 million gallons. This shortage will be met either through expansion of virgin lube refining capacity (at greater than historical rates), expansion of the re-refining industry, reduction of exports, or curtailment in demand. While this potential shortage appears to represent an attractive market opportunity for the re-refining industry, it represents less than 3 percent of the predicted market, and as such may never materialize. A projected oversupply of 1440 million gallons or 33 percent of the predicted market is considered more significant.

In light of these demand/supply projections, it appears that re-refiners should plan future production expansion on the premise that sufficient virgin lube oil quantities will be available to satisfy demands. Re-refiners should seek market opportunities based on the economic advantages of using re-refined lube oils in lieu of virgin lube products. These opportunities are examined in the following section.

## 8.4 MARKET ANALYSIS FOR RE-REFINED OIL POSTULATING AMPLE SUPPLY OF VIRGIN LUBE OIL

This scenario, derived from the preceding demand/supply analysis, examines market opportunities that may exist for re-refined oil, based on an ample supply of virgin lube oils. In this case, virgin lubes are replaced by re-refined oils only if it is economically advantageous.

### 8.4.1 Automotive Oil Demand Trend and Re-Refining Market Locations

As shown in Figure 8-1, the total demand for automotive lube oil in the year 2000 is projected to vary between 1290 million and 1500 million barrels. The amount available for re-refining has been estimated by experts in the field to range between 40 and 60 percent of the total automotive lube oil consumption (Refs. 8-9 and 8-10).

Historically, lube oil consumption in the United States has shown large regional variations. As illustrated in Table 8-2, the East North Central and Pacific regions have the potential of becoming excellent growth areas for re-refined automotive oil. The increasing use of large highway diesel trucks in these areas (Figure 3-3), combined with rising fuel and oil prices, provide an attractive incentive for marketing for this sector at a price below that of virgin lube oil. In both rural and city areas, the continued growth of the school

Table 8-2. Estimated Used Lubricating Oil Annual Supply
Selected States and Regions 1971
(Data combined from Refs. 8-10 and 8-11)

| Region/State | Automotive | | Industrial | |
|---|---|---|---|---|
| | $10^3$ GAL | Gal/Capita | $10^3$ GAL | Gal/Capita |
| Middle Atlantic | | | | |
| New York | 32,016 | 2.66 | 15,546 | 2.88 |
| New Jersey | 18,071 | 3.82 | 18,459 | 8.70 |
| Pennsylvania | 35,728 | 4.57 | 27,823 | - |
| Total | 85,815 | | 61,828 | |
| East North Central | | | | |
| Ohio | 36,627 | 5.21 | 29,795 | 9.45 |
| Indiana | 17,722 | 5.17 | 12,991 | 8.45 |
| Illinois | 37,263 | 5.08 | 26,383 | 8.02 |
| Michigan | 37,488 | 6.40 | 19,571 | 7.45 |
| Wisconsin | 17,262 | 5.92 | 5,073 | 3.88 |
| Total | 146,362 | | 93,813 | |
| West North Central | | | | |
| Minnesota | 14,533 | 6.45 | 3,213 | 3.18 |
| Iowa | 11,103 | 6.10 | 2,400 | 2.94 |
| Missouri | 19,701 | 6.91 | 4,283 | 3.35 |
| North Dakota | 4,046 | 9.70 | 271 | 1.45 |
| South Dakota | 4,400 | 9.79 | 203 | 1.01 |
| Nebraska | 8,846 | 9.50 | 1,633 | 3.91 |
| Kansas | 14,381 | 10.0 | 2,979 | 4.62 |
| Total | 77,010 | | 14,982 | |
| West South Central | | | | |
| Arkansas | 8,008 | 6.31 | 3,085 | 5.42 |
| Louisiana | 15,163 | 6.31 | 12,070 | 11.2 |
| Oklahoma | 12,195 | 7.28 | 4,249 | 5.61 |
| Texas | 47,222 | 6.39 | 32,778 | 9.39 |
| Total | 82,688 | | 52,182 | |
| Pacific | | | | |
| Washington | 11,047 | 4.91 | 2,845 | 2.82 |
| Oregon | 12,020 | 8.71 | 2,977 | 4.81 |
| California | 72,034 | 5.47 | 20,021 | 3.39 |
| Total | 95,101 | | 25,843 | |

bus sector suggests another opportunity for re-refined oil. For economic reasons, local and state government agencies are expected to show increasing interest in re-refined oil for use in their vehicles. Developments of this type may lay the groundwork for subsequent widespread use by public transportation and by private consumers. Although the total oil demand is not expected to rise significantly in the 1980 to 2000 time period, an increasingly greater share of used lube oil may be re-refined for use in various types of fleet applications so that a definite business growth opportunity can be projected for the re-refining industry. A plausible market by the year 2000 might be 15 to 20 percent of total sales or about 195 million to 300 million gallons. Although this would represent a significant growth in the use of re-refined oil, it represents only about one quarter to one half of what could be collected and processed.

In addition to the domestic market, there is a possible international market for re-refined lube oils. The international demand for automotive lube oils has been growing at a rate in excess of that in the United States. Although foreign refinery construction is expanding, a potential world shortage of lube oils may occur before 1990 (Ref. 8-3), which would provide international marketing opportunities for the re-refining industry. Major sources of anticipated international growth are shown in Table 8-3.

Table 8-3. Expected Free World Lube Demand by Area (millions of barrels) (Ref. 8-3)

| Area | 1973 Actual[a] | 1974 | 1975 | 1976 | 1977 | 1979 | 1981 |
|---|---|---|---|---|---|---|---|
| Canada, Mexico, and Bermuda | 8.7 | 9.0 | 9.2 | 9.6 | 9.8 | 10.8 | 11.7 |
| Central America and Caribbean | 1.1 | 1.1 | 1.0 | 1.1 | 1.1 | 1.2 | 1.3 |
| South America | 7.2 | 11.7 | 12.1 | 12.7 | 13.3 | 14.7 | 16.2 |
| Western Europe | 41.1 | 40.8 | 40.0 | 41.4 | 43.2 | 46.3 | 49.5 |
| Mid-East | 3.2 | 3.5 | 4.0 | 4.4 | 4.8 | 5.7 | 6.7 |
| Africa | 5.4 | 5.7 | 5.9 | 6.2 | 6.6 | 7.3 | 8.2 |
| Asia | 33.4 | 32.7 | 33.8 | 35.6 | 37.3 | 40.9 | 44.8 |
| Free World total (less U.S.) | 100.1 | 104.5 | 106.0 | 111.0 | 116.1 | 126.9 | 138.4 |

(a) Volumes are base stock, not compounded lube.

### 8.4.2 Industrial Oil Demand Trend and Re-Refining Market Locations

The general status of the economy places increasing near-term cost pressure on manufacturing industries so there should be immediate opportunities for re-refining industrial oil. Metal-forming and automatic high-speed machining operators are large users of industrial oils and may be receptive to the idea of re-refined oil utilization. While these operators may decide to install their own used oil reclaiming equipment, re-refining opportunities for independent re-refiners may be found in small to medium size industrial plants. Therefore, to exploit the industrial market, re-refiners must move quickly and enlarge their options before company decisions are inflexibly directed to in-house reprocessing.

Similar to the automotive sector, re-refining opportunities for industrial oils are regional in nature. The expansion of the coal industry in the North Central and Mountain states requires appropriate earth-moving and construction equipment. Idaho, Montana, Wyoming, and Utah are four states with a high potential for development. Related to the expected massive development of the coal mining industry is the buildup in rail transportation necessary to move the coal to the consumer. Finally, the large anticipated growth of the electric utility industry suggests that re-refined transformer and turbine oils represent a growing market (Ref. 8-10).

A more detailed analysis might develop separate trend projections for industrial oils. For now, it can only be estimated that probably within the next 20 years, demand for process oil will exceed that for lube oil. The lube oil fraction of industrial oil in the year 2000 is estimated to be 40 percent or about 630 million to 1170 million gallons. Approximately 30 percent of this quantity, which amounts to about 190 million to 350 million gallons, is expected to be available for re-refining (Ref. 8-9).

## 8.5 FACTORS AFFECTING INDUSTRY DEVELOPMENT

The market for re-refined automotive and industrial lube oils is estimated to vary between 385 million and 650 million gallons per year. The ability of the re-refining industry to meet this demand is dependent upon feedstock availability, available re-refining capacity, and availability of capital. These factors are briefly addressed in the following subsections.

### 8.5.1 Feedstock Availability

It has been estimated that, within the United States, a concerted effort might recover for reuse approximately 55 percent of the automotive oil and 30 percent of the lube oil fraction of industrial oils (Refs. 8-9 and 8-10). A summary of lube oil availability in the year 2000 is presented in Table 8-4, which shows that sufficient used oil feedstock is available to supply the potential demand.

Table 8-4. Estimated Potential Re-Refined Lube Oil Availability in the U.S. in the Year 2000 (millions of gallons)

| Lube Oil Type[(a)] | Lube Oil Demand | Recoverable Lube Oil[(a)] | Re-refined Lube Oil[(b)] |
|---|---|---|---|
| Automotive | 1290 to 1500 | 710 to 820 | 460 to 660 |
| Industrial (total) | 1570 to 2920 | 190 to 350 | 120 to 280 |
| Total | 2860 to 4420 | 900 to 1170 | 580 to 940 |

(a) As used oil. Recovery factors 0.55 for automotive and 0.30 for lube oil fraction of industrial oils (Refs. 8-9 and 8-10).

(b) Based on a range of process yields of 65 to 80 percent.

### 8.5.2 Available Re-Refining Capacity

Various estimates have been made of the capacity currently available within the re-refining industry. Weinstein has published an estimate of re-refining capacity for 1973 (Ref. 8-12). By modifying these data to eliminate fuel processors and those who indicated that they were going out of business, the refining capacity for 1974 was estimated as shown in Table 8-5. Both Frost and Sullivan (Ref. 8-4) and Swain (Ref. 8-11) provided estimates for 1975 which are also listed in Table 8-5.

The capacity required for re-refining sufficient quantities of used oil to satisfy the projected annual market of 385 million to 650 million gallons in the year 2000 is about 5 to 9 times the current industry capacity, assuming a process yield of 75 percent. This increase in needed capacity would be reduced by about 30 percent if the plants could be operated over the entire year rather than only for 250 days.

Table 8-5. Estimates of Re-Refining Industry Lube Oil Base Stock Capacity

| Source | Year | Total Number of Re-refineries | Plant Capacity, $10^3$ gal/day | Base Stock Production, $10^6$ gal/year |
|---|---|---|---|---|
| Weinstein (Ref. 8-12) | 1973 | 34 | 500[a] | 83 |
| Weinstein (Ref. 8-12 modified)[b] | 1974 | 28 | 420 | 68 |
| Frost and Sullivan (Ref. 8-4) | 1975 | NA | 640 | NA |
| Swain (Ref. 8-11) | 1975 | NA | 400 | 50 |

[a] Includes capacity used by fuel processors.

[b] Excludes fuel processors and those indicating that they were going out of business.

## 8.5.3 Capital Requirements of the Re-Refining Industry

To assess the future capital requirements of the re-refining industry as a whole, a plant and equipment (P & E) investment of $0.18 to $0.32 per gallon feedstock was used. Based on a 10 million gallon per year plant operating 250 days per year, processing the approximately 500 million to 870 million gallons of used oil feedstock to satisfy estimated market demand by the year 2000 would require capital investments of at least $90 to $280 million (1977) dollars. Raising this sum may pose serious difficulties for the re-refining industry.

## 8.6 REFERENCES

8-1 J. L. Helm, "The Outlook for Lubricants," AM-75-25, Paper presented at the National Petroleum Refiners Association 73rd Annual Meeting, Sun Oil Company, Philadelphia, (March 1975).

8-2 A. Cantrell, "Annual Refining Survey," Oil and Gas Journal, Vol. 75, No. 13 (28 March 1977).

8-3 E. M. Lee, "World Lubricant Supply/Demand -- Its Impact on the United States," AM-76-15, Paper presented at the 1976 National Petroleum Refiners Association Annual Meeting, Atlantic Richfield Company, Los Angeles, (1976).

8-4 Waste Lubricating Oil Re-Refining, Frost and Sullivan, Inc., New York, (1975).

8-5 J. L. Helm, "Domestic Lube Oil Outlook," AM-77-16, Paper presented at the 1977 National Petroleum Refiners Association Annual Meeting, Sun Petroleum Products Company, Philadelphia (1977).

8-6 "Sales of Lubricating and Industrial Oils and Greases", Current Industrial Reports, MA-29C(75)-1, Bureau of the Census, Washington, D. C. (September 1976).

8-7 The National Energy Plan, Executive Office of the President, Energy Policy and Planning, Washington, D. C. (29 April 1977).

8-8 P. M. Cukor, et al., A Technical and Economic Study of Waste Oil Recovery, Part III, Teknekron, Inc., Berkeley, California (October 1973).

8-9 Waste Oil Recovery Practices -- State of the Art (1972), U.S. Environmental Protection Agency, NTIS No. PB-229801 (December 1972), Prepared by Environmental Quality Systems, Inc., Washington, D. C.

8-10 S. Chansky, et al., Waste Automotive Lubricating Oil Re-Use As a Fuel, EPA-600/5-74-032, U. S. Environmental Protection Agency, Washington, D. C. (September 1974).

8-11 J. W. Swain, Jr., Assessment of Industrial Hazardous Waste Management Practices -- Petroleum Re-Refining Industry, U. S. Environmental Protection Agency, Washington, D. C. (January 1977).

8-12 N. J. Weinstein, Waste Oil Recycling and Disposal, EPA-670/2-74-052, U. S. Environmental Protection Agency, Washington, D. C. (August 1974).

# SECTION 9

# INSTITUTIONAL IMPACTS ON RE-REFINING

## 9.1 QUALITY

This section focuses on the quality of lube oils used in internal combustion engines, which is the largest application of lube oil. In service, crankcase oils are exposed to harsh conditions caused by many factors, including operation of the engine at high speeds and high pressures and, most importantly, by the contaminating effects of fuel and combustion products. In addition, the engine duty cycle varies from stop-and-go traffic encountered by passenger cars in the subzero winter weather of the Northern states to hauling heavy loads through the deserts of the Southwest during summertime. If the quality of re-refined lube oil can be established as equivalent to virgin lube oil in automotive applications, the existing barriers for its use in other applications would be eliminated. Quality is also of interest to users of industrial oils. Since the severity of the operating conditions encountered in industrial applications is less than in internal combustion engines, oil specifications and oil quality tests are easier to define. Therefore, the significance of the oil source, either virgin crude or used oil, is diminished. This is evidenced by a general acceptance of re-refined machine tool hydraulic oil but not of re-refined engine crankcase oil. While the use of re-refined oil currently has limited acceptance in the automotive sector, it is widely used in railroad diesel engines. In this case, adequate lube oil quality is maintained and controlled by the railroad operators through tight control of the recycling process and the practice of frequent laboratory analysis of lube oil conditions in engine service.

### 9.1.1 API Service Classifications

#### 9.1.1.1 Background

The first attempt to classify crankcase lube oils, to serve as a guide for selection of a proper oil, was made in 1911 with the adoption of the Society of Automotive Engineers (SAE) Crankcase Oil Viscosity Classification System. In 1947, the American Petroleum Institute (API) established a system which addressed the performance (quality) capability of lube oil. This system is shown in Table 9-1.

Table 9-1. Original API Lube Oil Rating System (1947)

| Quality Designation | Constituent |
|---|---|
| Regular | Straight mineral oil |
| Premium | Oxidation inhibitor added |
| Heavy duty | Oxidation inhibitors and detergent-dispersants added |

In 1950, the API developed another classification system (designated "old"), which considers differences between gasoline and diesel engines and which describes in general terms the conditions under which engines are operated. Each oil classification category is assigned a letter designation, as shown in Table 9-2. Service classifications are described in Table 9-3.

Table 9-2. Old API Lube Oil Classification System (1950)

| Engine Type | Operating Condition | Letter Designation |
|---|---|---|
| Gasoline | Light | ML |
| | Moderate | MM |
| | Severe | MS |
| Diesel | Light | DG |
| | Moderate | DM |
| | Severe | DS |

To implement these engine service classifications, API consulted the United States passenger car manufacturers regarding the definition of laboratory engine tests which would be representative of the most severe engine operating conditions encountered in service. These test specifications then formed the basis for the MS classification. The ML and MM classifications are analogous to the original regular and premium classifications. The MS test sequences are presented in Table 9-4. The corresponding test

Table 9-3. Old API Engine Service Classifications

| | Part 1: Gasoline Automotive Type Engines |
|---|---|
| Service MS | Service typical of gasoline and other spark ignition engines where there are special lubrication requirements for deposit, wear, or corrosion control. The severity of these special lubrication requirements varies with engine design factors which in themselves may vary with different makes and models, with fuel characteristics, and particularly with engine operating conditions. |
| Service MM | Service typical of gasoline and other spark ignition engines used under moderate to severe operating conditions but presenting problems of deposit or bearing corrosion control when crankcase oil temperatures are high. |
| Service ML | Service typical of gasoline and other spark ignition engines used under the most favorable operating conditions where the engines have no special lubrication requirements or no design characteristic sensitive to deposit formation. |
| | Part 2: Diesel Automotive Type Engines |
| Service DS | Service typical of diesel engines operating under severe conditions or having design characteristics or using fuel tending to produce excessive wear or deposits. |
| Service DM | Service typical of diesel engines operating under severe conditions or using fuel of a type normally tending to promote deposits and wear, but where there are design characteristics or operating conditions which may make the engine either less sensitive to fuel effects or more sensitive to residues from lubricating oil. |
| Service DG | Service typical of diesel engines in any operation where there are no severe requirements for wear or deposit control because of fuel, lubricating oil, or engine design characteristics. |

Table 9-4. MS Test Sequence

| Manufacturer | Original | Latest Revision | Lubricant Properties Evaluated | Test Engine |
|---|---|---|---|---|
| General Motors | I, II, III | IIA, IIIA | Low temperature deposits and rusting; high temperature oxidation and bearing corrosion | 1964 Oldsmobile V-8 |
| Chrysler | IV | -- | High temperature, high speed scuffing and wear | 1963 Chrysler V-8 |
| Ford | V | VB | Low temperature sludging and insolubles control | 1965-66 Ford V-8 |

procedures were published by the American Society for Testing and Materials (ASTM) as Publication No. 315A.

No test procedures were developed by API for the DS classification (Ref. 9-2). In the 1930s, the Caterpillar Tractor Company developed lube oil test procedures for its diesel engines (Ref. 9-3.) Using these procedures, Caterpillar conducted tests of commercially available lube oils and specified lube oils for its engines by brand name. These test procedures and those developed later by the Mack Truck Corporation were eventually incorporated into test procedures meeting the API diesel engine service classification.

### 9.1.1.2 Current System

The old (1950) API classification system was found inadequate to satisfy changing lubrication and warranty service requirements established by the engine manufacturers. Therefore, a cooperative effort was initiated by the API, ASTM, and SAE to develop a new classification system. The new system is open-ended, and new classifications can be added as required. Engine oil performance and service classifications are published as SAE Recommended Practice J 183 A. A description of the classification system is provided in Table 9-5.

The new classification system is essentially an extended version of the old system. The number and type of tests specified have been changed to reflect new and more severe performance requirements. A complete set of engine test specifications, relating the two systems, is shown in Table 9-6. This table also shows test requirements for Military Specification qualification, which is addressed in Section 9.1.3.

### 9.1.1.3 Usage

Use of the API oil classification system is not mandatory and is left to the discretion of the lube oil producer and engine manufacturer. The oil producer establishes the suitability of the lube oil for each designated class of service, while the engine manufacturer recommends the appropriate service classification for use in its engines. Neither the API nor any regulatory agency has an interest in lube oil quality and labeling practices. There is no assurance that an oil is capable of meeting the designated service requirements, except for trust in the integrity of the producer, as there are no formal requirements for designating the service classification of lube oils.

## 9.1.2 Engine Sequence Tests

### 9.1.2.1 Background

## Table 9-5. Current API Engine Service Classifications

| Part 1: "S" - SERVICE (Service Stations, Garages, New Car Dealers) | |
|---|---|
| SA for Utility Gasoline and Diesel Engine Service | Service typical of engines operated under such mild conditions that the protection afforded by compounded oils is not required. This classification has no performance requirements. |
| SB for Minimum Duty Gasoline Engine Service | Service typical of gasoline engines operated under such mild conditions that only minimum protection afforded by compounding is desired. Oils designed for this service have been used since the 1930s and provide only antiscuff capability and resistance to oil oxidation and bearing corrosion. |
| SC for 1964 Gasoline Engine Warranty Maintenance Service | Service typical of gasoline engines in 1964 through 1967 models of passenger cars and some trucks operating under engine manufacturer's warranty in effect during those model years. Oils designed for this service provide control of high- and low-temperature deposits, wear, rust, and corrosion in gasoline engines. |
| SD for 1968 Gasoline Engine Warranty Maintenance Service | Service typical of gasoline engines in 1968 through 1970 models of passenger cars and some trucks operating under engine manufacturer's warranty in effect during those model years. Also may apply to certain 1971 and/or later models as specified (or recommended) in the owner's manual. Oils designed for this service provide more protection against high- and low-temperature engine deposits, wear, rust, and corrosion in gasoline engines than oils which are satisfactory for API engine service classification SC and may be used when API engine service classification SC is recommended. |
| SE for 1972 Gasoline Engine Warranty Maintenance Service | Service typical of gasoline engines in passenger cars and some trucks beginning with 1972 and certain 1971 models operating under engine manufacturer's warranty. Oils designed for this service provide more protection against oil oxidation, high-temperature engine deposits, rust, and corrosion in gasoline engines than oils which are satisfactory for API engine service classifications SD or SC and may be used when either of these classifications is recommended. |

| Part 2: "C" - COMMERCIAL (Fleets, Contractors, Farmers) | |
|---|---|
| CA for Diesel Engine Service | Service typical of diesel engines operated in mild to moderate duty with high-quality fuels and occasionally has included gasoline engines in mild service. Oils designed for this service provide protection from bearing corrosion and from ring belt deposits in some naturally-aspirated diesel engines when using fuels of such quality that they impose no unusual requirements for wear and deposit protection. These oils were widely used in the late 1940s and 1950s. |
| CB for Diesel Engine Service | Service typical of diesel engines operated in mild to moderate duty but with lower quality fuels which necessitate more protection from wear and deposits. Occasionally has included gasoline engines in mild service. Oils designed for this service provide necessary protection from bearing corrosion and from ring belt deposits in some naturally-aspirated diesel engines with higher sulfur fuels. Oils designed for this service were introduced in 1949. |
| CC for Diesel Engine Service | Service typical of certain naturally-aspirated, turbocharged, or supercharged diesel engines operated in moderate to severe duty service and certain heavy-duty gasoline engines. Oils designed for this service provide protection from high-temperature deposits and bearing corrosion in these diesel engines and also from rust, corrosion, and low-temperature deposits in gasoline engines. These oils were introduced in 1961. |
| CD for Diesel Engine Service | Service typical of certain naturally-aspirated, turbocharged, or supercharged diesel engines where highly effective control of wear and deposits is vital or when using fuels of a wide quality range including high sulfur fuels. Oils designed for this service were introduced in 1955 and provide protection from bearing corrosion and from high-temperature deposits in these diesel engines. |

## Table 9-6. U.S. Engine Test Specifications for Crankcase Oils (Ref. 9-4)

| API SERVICE CLASSIFICATIONS | | RELATED DESIGNATIONS | FIELD SERVICE SPECIFICATIONS: | STATUS | GASOLINE ENGINES | | | | | | | | | | | | | DIESEL ENGINES | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NEW | OLD | | | | SEQUENCE | | | | | | | | | | FALCON RUST | CRC L-38 | CLR LTD | GM 3-71 | CATERPILLAR | | | | | MACK | |
| | | | | | IIA | IIB | IIC | IIIA | IIIB | IIIC | IV | V | V-B | V-C | | | | | .4 L-1* | 1.0 L-1* | 1-D | 1-H | 1-G | T-1 | T-4 |
| SA | ML | STRAIGHT MINERAL OIL | | | | | | | | | | | | | | | | | | | | | | | |
| SB | MM | INHIBITED OIL | | | | | | | | | ● | | | | | ●** | | | | | | | | | |
| SC | MS | 1964 MS WARRANTY APPROVED | FORD ESE-M2C101-A (1964) | ■ | ● | | | ● | | | ● | ● | | | | ● | | | | ● | | | | | |
| SD | MS | 1968 MS WARRANTY APPROVED | FORD ESE-M2C101-B (1968) | ■ | | ● | | | ● | | ● | | ● | | ● | ● | | | | ● ← | OR | → ● | | | |
| | | | GM 6041-M (Prior to July, 1970) | ■ | | ● | | | ● | | ● | | ● | | | | | | | | | | | | |
| | | | GM 6041-M (Revised July, 1970) | ■ | | ● | | | | ● | ● | | ● | | | | | | | | | | | | |
| SE | NONE | 1972 GASOLINE ENGINE WARRANTY MAINTENANCE SERVICE | GM 6136-M (Revised June, 1975) | ☑ | | | ● | | | ● | | | | ● | | ● | | | | | | | | | |
| | | | FORD M2C101-C (Revised August 1973) | ☑ | | OPTIONAL ● | ● | | | ● | | | | ● | | ● | | | | | | | | | |
| | | | AMERICAN MOTORS | ☑ | | ● | | | | ● | | | | ● | | ● | | | | | | | | | |
| SE | | | CHRYSLER | ☑ | | ● | | | | ● | | | | ● | | ● | | | | | | | | | |
| | | | MACK TRUCK EO-G | ☑ | | ● | | | | | | | | | | ● | ● | | | | ● | | ● | | |
| | | | MACK TRUCK EO-H | ☑ | | | | | | | | | | | | | | | | | | | | ● | |
| | | | MACK TRUCK EO-J | ☑ | | | | | | | | | | | | | | | | | | | | | ● |
| | | | CATERPILLAR SERIES 3 | ■ | | | | | | | | | | | | | | | | | ● | | ● | | |
| | | | **FACTORY FILL:** | | | | | | | | | | | | | | | | | | | | | | |
| | | PASSENGER CARS | FORD M2C96-C (Revised August, 1973) | ☑ | | OPTIONAL ● | ●2 | | | ● | ●3 | | | ● | | ● | | | | | | | | | |
| | | GASOLINE TRUCKS | FORD M2C35-C thru 39-C (Rev. Aug. '73) | ☑ | | OPTIONAL ● | ●2 | | | ● | ●3 | | | ● | | ● | | | | | | | | | |
| SE$^{4}$ | | PASSENGER CARS | CHRYSLER 4071J (1974) | ☑ | | | ● | | | ● | | | | ● | | ● | | | | | | | | | |
| SE$^{5}$ | | PASSENGER CARS | AMERICAN MOTORS 4042 (1972) | ☑ | | OPTIONAL ● | ● | | | ● | | | | ● | | ● | | | | | | | | | |
| | | | GM 6041-M (Revised July, 1970) | ■ | | ● | | | | ● | ● | | ● | | | | | | | | | | | | |
| SE | | | GM 6136-M (Revised June, 1975) | ☑ | | | ● | | | ● | | | | ● | | ● | | | | | | | | | |
| | | | **MILITARY:** | | | | | | | | | | | | | | | | | | | | | | |
| CA | DG | MIL-L-2104A | MIL-L-2104A | ■ | | | | | | | | | | | | ●** | | | ● | | | | | | |
| CB | DM | SUPPLEMENT 1 | U.S. ARMY 2-104B, SUPPL 1 | ■ | | | | | | | | | | | | ●** | | | | ● | | | | | |
| CC | DM | MIL-L-2104B | MIL-L-2104B | ■ | | ● | | | | | | | | | | ● | ● | | | | | ● | | | |
| CD+SC | -- | TACTICAL SERVICE VEHICLES | MIL-L-2104C<br>Oils meeting performance requirements of MIL-L-2104C also meet both API Service CD and SC. | ☑ | | | ●6 | | | | | | | ● | | ● | | | | | ● | | ● | | |
| CC+SE | -- | PASSENGER CARS<br>LIGHT TRUCKS | MIL-L-46152<br>Oils meeting performance requirements of MIL-L-46152 also meet both API Service SE and CC | ☑ | | | ●6 | | | ● | | | | ● | | ● | | | | | | ● | | | |
| -- | -- | | MIL-L-21260B TYPE 1 | ☑ | | | ● | | | | | | | ● | | ● | | | | | | ● | | | |
| CD | DS | | MIL-L-21260B TYPE 2 | ☑ | | | | | | | | | | | | ● | | | | | ● | | ● | | |
| CD | DS | MIL-L-45199B, SERIES 3 | MIL-L-45199B | ■ | | | | | | | | | | | | ● | | | | | ● | | ● | | |
| CE*** | | | | ☐ | | | | | | | | | | | | ● | | | | | ● | | ● | ● | |
| CF*** | | | | ☐ | | | | | | | | | | | | ● | | | | | | ● | | ● | |
| -- | -- | | MIL-L-9000F | ■ | | | | | | | | | | | | | | ● | | ●7 | | | | | |
| -- | -- | | MIL-L-9000G | ☑ | | | | | | | | | | | | | | ● | | | | | ●7 | | |

[2] Duplicate tests required

[3] Replaced by 100 hours Ford QC6-1

[4] Plus special Anti-scuff test

[5] Plus special Cold Start-up test

[6] IIB Acceptable prior to 4/1/72

[7] 1% Sulfur Fuel – 480 hours no oil change

☑ Current ☐ Proposed ■ Obsolete

*.4 = .35% min. Sulfur: 1.0 = .95% min. Sulfur fuel

** L4 or L38

*** Proposed New Classifications

The intent of the engine sequence tests is to simulate actual field operating conditions in the laboratory on an accelerated time scale. Sequence tests are established by the engine manufacturers for use in specific production engines to resolve lube oil related problems associated with these engines. Much effort goes into devising these test procedures to make them relevant to field service and to make the results reproducible from test to test and from laboratory to laboratory. For example, General Motors (GM) has investigated 810 separate tests over the past 10-1/2 years. The sequence tests are used by GM as a means for screening lube oils for acceptability. However, GM recommends real field tests to conclusively determine lube oil quality (Ref. 9-3).

### 9.1.2.2 Test Descriptions

As shown in Table 9-6, lubricants may be qualified to the SE service classification (highest grade for gasoline engine service) by completion of four engine sequence tests, IIC, IIIC, VC, and CRC* Test L-38. A brief description of these tests, as defined in References 9-2, 9-6, and 9-7, follows.

#### Oldsmobile Sequence Test IIC

Purpose: To evaluate rusting characteristics of motor oils. This test relates to short trip service under typical winter conditions in the upper midwestern U.S.

Equipment: A 1967 Oldsmobile 425 CID V-8 engine, with a 10.25:1 compression ratio and equipped with a 2-barrel carburetor and water cooled rocker arm covers.

Test Conditions:

| | | |
|---|---|---|
| Part 1: | Speed | 1,500 rpm |
| | Load | 25 hp |
| | Oil Temperature | 120°F |
| | Engine Coolant Temperature, Inlet | 105°F |
| | Rocker Arm Coolant Temperature, Outlet | 60°F |
| | Test Duration | 28 hr |
| Part 2: | Speed | 1,500 rpm |
| | Load | 25 hp |
| | Oil Temperature | 120°F |
| | Engine Coolant Temperature, Inlet | 115°F |
| | Rocker Arm Coolant Temperature, Outlet | 60°F |
| | Test Duration | 2 hr |

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*Coordinating Research Council of the SAE

| | | |
|---|---|---|
| Part 3: | Speed | 3,600 rpm |
| | Load | 100 hp |
| | Oil Temperature, Inlet | 260°F |
| | Engine Coolant Temperature, Inlet | 190°F |
| | Rocker Arm Coolant Temperature, Outlet | 198°F |
| | Test Duration | 2 hr |

Inspections:

Rust: Using CRC Manual No. 7, average rust ratings are made of the five parts listed below. An average rating of 8.4 or better (scale of 0 to 10 where 10 is "clean") meets the requirements for SE classification.

1. Valve lifter bodies
2. Valve lifter plungers
3. Valve lifter balls
4. Oil pump relief valve
5. Pushrods

Other: Sticking of the oil pump relief valve and of valve lifters is noted.

## Oldsmobile Sequence Test IIIC

Purpose: To evaluate high temperature performance of motor oils. This test relates to high-speed turnpike operation under high ambient temperatures typical of the southwestern parts of the U.S.

Equipment: Same as Sequence Test IIC.

Test Conditions:

Cycle 1:

| | | |
|---|---|---|
| Part 1: | Speed | 3,000 rpm |
| | Load | 100 hp |
| | Oil Temperature, Inlet | 300°F |
| | Engine Coolant Temperature, Outlet | 235°F |
| | Rocker Arm Coolant Temperature, Outlet | 240°F |
| | Test Duration | 8 hr |

Part 2: Shutdown for 15-30 minutes to measure oil viscosity and replenish oil to proper level.

Cycle 2 through Cycle 8: Repeat Cycle 1 so as to accumulate 64 hr total running time.

Inspections:

Sludge: Using CRC Manual No. 10, average sludge ratings of the three parts listed below are made. An average rating of 9.0 or better meets requirements for an SE oil.

Varnish: Using CRC Manual No. 9, average varnish ratings are made of all eight pistons. An average rating of 9.3 meets requirements for an SE oil.

Sticking: Note and report number of stuck rings and lifters. No sticking is allowed for an SE oil rating.

Scuffing: Note and report number and condition of the following five parts. No scuffing is permitted for an SE quality oil.

1. Valve lifters
2. Cam lobes
3. Valve stemtips
4. Rocker arm pads
5. Rocker pivots

Wear: Determine wear by before and after measurements of the following two parts. An average wear (cam lobe plus lifter body) of under 0.0010 inches, with a maximum individual value of 0.0020 inches, meets the requirements of an SE oil.

1. Cam lobes
2. Lifters

Viscosity Increase: Engine oil viscosity increase (viscosity measured at 100°F) at the end of 40 hours operation must be less than 400 percent to meet SE oil requirements.

Oil Consumption: Must be less than 20 ounces at the end of any 8 hour test cycle. Otherwise, the test is concluded.

## Ford Sequence Test VC

Purpose: To evaluate sludge and varnish forming tendencies under average driving conditions. This test relates to low speed, low temperature, stop-and-go city driving combined with moderate turnpike operation.

Equipment: A 302 CID V-8 Ford engine (Part No. 302-GP-6003-A-S06000-A) equipped with a two barrel carburetor.

Test Conditions:

Cycle 1:

| | | |
|---|---|---|
| Part 1: | Speed | 2,500 rpm |
| | Load | 87 hp |
| | Oil Temperature, Gallery | 175°F |
| | Engine Coolant Temperature, Outlet | 135°F |
| | Test Duration | 2 hr |
| Part 2: | Speed | 2,500 rpm |
| | Load | 87 hp |
| | Oil Temperature, Gallery | 200°F |
| | Engine Coolant Temperature, Outlet | 170°F |
| | Test Duration | 1.25 hr |
| Part 3: | Speed | 500 rpm |
| | Load | 2 hp |
| | Oil Temperature, Gallery | 120°F |
| | Engine Coolant Temperature, Outlet | 115°F |
| | Test Duration | 0.75 hr |

Cycle 2 to Cycle 48: Repeat Cycle 1 four times in one day, followed by an 8-hour soak period. The daily cycle is repeated for 12 days so as to accumulate a total of 192 hr running time. Oil additions of up to 16 ounces are permitted after the first 16 hr of running time and 12 ounces for each succeeding 16 hr. Failure to restore to the full mark results in test termination.

Inspections:

Sludge: Using CRC Manual No. 10, average sludge ratings of the six parts listed below are made. An average rating of 8.5 meets requirements for an SE oil.

1. Rocker arm covers
2. Intake manifold
3. Oil pan
4. Valve deck areas
5. Push rod chamber
6. Timing gear cover

Varnish: Using CRC Manual No. 9, average varnish ratings are made for the five parts listed below. An average rating of 8.0 meets requirements for an SE oil.

1. Piston skirts
2. Rocker arm covers
3. Valve lifters
4. Cylinder walls
5. Oil pan

Clogging: The percent clogging of the oil rings (average) and oil screen are measured. A rating of less than 5 percent for each item meets requirements for an SE oil.

Sticking: The number of stuck compression rings are noted. No stuck rings are permitted for an SE oil rating.

## CRC Test L-38

Purpose: To evaluate bearing corrosion characteristics of lube oils.

Equipment: A single cylinder 42.5 CID engine developed by the Committee on Lubricant Research (CLR) and manufactured by the Laboratory Equipment Company (LEC).

Test Conditions:

| | |
|---|---|
| Speed | 3,150 rpm |
| Fuel Flow | 4.75 lb/hr |
| Air-Fuel Ratio | 14.0 : 1 |
| Oil Temperature | 290°F (a) |
| Coolant Temperature | 200°F |
| Test Duration | 40 hr |

(a) Except for SAE 10 oil, then use 275°F.

Inspections:

Wear: Connecting rod bearing weight is measured before and after completing the test. A weight loss of less than 40 mg meets the requirements of an SE oil.

### 9.1.2.3 Test Costs

Costs of completing these sequence tests are illustrated by the following fees charged by Southwest Research Institute (SRI) (Ref. 9-5).

| | |
|---|---|
| Sequence Test IIC | $ 2,570 |
| Sequence Test IIIC | 3,995 |
| Sequence Test VC | 4,300 |
| CRC Test L-38 | 1,195 |
| Total | $12,060 |

### 9.1.2.4 Test Engine Reuse

Generally, the engines used for sequence tests are reused. After inspection, they are cleaned and rebuilt in accordance with detailed requirements contained in the test specification (Ref. 9-6). In general, parts meeting new engine specifications are reused. Specific instructions are provided for the various parts. For example, in the IIIC test, connecting rod bearings may be reused, while camshaft bearings are replaced after each test; the camshaft sprocket and timing chain are replaced after every second test.

The total life of an engine used in sequence testing is highly variable, depending on the specific tests conducted and the quality of the oil tested. Minimum life is less than one test if a catastrophic failure occurs, such as a thrown rod, while maximum life is reached when cylinder wear is outside specifications and the block must be replaced, as the engine block is generally considered to represent the engine and not just a replaceable component of the engine.

### 9.1.2.5 Test Facilities

Major independent laboratories performing engine sequence testing are SRI and Automotive Research Associates (ARA), both located in San Antonio, Texas. These two facilities are approved for all testing required for Military Specification approval. A third independent laboratory is the Automotive Research Laboratories (ARL) of Chicago, Illinois. ARL is only approved for a portion of the required Military Specification (Mil-Spec) tests. Other facilities approved for Mil-Spec testing (all or part) are Lubrizol and Edwin Cooper Company, as well as Amoco, Shell, Sun Oil, and Texaco. Other major lube oil companies, such as Chevron and Exxon, have in-house engine test facilities which are used for development work and are acceptable for lube oil qualification tests.

### 9.1.2.6 Pass/Fail Frequency

Lube oils submitted by producers to independent laboratories for military qualification, or for other purposes, are generally thoroughly pre-screened in-house. Therefore, the expected pass/fail ratio of tested oils should be fairly high. According to Exxon (Ref. 9-8), of about 100 tests performed in the 1975 to 1976 time frame, only three failures occurred. However, according to the ASTM Engine Test Monitoring Center, Pittsburgh, Pennsylvania (Ref. 9-9), a high failure rate was experienced in the early 1970s. At that time, even reference oils were failing. A qualified laboratory is generally required to perform reference oil tests every 15 tests or 60 days, whichever occurs first, to maintain its qualified status. When reference oils fail, the criterion for qualification of a candidate oil is the degree of failure of the oil relative to the reference oil (Ref. 9-9). For example, if the reference oil scored 9.0, instead of 9.3 as required for a pass, any candidate oil with a score of 9.0 or better would be considered to have passed.

Once an oil has successfully passed a series of qualification tests, it becomes qualified. There are no restrictions on the number of attempts required for qualification. For cost reasons, some oils are specifically blended with a low amount of additives to obtain a minimum pass score. Should failure occur, reformulation is implemented, and the tests are then rerun. For a small manufacturer, who would have difficulty paying for successive tests, an additive overdose may be used to obtain a passing score on the first try.

The system of sequence test qualification is premised on the belief that if the oil base stock, the refining process, and the additive package remain unchanged, the oil produced by this procedure is of equivalent quality to the sample of oil originally qualified. No specific criteria for measuring the constancy of oil production parameters were found in the course of the study. However, Chevron stated that in-house engine tests are performed continuously to assure product quality.

### 9.1.3 Military Specifications

### 9.1.3.1 Background

The United States Army has, through its Fuels and Lubricants Laboratory at Ft. Belvoir, Virginia, responsibility within the Department of Defense (DOD) for setting specifications for lubricants used by all ground vehicles. Two lube oil specifications are of concern: (1) Mil-L-46152, which is for administrative service vehicles typified by commercial types of gasoline and diesel powered vehicles; and (2) Mil-L-2104C, which is for tactical vehicles typified by high-speed, high-output engines, both gasoline and diesel. Both specifications require engine sequence testing.

The Fuels and Lubricants Laboratory is responsible for specification content and product qualification. Assistance is provided by the Army Review Board (ARB), which consists of an Engine Oil Review Committee and a Gear Oil Review Committee. The Engine Oil Review Committee is chaired by the Laboratory and consists of representatives from GM, Ford, Chrysler, Caterpillar Tractor, and International Harvester (Ref. 9-11).

The ARB, in cooperation with industry, defines qualification tests for MIL-Specs and reviews oil qualification test data for the purpose of recommending acceptance or rejection. It has considerable discretion in specifying tests for the qualification or requalification of lube oil. This is particularly true for requalification, which must be done every four years or when a change in base stock, process, or additive is made. The amount of testing to be done for requalification depends on the types of changes, both to the oil and to the specifications. For instance, if the specification was modified to require sequence test IIC in place of IIB, a lube oil previously qualified in accordance with IIB would now only have to pass the IIC test to remain qualified. A change to the oil makeup, such as the antioxidant additives, may in the judgment of the ARB only require passage of the IIIC test.

### 9.1.3.2 Oil Qualification

Lube oil is purchased by the military for its own use and for most other federal agencies on a bid basis. All bids submitted are limited to those products included in the applicable Qualified Products List (QPL). In contrast to the API service designations covering commercial uses, inclusion in this list requires passage of appropriate engine sequence and other tests. Approval remains in effect for four years, provided no changes are made to the base stock, process, or additives. There are about 600 to 700 approved oils of various types on this list.

When an approved oil is purchased by the military, a Quality Assurance (QA) test is performed on each lot to determine such properties as viscosity, flash point, foaming, and organo-metallic component content. All performance parameters which require engine sequence testing are specifically excluded from the QA tests.

### 9.1.3.3 The Military and the Re-refiners

Currently, re-refiners are not permitted to sell their lube oil products to the military. In accordance with the Mil-Spec (Section 3.2, Materials), no re-refined constituent materials shall be used. Even removal of this restriction may not open this market to re-refiners. The Mil-Spec also states: "Whenever there is a change in the base stock, ... requalification will be required." Currently, the Fuels and Lubricants Laboratory considers re-refined oil as a product from a variable base stock. Therefore, each batch processed would have to undergo separate qualification testing.

The objection of the military to re-refined oil dates back to the 1950s and engine problems experienced by the United States Army while running field tests with re-refined oil. More recently, tests were conducted with two re-refined oil samples (Ref. 9-11). One oil stenciled with the appropriate Mil-Spec number was purchased off the shelf, and the other oil was provided by a re-refiner. Based on bench tests, it appeared that both oils were compounded (Ref. 9-3). Both oils failed in subsequent engine tests. Unfortunately, no documentation is available from these tests.

Individuals involved with military oil specifications are genuinely concerned over lube oil quality and the potential for engine damage. The military is dealing with expensive equipment, and in the case of actual tactical usage engine failure may result in the loss of more than the value of the equipment. There is no so-called plot to reserve the lube oil market for the virgin lube oil producers.

### 9.1.4 NBS Quality Tests

The National Bureau of Standards (NBS) has been given a charter (Public Law 94-163) to devise tests to determine the substantial equivalency of re-refined oils to that of virgin lube oil products. NBS will initially address fuel oil tests and progressively work up to crankcase lube oil tests (Ref. 9-12). Newly developed test procedures will be published by NBS as they are formulated.

As part of the NBS effort in developing these tests, a Workshop on Measurements and Standards for Recycled Oils was held at Gaithersburg, Maryland, in November 1976. Attendees were individuals involved with lubricating oil: virgin oil producers, re-refiners, engine manufacturers, and others. The purpose of the meeting was to enable the NBS to obtain inputs relative to recycling used oil. The basic NBS program plan involves (1) identification of oil test procedures, (2) acquisition of test procedure data through a nonlaboratory program, (3) development of a laboratory program to verify applicability of test procedures, and (4) establishment of the adequacy of the entire test procedure package.

The final session of the workshop, entitled "Problems and Needs in Establishing Quality for Recycled Oil Products," focused primarily on the API service classification system, particularly that for SE service. In these discussions, the need to perform actual engine testing for the purpose of evaluating oil quality was strongly advocated by attendees representing lube oil, lube oil additive, and engine manufacturers. Bench tests or other simple tests are not capable of duplicating the environment within the engine, particularly the effects of fuel and combustion products. It was concluded that engine testing in the laboratory, without supporting field tests, was insufficient to determine lube oil quality. There are no published field test specifications analogous to engine sequence tests, and there is no formal SE approval system that examines an oil and approves of a rating. While it may not be "correct" to do so, any company can legally place an SE label on its product. The company thus assumes warranty for the product's performance in service. It is performance in service that the API system is aimed at by specifying a level of service rather than a set of specifications for measuring the properties of a lubricant. The lube oil and engine manufacturers maintain close working relationships through committees of the ASTM, SAE, and ASLE, with the objective of developing lubricants that will provide satisfactory service. Lube oil re-refiners were encouraged by these committees to participate and to work together in the areas of research and testing of lube oils.

### 9.1.5 EPA/DOD Lube Oil Tests

The DOD, through use of Environmental Protection Agency (EPA) funding, is involved in a program to determine if re-refined oil can meet SE quality requirements. While the primary objective of this effort is directed to SE quality, meeting the more stringent Mil-C-46152 requirements is also being evaluated.

As part of this program, samples of re-refined base stock obtained from various re-refiners were sent to the Army Fuels and Lubricants Laboratory. Each oil will be categorized by use of standard ASTM tests for viscosity, flash point, carbon residue, aniline point, and other properties. The oils will then be classified according to quality into four groups, with the worst group to be eliminated from further testing (Ref. 9-11).

Additive packages will then be developed for these oils. The preferred approach is the development of an additive package for each group. An alternate approach is the development of a package for the lowest quality oil which would then also be used for all other oils. Additive package development will be based on recommendations of additive manufacturers.

### 9.1.6 Engine Sequence Tests of BERC Processed Oil

The Department of Energy (DOE) Bartlesville Energy Research Center (BERC) has been working since 1971 on a broad program related to reclamation of used oil. Currently, an in-house developed process is used which appears to produce high quality lube oil on the basis of bench tests. Subsequently, engine sequence tests were performed to establish the actual quality of the oil. Two samples of BERC processed re-refined oil, and a third sample obtained from a commercial re-refiner, were sequence-tested at SRI to determine their performance relative to SE service requirements (Ref. 9-13). The oils tested were as follows:

Oil A: BERC SAE 10W30 oil formulated from a 165 SUS (Saybolt Universal Seconds at 100°F) hydrofinished base stock.

Oil B: BERC SAE 10W30 oil formulated from a 180 SUS clay treated base stock.

Oil C: Motor Oils Express Extra, SAE 20 oil rated for API Service SE/CC.

Results of the engine sequence tests and the L-38 bearing test are shown in Table 9-7. Initially, both Oil A and Oil B failed the IIC rust test.

Table 9-7. Engine Sequence Tests of BERC Re-refined Oils (Ref. 9-13)

| Rating Parameter | Test Limit | Oil Sample | | |
|---|---|---|---|---|
| | | A | B | C |
| **Test Sequence IIC** | | | | |
| Rust(a) | 8.4 min | (7.71)(b) | (7.73)(b) | 8.50 |
| **Test Sequence IIIC** | | | | |
| 100° Viscosity Increase at 40 hr, % | +400 max | +21 | +18 | +60 |
| Piston Varnish(a) | 9.3 min | 9.39 | 9.37 | 9.44 |
| Oil-Ring Land Face Deposits(a) | 6.0 min | 7.52 | 8.03 | 7.97 |
| Sludge(a) | 9.0 min | 9.69 | 9.80 | 9.63 |
| Ring Sticking | None | None | None | None |
| Cam or Lifter Scuffing | None | None | None | None |
| Cam plus Lifter Wear, in. | 0.0010 avg | 0.0004 | 0.0006 | 0.0009 |
| | 0.0020 max | 0.0010 | 0.0009 | 0.0014 |
| **Test Sequence VC** | | | | |
| Total Sludge(a) | 8.5 min | 9.5 | 9.5 | 9.3 |
| Total Varnish(a) | 8.0 min | 8.4 | 8.3 | 8.0 |
| Piston Skirt Varnish(a) | 7.9 min | 7.9 | (7.7)(b) | 8.1 |
| Oil Ring Clogging | 5 % max | 0 | 0 | 0 |
| Ring Sticking | None | None | None | None |
| **Test Sequence CRC L-38** | | | | |
| Bearing Weight Loss, mg | | | | |
| Top (at 40 hr) | | | | 10.9 |
| Bottom (at 40 hr) | | | | 9.5 |
| Total Bearing Weight Loss, mg | 40 max | | | 20.4 |
| **Repeat of Test Sequence IIC** | | | | |
| Rust(a) | 8.4 min | | 8.45(c) | |

(a) 0 to 10 where 10 is "clean."

(b) Parameters in parentheses indicate failure.

(c) Additional corrosion inhibitor used in this sample.

However, after adding an additional 1 percent of corrosion inhibitor, the Oil B passed the test. Oil B also failed part of the VC test, whereas Oil A only failed the IIC rust test. However, there was insufficient oil available to reformulate and retest Oil A. The BERC-formulated oils were not submitted to the L-38 engine test. However, Oil B was submitted to a bench test designed to simulate the L-38 test and passed easily. Oil C, provided by Motor Oil Refining, passed all engine sequence tests for an SE quality oil.

It is believed that this is the first time that a re-refined oil has been demonstrated as being capable of passing engine sequence tests.

### 9.1.7 Manufacturer Warranty Requirements

Engine manufacturers have a natural desire to see that their equipment performs satisfactorily in service. This is a good business practice as it leads to customer satisfaction and repeat sales and reduces warranty claims. Therefore, manufacturers recommend the use of high-grade lubricants combined with specific maintenance procedures. A review of the owner manuals issued by GM, Ford, and Chrysler for model year 1977 shows that the use of an SE oil is recommended. There are no specifications as to whether the oil must be virgin or that re-refined products are excluded.

Warrantees generally call for the repair and replacement of parts found to be defective in materials or workmanship within a specified time and mileage. Typically, they apply for 12 months or 12,000 miles. Emission control systems are an exception and must be, due to federal law, warranted for 5 years or 50,000 miles.

Materials and workmanship are fixed parameters when the engine leaves the factory. Subsequent use, abuse, care, or neglect will not alter these qualities. As stated in a Ford owner manual, "Claims ... will not be denied solely because the vehicle or engine was not properly maintained and used." This point was emphasized at the NBS Workshop (Ref. 9-3) when one of the engine manufacturers stated that if an in-warranty engine failed because of lubrication, the lubricant manufacturer would have to be contacted for repairs and not the engine manufacturer. Irrespective of the engine warranty status, there is an implied warranty between the oil producer and the user. Equipment failure due to the performance of the lubricant will be rectified by the oil producer. Conversely, it was implied by a number of attendees at the NBS Workshop (Ref. 9-3) that re-refiners, because of their small size, may not stand behind their product.

## 9.2 LEGISLATION

Governmental action, through direct legislation and the resulting interpretation of these laws, has affected the economic viability of the re-refining industry. The early history of legislation relative to re-refining was indirect and related to revenue-raising codes. The more recent legislation reflects current awareness of the need for conservation and attempts to stimulate the recycling of lube oils.

Other governmental action which has had a significant effect on the re-refining industry occurred under the power of consumer protection laws including the labeling requirements promulgated by the Federal Trade Commission (FTC) for application to containers of re-refined oil.

### 9.2.1 Labeling Requirements

Labeling requirements on re-refined oils are, and have been, a mixture of state laws and federal regulations. An apparent reason for these requirements is an underlying feeling that re-refined oil is of inferior quality relative to virgin lube oil.

State labeling laws preceded federal regulations in this field, with laws being enacted as early as the 1920s. About 20 states have labeling laws, of which 17 have generally similar provisions relative to deception. These laws tend to be predicated on two basic premises. One states that the public should not be deceived as to the quality of the product. However, the mechanism as to how the public is to be protected is not spelled out in the law. The other specifically states that re-refined oil must be labeled as to its previous use. Both premises effectively require labeling since, it is argued, in the absence of a previous use disclosure label, the customer might think he was buying virgin lube oil and hence be deceived about the quality of the purchase. The counter argument, which has not prevailed, is that lube oil feedstock origin, whether it be used oil or crudes of diverse origins, is not necessarily related to the quality of the final product.

Specific labeling requirements exist in about 20 states. In contrast to the relatively similar general deception statutes that necessitate these labels, labeling requirements; i.e., format, words, and letter size, are diverse. In some states, these requirements are part of the general mis-branding provisions. In others, they apply specifically to re-refined lube oil. The diversity in the labeling formats imposes a difficulty on re-refiners who market in more than one state.

Federal activities, relative to labeling, began in the 1940s through the FTC, covering cases of affirmative misrepresentation, such as mislabeling re-refined oils with labels stating "100% Pennsylvania." From this beginning, the FTC progressed to nondisclosure cases. The basic argument of the FTC was that the consumer has a preference for virgin lube oil and would assume that he was getting it if no indication to the contrary was provided.

A number of court cases and appeals were brought relative to the FTC rulings. These suits covered a number of items, starting with the fundamental requirement for a label to the specific words ("re-processed oil" was not a strong enough warning that the oil had been previously used) and where the words should be displayed (front panel or side panel). All rulings were in favor of labeling regulations.

The net effect of requiring re-refined oil to be prominently labeled as coming from used oil was to denote inferior quality. This image then required the product to compete in the marketplace on the basis of price. As such, re-refined oils tended to compete against low quality virgin lube oils, which could be produced at a somewhat lower cost than a quality re-refined oil. This marketing situation tended to hurt the re-refiners economically, by reducing their profit margin in order to remain price-competitive with low quality oils. In some instances, quality was sacrificed for price, which tended to reinforce the poor quality image of re-refined oil.

### 9.2.2 Tax Structures

Federal taxation of lube oil started in 1932 at a level of 4 cents per gallon and was to be paid by the manufacturer. All funds raised went into the general revenue fund. To raise additional revenue, the tax was increased an additional 2 cents per gallon during World War II. All lubricating oils were taxed, even though the intent was to tax only those viscosities usable in internal combustion engines. Congress decided, when drafting the legislation, that someone could blend nontaxed light and nontaxed heavy oil and produce a nontaxed motor oil.

The only problem with the legislation was that the definition of a manufacturer was not provided. The Bureau of Internal Revenue made its own decision as to whether re-refiners were manufacturers. Its decision was that a re-refiner producing an oil substantially equivalent to new oil would be considered a manufacturer and be taxed. Re-refiners could apply for exemptions and receive them on a case-by-case determination. By 1938, all who applied were given exemptions. An Internal Revenue Service (IRS) ruling in 1954 formally exempted re-refiners from being manufacturers without the need of applying for an exemption.

The Excise Tax Reduction Act of 1965 maintained the previously established tax level of 6 cents per gallon on lube oil, with the revenue obtained going into the Highway Trust Fund. Now, only lube oil used in highway vehicles and produced from virgin sources is taxed, while all non-automotive lube oil and all re-refined oil is tax-free. Virgin lube oil used in nonhighway vehicles can be sold without tax, provided the manufacturer obtains an exemption certificate. Alternatively, the tax can be paid by the manufacturer, passed on to the purchaser (in the form of increased price), and the purchaser can obtain a tax refund through a rebate or credit against income tax. Nonhighway users of automotive lube oil, which are exempt from this tax, rely on the refund system since an automotive lube oil manufacturer does not know a priori whether its lube oil will be used in highway or nonhighway equipment and, hence, generally pays the tax. Similarly, virgin oils purchased by re-refiners for blending are purchased at a price that includes payment of the tax by the manufacturer, and the re-refiner has to obtain a refund through the rebate system.

The tax advantage of re-refined oil was eliminated in 1968 by the IRS ruling 68-108, which states that virgin lube oils purchased by re-refiners are no longer eligible for rebates. Further, the nonhighway user of a re-refined oil cannot get a rebate on the taxed virgin oil portion blended with the re-refined oil in that re-refined oil is tax-free. Thus, for a 50/50 blend of virgin and re-refined oil, the re-refiner's tax advantage over virgin oil in the highway field is reduced from 6 cents per gallon to 3 cents per gallon. In the nonhighway use field, re-refined oil now has a 3 cents per gallon disadvantage. This shift in profitability of 3 cents per gallon may seem small. However, prior to the 1973 oil price increase and increased profitability in re-refining, it represented a significant portion of the profit margin in re-refining.

This IRS ruling appears to be in opposition to the intent of Congress, which was to promote highway building through funds raised from highway users. Nonhighway users of re-refined lube oils blended with virgin lube would be contributing to the highway fund.

### 9.2.3 Effect of Public Laws 94-163 and 94-580

#### 9.2.3.1 Public Law 94-163

Public Law 94-163 was passed on 22 December 1975 and is entitled "Energy Policy and Conservation Act." This rather broad Act, which grants the President standby rationing powers, provides for a Strategic Petroleum Reserve, and provides for increased efficiency of motor vehicles, also includes a section for federal actions with respect to recycled oil.

Section 383 of the Act addresses two of the problems that have economically hindered the re-refining of used oil: the question of quality and labeling requirements. The purpose of this section of the Act is to encourage the recycling of used oil and the subsequent use of this recycled oil, which in turn reduces the consumption of new oil and helps protect the environment from indiscriminate disposal of used oil.

The term "used oil" is defined as any oil that has been refined from crude oil and as a result of its usage has become contaminated with physical or chemical impurities. The term "recycled oil" is also defined as a used oil with the contaminants removed by re-refining or other processes and is substantially equivalent to virgin oil. This recycled oil may be either wholly re-refined oil, a blend with virgin lube oil, or compounded with additives. The Act states that it is the manufacturer who determines that the oil is substantially equivalent to a new oil for a particular end use. Therefore, the manufacturer, who in this case is the re-refiner, has been given the authority to certify that his product is equivalent to new oil. Most re-refiners contacted during the course of this study claim that their oil is as good as or better than virgin lube oil. The claims are based on experience with customers who are actually using the re-refined oil and not from rigorous engine testing programs.

Part C of Section 383 deals with the question of how substantial equivalency is to be determined. The NBS is given the charter to determine test procedures that will establish substantial equivalency of recycled oil to new oil for a given end use. It should be pointed out that the end use of a recycled oil may be any end use, including use as a fuel. The Act is not necessarily intended to encourage the recycling of high quality automotive crankcase lube oil back to its original use. It is equally satisfactory if the used lube oil is recycled back to replace virgin residual fuel oil.

The NBS program to develop tests is currently under way. The task is difficult. Among many problems is the question of equivalency since many oil products lack a standard definition or specification. For example, No. 6 fuel oil is composed of residuals from the distillation of crude and has, according to ASTM D 396, no specifications except for flash point, water content, sediment, and viscosity. Sulfur limit is usually determined by mutual consent between buyer and seller, but is not a specification. The same is true for an SA quality motor oil. This API service classification is for a straight mineral oil, has no performance specifications to meet, and is marketed according to viscosity rating only. In other areas, where specifications exist, the specifications may not be adequate for recycled used oil. For example, No. 4 fuel oil has a maximum ash specification of 0.10 percent, but the type of ash is not specified. The specifications were written for fuels obtained from crude and not from crankcase drainings. Virgin crude contains very little lead, whereas large amounts of lead are found in used crankcase oil.

Upon completion, the NBS test procedures will be turned over to the FTC. The FTC will then prescribe test procedures to determine substantial equivalency for a given end use and labeling requirements for recycled oil. The new labeling requirements shall specify the end use for which the recycled oil is the equivalent of a new oil. The label must not bear any connotation that the recycled oil is not substantially equivalent to a new oil.

The final part of Section 383 is to encourage the use of recycled oil. This part requires all federal officials to act within their authority to revise procurement policies to encourage use of recycled oils and to educate federal, state, and private sector employees of the economy in the merits of recycled oil.

This Act is of extreme importance to marketing re-refined oils. There has been great reluctance on the part of many people to use recycled oils in a demanding lubricating environment. If re-refined oils can be tested and shown to be equivalent to a quality virgin motor oil, with an SE service classification, the question of quality will disappear as a barrier to marketing the product.

A word of caution should be exercised. If the NBS test procedures for equivalency to motor oils with API service classifications are lengthy and expensive, requiring engine sequence testing, these test procedures may become a barrier to marketing recycled oils for this application. Typically, a re-refiner may not be able to afford to have these tests performed. Presumably, he would be prohibited from marketing his product for this end use even though his product might be capable of passing the tests.

### 9.2.3.2 Public Law 94-580

Public Law 94-580 was passed on 21 October 1976 and is entitled the "Resource Conservation and Recovery Act of 1976" (Ref. 9-17). The purpose of this Act is to provide technical and financial assistance for developing plans and facilities to recover energy and resources from discarded materials and to regulate the management and safe disposal of hazardous wastes. This Act, which amends the Solid Waste Disposal Act, is related to solid waste disposal and, in particular, hazardous solid waste disposal. No specific words relate to used oil. It is noted that the definition of solid waste within the Act is broad enough to cover liquids and contained gases.

The importance of Public Law 94-580 is that it will set up management procedures for the safe disposal of hazardous wastes, with emphasis on the recovery of recyclable materials. For this Act to be applicable to the used oil industry, used oil must first be classified as a hazardous waste. The EPA, which is charged with administering this Act, is required to, within 18 months, develop criteria for characterizing hazardous wastes and to develop a list of such items. It is understood, based on past work the EPA has performed on used oils, particularly in regard to crankcase drainings, that used oil will be listed as a hazardous waste. On the assumption that this will indeed occur, the effects of the Act on the re-refining industry are examined in the following paragraphs.

Section 3002 of the Act requires the EPA to generate standards applicable to generators of hazardous wastes such as used oil. These standards require record-keeping of the amounts generated and the use of prescribed storage containers, as well as the development of systems for handling the storage, shipping, and disposal of the waste material. This provides information on the amount and the availability of used oil, data which are essentially unavailable today.

The next section of the Act addresses standards for the transportation of hazardous wastes. Hazardous waste may be transported only to an approved treatment, storage, and/or disposal site. Activities at the treatment and disposal site must follow methods acceptable to the EPA. In Subtitle D of the Act, which is related to setting up solid waste plans with states and regions, the development of disposal methods that maximize the utilization and conservation of resources is encouraged.

The potential impact of this Act, depending on EPA action, would be to make available used oil feedstock which could be funneled to re-refiners. However, if other uses of untreated used oil are considered to be acceptable, including road oiling and asphalt manufacture, then the Act will provide no help to the re-refiners. Conversely, as the current utilization options for used oil are disallowed, the availability of feedstock to the re-refiner will increase, resulting in a price reduction of used oil.

Other parts of the Act affecting re-refining of used oil attempt to encourage the use of materials recovered from the treatment and disposal of hazardous wastes. The Secretary of Commerce, through the NBS, is required to develop physical and chemical properties of recovered materials with regard to their use in replacing virgin materials. In the case of recycled oil, this work was authorized by Public Law 94-163 and is already under way at the NBS. The Secretary of Commerce is also required by the Act to encourage the development of new markets. Section 6002 of the Act requires federal agencies to procure products containing the highest practical percentage of recycled materials unless they fail to meet performance standards or are unreasonably priced. The recycled product need not even be priced competitively to virgin materials in order to obtain a procurement contract. This is significant since, at equivalent quality levels, a re-refined motor oil may exceed the cost of virgin lube oil.

To further encourage the use of recovered products, certain federal specifications must be modified to eliminate exclusion of recycled materials; those requiring manufacture from virgin sources must be re-written to encourage the maximum use of recycled materials. Federal utilization of recycled oil would do much to stimulate its market. This stimulus would go beyond federal purchases if a recycled oil could be qualified to a Mil-Spec since many agencies, state and local, as well as in the private sector, make use of Mil-Specs when purchasing materials. This tendency is somewhat natural in that the procuring office is taking little personal risk of obtaining an unsatisfactory product.

In summation, the two Acts should serve to remove current institutional and economic barriers to marketing re-refined oil. The principal steps to be taken are as follows:

a. Settle the quality issue of re-refined lube oil versus virgin oil.
b. Remove labeling requirements that connote an inferior product.
c. Make feedstock available and at a lower cost.
d. Provide a captive market in terms of federal agencies.

## 9.3 REFERENCES

9-1 Engine Service Classifications and Guide to Crankcase Oil Selection, Sixth Edition, Publication 1509, American Petroleum Institute, Washington, D.C. (September 1974).

9-2 Smalheer and Smith, Lubricant Additives, Lexius-Hiles Company, Cleveland, Ohio (1967).

9-3 Workshop on Measurements and Standards for Recycled Oil, National Bureau of Standards, Gaithersburg, Maryland (22-23 November 1976).

9-4 Fuel and Lubricant Test Capabilities, Lubrizol Corporation, Cleveland, Ohio (1975).

9-5 Schedule of Engine Evaluation Fees, 1977, Southwest Research Institute, Division of Engines, Fuels and Lubricants, San Antonio, Texas (1977).

9-6 Multicyclinder Test Sequences for Evaluating Automotive Engine Oils, ASTM 315F, American Society for Testing and Materials, Philadelphia, Pennsylvania (January 1973).

9-7 Automotive Engine Oils: What They Are and How They Work, Marketing Services Division, Chevron Research Corporation, Richmond, California (1975).

9-8 Personal communication: Dr. E. W. Nommensen, Exxon Oil Company, Houston, Texas (30 November 1976).

9-9 Personal communication: P. Bennett, ASTM Engine Test Monitoring Center, Pittsburg, Pennsylvania (10 January 1977).

9-10 Personal communication: F. Sam, Chevron Research Company, Richmond, California (21 October 1976).

9-11 Personal communication: T. Bowen, U.S. Army Fuels and Lubricants Laboratory, Ft. Belvoir, Virginia (9 November 1976).

9-12 Personal communication: D. Becker, National Bureau of Standards, Gaithersburg, Maryland (9 November 1976).

9-13 J. Reynolds, M. Whisman, and C. Thompson, *Engine Sequence Testing of Re-refined Lubricating Oils,* Preprint BERC/OP-76/29, Bartlesville Energy Research Center, Bartlesville, Oklahoma, (8 October 1976).

9-14 "Waste Oil Study," Report to Congress, U. S. Environmental Protection Agency, Washington, D.C. (April 1974).

9-15 "Used Oil Law in the United States and Europe," PB-239449, Environmental Law Institute, Washington, D.C. (July 1974).

9-16 Public Law 94-163, "Energy Policy and Conservation Act," (22 December 1975).

9-17 Public Law 94-580, "Resource Conservation and Recovery Act Of 1976" (21 October 1976).

# SECTION 10

# COMBUSTION OF USED OIL

## 10.1 COMBUSTION OPTIONS

The heat content of used oil can be recovered by using it as a fuel. Several combustion options are available, such as blending with a fuel oil and mixing with coal. Used oil and virgin fuel can be burned separately in the same furnace, using "separate burners". Another option is the burning of used oil without dilution by a virgin fuel. The latter option is usually not exercized because sufficient quantities of used oil are generally not available to allow its use as a primary fuel. However, small heating installations which have a ready supply of used oil, such as truck service centers, have been operated on used oil only.

When used as a supplement to virgin fuel oil, the two fuels are generally blended together prior to burning. Blend ratios are dependent on a number of factors: (1) the available supply of used oil, (2) the ability of the equipment to handle a fuel mixture with characteristics different from those for which it was originally designed, (3) the tendency toward buildup of deposits, and (4) the local emission regulations.

In the case of coal combustion, used oil is sometimes applied with the intent of reducing dust problems associated with coal handling. However, the more common method of burning used oil in a furnace involves misting of the oil over the burning coal.

Some installations are set up to burn used oil and virgin fuel oil separately. These installations make use of two burners: one for the used oil and one for the virgin fuel oil. Reference 10-1 describes an installation using a low-pressure burner for the used oil and a high-pressure burner for No. 2 fuel oil. This type of arrangement illustrates the attempt to use equipment best suited to the individual characteristics of each fuel.

## 10.2 CHARACTERISTICS OF FUELS

### 10.2.1 Fuel Oil

Fuel oils range from light distillates to heavy residuals and are generally liquid at ambient temperatures, although heavy residual oils can be almost solid, requiring preheating before burning. The American Society of Testing and Materials (ASTM) has developed standard specifications for fuel oils. Of all the fuel oil types, No. 2 and No. 6 oil are the most widely used.

Heat content available from fuel oil is related to its density, which is usually measured in American Petroleum Institute (API) degrees. The API degree is inverse to specific gravity. A low API gravity number indicates an oil with a high specific gravity. Table 10-1 shows fuel oil heat content as a function of gravity. As indicated, the heat content per pound of fuel increases with increasing API gravity number. On a gallon basis, the heat content decreases. A graphical presentation of the relationship between density and heat content (higher heating value) is shown in Figure 10-1 (Ref. 10-3).

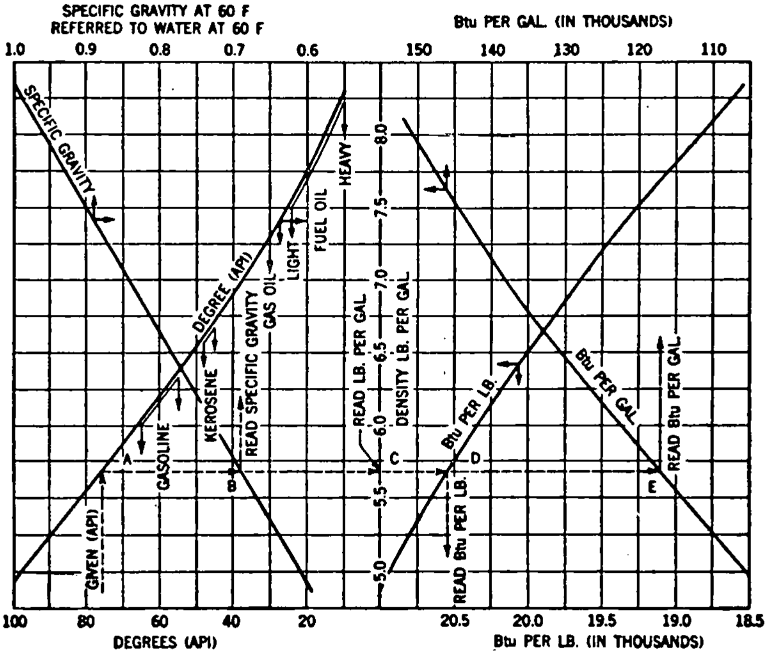


Figure 10-1. Chart Showing the Relationship Between Several Important Characteristics of Liquid Fuels (Ref. 10-3)

Physical properties of No. 2 and No. 6 fuel oils are shown in Table 10-2. These data show a range of values for each property and are intended to reflect the actual characteristics of fuels produced.

## Table 10-1. Gravities, Densities and Heats of Combustion of Fuel Oils (Ref. 10-2)

| 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 | 132,000 | 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 |

### 10.2.2 Used Oils

Used oils are a hetrogeneous group: crankcase oil, hydraulic oil, cutting oil, and others. The most readily available used oil is crankcase oil, which is also the most likely type to be used as a fuel. Properties of used crankcase oil are shown in Table 10-2.

Table 10-2. Properties of Virgin Fuel Oil (No. 2 Distillate and No. 6 Residual) and Used Oil (Automotive Crankcase Drainings) (Ref. 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 | - | 87 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 | 8 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 %.

### 10.2.3 Coal

Properties for bituminous, subbituminous, and lignite coals are presented in Table 10-3. As shown, coal contains considerably higher amounts of certain trace metals than residual and used oils do. The principal trace metals in coal are aluminum, beryllium, boron, calcium, iron, magnesium, manganese, molybdenum, nickel, silicon, silver, sodium, sulfur, strontium, titanium, and vanadium. Except for lead and phosphorus, substituting waste oil for a portion of the coal reduces trace metal emissions. However, the lead emissions are of considerable concern as a hazardous pollutant.

Table 10-3. Properties of Coal: Bituminous Subbituminous, and Lignite (Ref. 10-4)

| Property[a] | Composite Range Values | | |
|---|---|---|---|
| | Bituminous | Subbituminous | Lignite |
| Fixed Carbon, wt % | 39 to 86 | 38 to 40 | 31 |
| Volatile Matter, wt % | 14 to 40 | 28 to 34 | 28 to 59 |
| Moisture, wt % | 2.6 to 20.6 | 16.5 to 24.6 | 34.8 |
| Heating Value, Btu/lb | 9,171 to 15,800 | 8,300 to 11,500 | 6,300 to 14,300 |
| Sulfur, wt % | 0.5 to 5.0 | 0.4 to 2.1 | 0.7 to 1.1 |
| Ash, wt % | 3.0 to 18.0 | 3.8 to 11.2 | 5.0 to 12.8 |
| Silicon, ppm | 9,818 to 38,500 | 7,390 | 4,180 to 25,000 |
| Calcium, ppm | 527 to 15,009 | 12,300 | 16,100 to 21,300 |
| Sodium, ppm | 293 to 645 | 98 | 74 to 1,921 |
| Iron, ppm | 3,230 to 25,703 | 5,080 | 2,100 to 5,910 |
| Magnesium, ppm | 190 to 2,533 | 1,590 | 603 to 5,271 |
| Lead, ppm | 4.5 to 137 | - | 8.9 to 89 |
| Vanadium, ppm | 19 to 41 | 0.8 to 44 | 8.9 to 89 |
| Copper, ppm | 23 to 105 | 1.5 to 53 | 8.9 to 89 |
| Barium, ppm | 53 to 462 | - | 132 to 134 |
| Zinc, ppm | 45 to 200 | < 525 | 8.9 to 35.8 |
| Phosphorus, ppm | 20 to 40 | - | 50 |
| Tin, ppm | 0.4 to 550 | 1.5 to 7.5 | - |
| Chromium, ppm | 20 to 28 | - | - |
| Nickel, ppm | 13 to 189 | - | - |
| Beryllium, ppm | 0.1 to 31 | - | - |
| Manganese, ppm | 13 to 189 | - | 131 |
| Silver, ppm | 0.5 to 2.9 | - | - |
| Strontium, ppm | 95 to 935 | - | - |
| Aluminum, ppm | 5,557 to 19,448 | 6,935 | 4,691 |
| Titanium, ppm | 315 to 1,574 | 188 | 102 to 782 |
| Boron, ppm | 8.4 to 101 | - | 185 |
| Molybdenum, ppm | 3.2 to 28 | - | - |

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

Many coal-burning facilities are required to utilize emission control devices, such as electrostatic precipitators. A properly designed and maintained precipitator is capable of an order of magnitude reduction in the emission of submicron particles. These devices should be capable of entrapping lead as well. Based on this brief review of used oil combustion with coal, it appears that this option may be the best fuel utilization for used oil. However, few data are available relative to the combustion of used oil with coal. A 6-day test performed by Northern States Power Company in 1973, using 6 percent of the heat input in the form of crankcase drainings, indicates that crankcase oil could be burned with no detectable increase in stack lead emissions. However, a precipitator was used in these tests (Ref. 10-4).

### 10.2.4 Blends of Used Oil and Fuel Oil

Properties of blends of used oil and fuel oils vary as a function of the blend ratio. All properties except viscosity may be considered a linear function of the two constituents. Viscosity may be determined from the chart shown in Figure 10-2.

The heating value of the used oil and feed oil blend for either No. 2 or No. 6 fuel oil declines as the used oil fraction increases. On average, the heat content of used oil is lower than for virgin fuel oils because of the higher water content of used oil.

## 10.3 EQUIPMENT REQUIREMENTS

### 10.3.1 Storage and Blending

The basic equipment requirements for storage and blending of used oil with virgin fuel oil are similar to those for storing residual fuels. Depending on size, storage tanks may be outdoors or indoors and above or below ground. Examples of these tanks are shown in Figure 10-3.

Two approaches may be taken for blending these oils. One approach is based on the use of tanks for each oil. Blending occurs on a continuous basis, as the fuels are being consumed, by use of a proportioning valve in the lines that connect each tank to the burner. The other approach is to mix the oils in the same tank. Best mixing occurs when both oils are loaded into the tank simultaneously. Heating coils are desirable to provide convective current mixing and prevent separation.

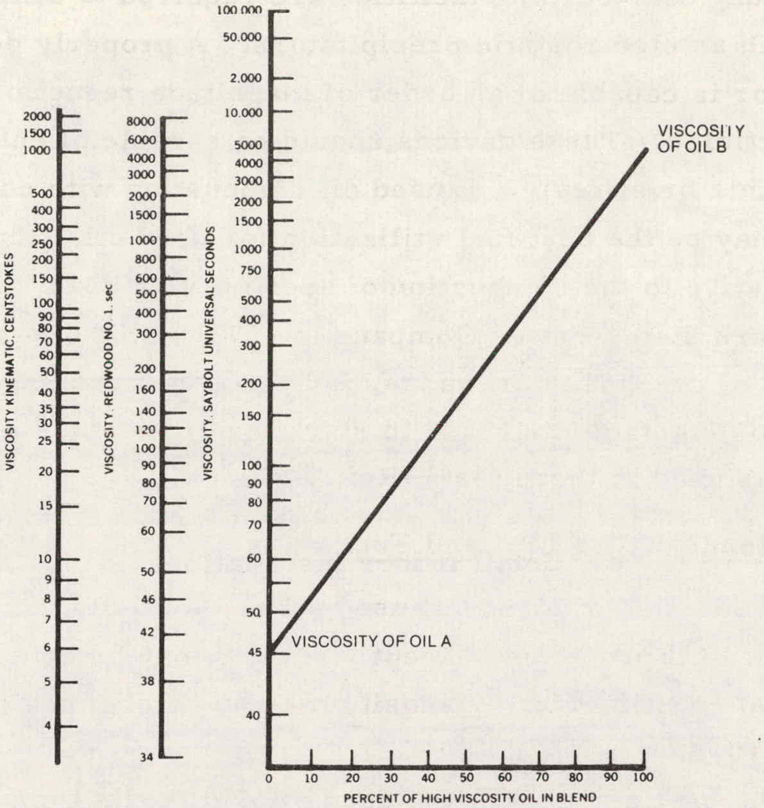
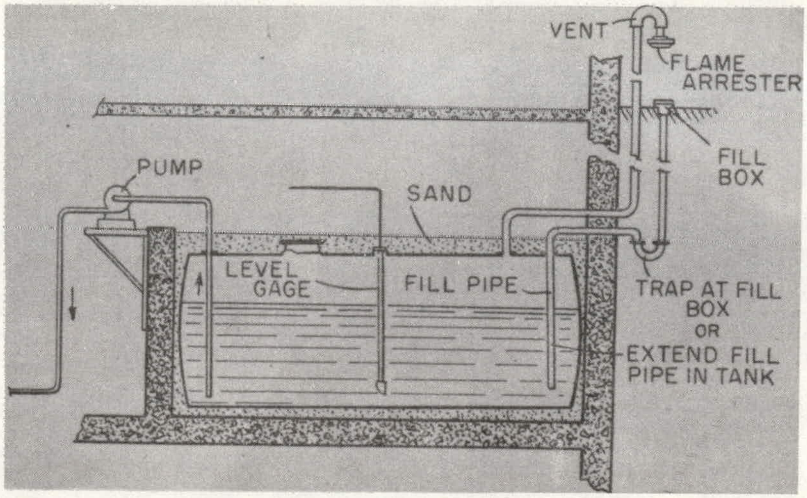


Figure 10-2. Viscosity Chart for Oil Blends (Ref. 10-2)

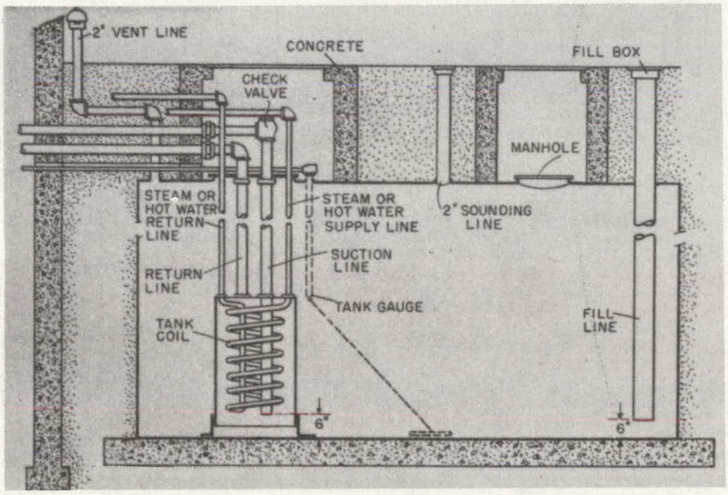
### 10.3.2 Burners

A variety of burner types are currently in use, including gun burners (high- and low-pressure designs), rotary burners, and burners using either high-pressure mechanical atomization or steam atomizers. The capacity of these burners ranges from 3 to 1000 gallons per hour.

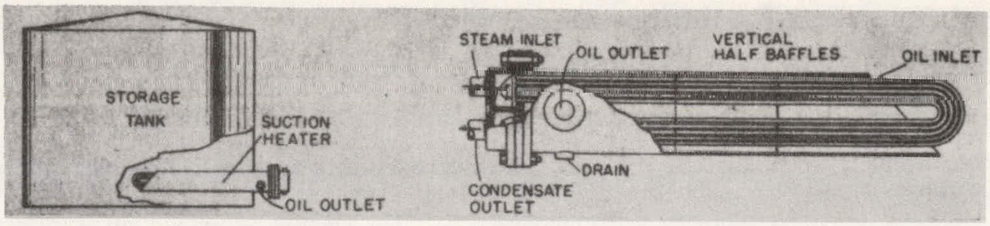
In a gun burner, a rotary fuel pump delivers pressurized fuel to a fixed orifice nozzle, which produces a whirling conical spray. Low-pressure air supplied by a squirrel cage blower is swirled concentrically with the fuel spray to provide good combustion. Ignition is provided by high-tension electricity and a spark gap located just outside the fuel spray. Gun burners generally



a. Small Indoor Installation



b. Medium Sized Outdoor, Below Ground, Installation



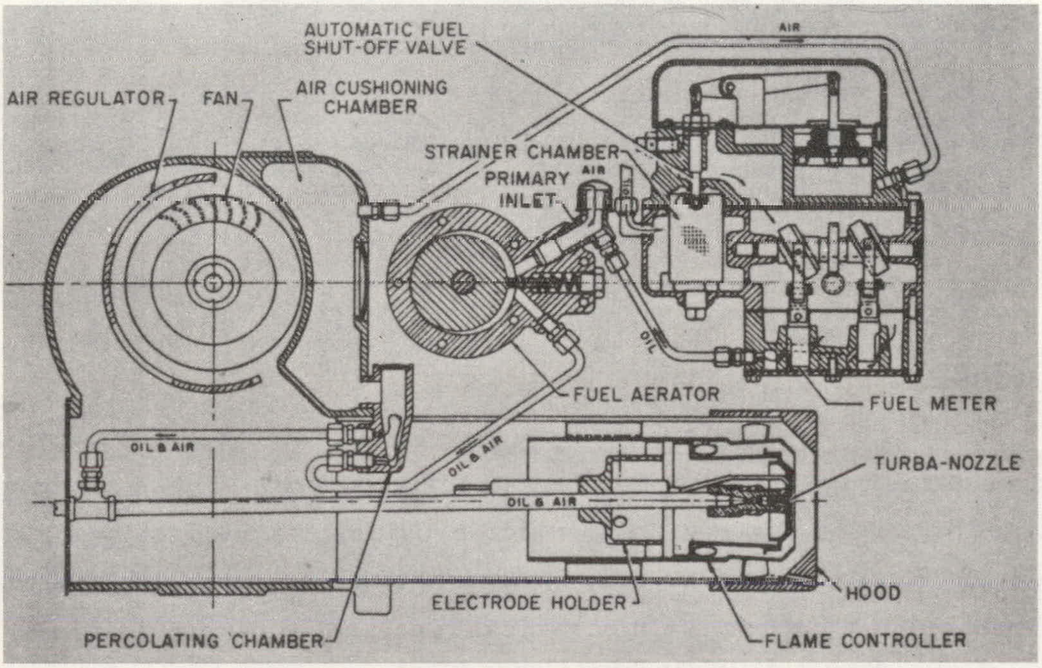
c. Large Outdoor Tank

Figure 10-3. Oil Storage Tanks (Ref. 10-2) operate at a fixed firing rate. Heat demand is satisfied by an on-off operation. A typical gun burner is shown in Figure 10-4.

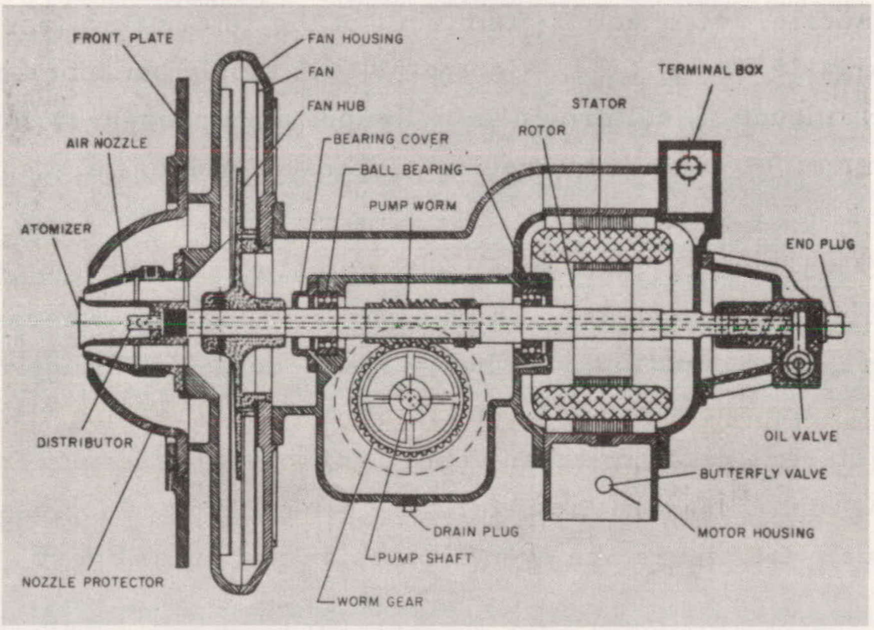
Rotary burners or cup burners are similar to gun burners in several ways. The main difference is that the fuel spray is produced by a rotating conical cup, which slings the fuel outward. An electrically ignited gas flame is usually used to provide ignition. Rotary burners are amenable to controllable firing rates by simple regulation of the fuel flow rate into the rotating cup. The atomizing mechanism of these burners is only dependent on the rotary speed of the cup. A typical rotary burner is shown in Figure 10-4.

High pressure mechanical and steam atomizers are components of burner systems used in larger installations. These atomizers are located in a wind box register, which provides the necessary air for combustion. These atomizers rely on high pressures, about 150 psi for the steam type and 300 psi for the mechanical type, and suitably designed nozzles to provide the desired atomization and spray patterns. To assist the nozzle in the atomization process, the steam atomizer uses a separate stream of steam, which meets the fuel oil just prior to entering the nozzle. Mechanical atomizers of the return flow type are capable of variable firing rates. Control of fuel supply backpressure regulates the amount of fuel provided by the primary pressure. Firing rate variations of 5 to 1 are obtainable. Typical atomizers are shown in Figure 10-5.

Gun burners which are used in smaller installations can handle fuel oils with a viscosity as high as a No. 4 fuel oil, whereas rotary burners are compatible with heavy fuels, up to No. 6 fuel oil. However, since the spray pattern deteriorates with increasing viscosity, some manufacturers recommend an upper limit of fuel viscosity for their burners. The high-pressure atomizers are generally used for heavy fuel oils. Steam atomizers are even capable of burning refinery acid sludge.



a. Gun Burner



b. Rotary (Cup) Burner

Figure 10-4. Fuel Oil Burner Types (Ref. 10-2)

No specific burner modifications are required for the combustion of used and virgin oil blends, provided the viscosity of the blend is within the requirements of the burner. Blending of used oils with heavy fuel oils generally results in a lower viscosity rating. For reduced viscosity, heavy fuel oils are usually preheated before combustion. Recommended operating viscosity ranges for the different burner types are shown in Table 10-4, and the effect of preheating on oil viscosity is presented in Table 10-5.

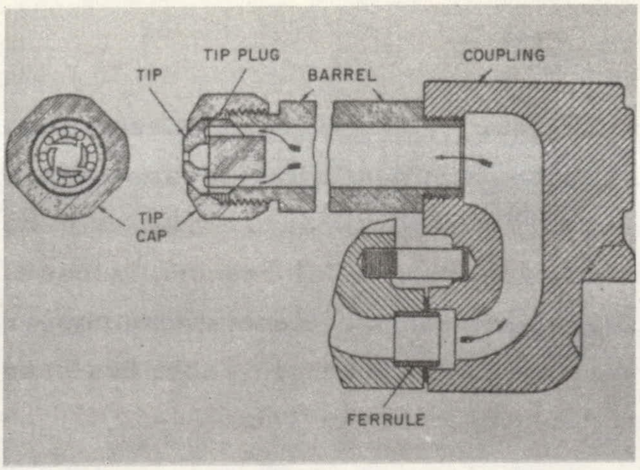
Table 10-4. Recommended Fuel Viscosities For Various Types of Burners

| Burner Type | Recommended Fuel Viscosity, SUS |
|---|---|
| Low Pressure | 85 to 100 |
| High Pressure | 125 to 150 |
| Steam | 150 to 200 |
| Rotary | 200 to 250 |

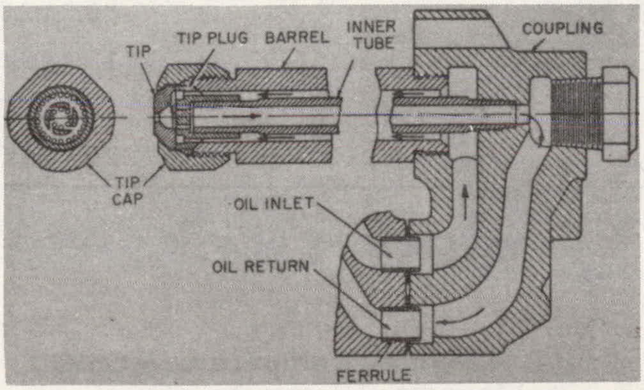
Table 10-5. Effect of Temperature On Oil Viscosity (Heavy No. 6)

| Temperature, °F | Viscosity, SUS |
|---|---|
| 130 | 1250 |
| 140 | 850 |
| 180 | 220 |

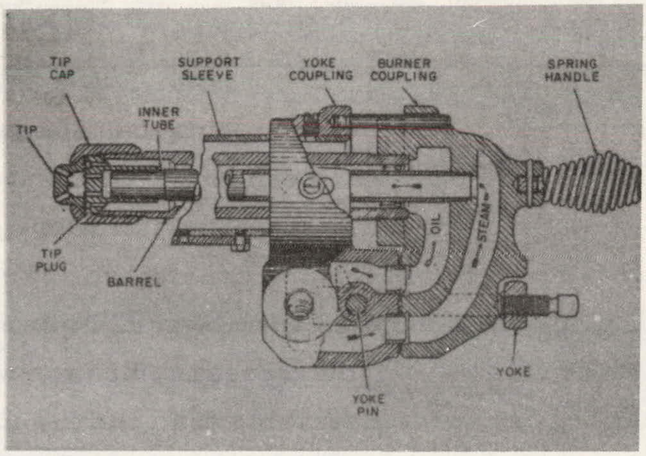
For heavier fuels, blending with used oil imposes no viscosity problem and generally results in lower preheating requirements. For the light fuels, typically used by small noncommercial installations, the most commonly used burner is the gun type with preheating provisions. For these units, the used oil to No. 2 fuel oil ratio should be less than 0.25 to maintain a sufficiently low blend viscosity. In this case, a low-pressure burner, which requires a larger nozzle orifice size, is more desirable than the high-pressure type



a. Straight Flow Mechanical Atomizer



b. Return Flow Mechanical Atomizer



c. Steam Atomizer

Figure 10-5. Atomizer Types (Ref. 10-2)

because particulates and sludge which might be contained in the used oil are more readily passed without causing nozzle fouling. To prevent clogging of fuel lines and burners, used oil should not be burned in small units; i.e., of less than about 3 gallons per hour throughput.

### 10.3.3 Furnaces

No specific furnace design requirements have been identified relative to burning used oil. The feasibility of combusting used oil in a given furnace is generally established in actual trial runs. While specific design requirements have not been identified, furnace configuration represents the main factor in the determination of the amount of ash emitted from the stack as compared to the amount deposited within. In combustion tests performed by Exxon (Ref. 10-5), a four-pass fire tube boiler was used, which proved to be susceptible to fouling. The large number of heat exchanger tubes contained in large steam generating boilers causes concern regarding possible corrosion and fouling as a result of used oil utilization.

## 10.4 COMBUSTION PROBLEMS

### 10.4.1 Explosion

The most serious problem associated with burning used oil is related to the potential occurrence of combustion instability and the associated danger of an explosion. While the probability of occurrence is believed to be low, an explosion attributed to burning used oil with a low flash point occurred in 1958 in a meat packing plant in Nebraska. Subsequently, the Nebraska state legislature passed a law requiring the flash point of used oil burned in furnaces to be greater than 60°F. This law also specifies a maximum combined water and solids content of 1 percent.

### 10.4.2 Fouling and Corrosion

During combustion, used oil ash constituents form various metal oxides, which may be emitted from the stack as particulates or form corrosive deposits on furnace walls and heat transfer surfaces. This results in a degradation of the heat transfer (thermal) efficiency, causing increased stack flue gas temperatures and lower heat transfer surface temperatures. Moreover, flue gases passing through the porous ash surface may be subcooled, dropping below the dew point temperature and hence, encouraging corrosion.

In utility boilers, the ash deposits are periodically removed to maintain boiler efficiency and inhibit corrosion. A burning test performed by American Oil Company showed furnace deposits equal to 6 months of normal operation after 1 week of burning a 40/60 used and residual oil blend. Combustion tests with used and virgin oil fuel blends performed by Exxon indicated considerable boiler fouling after only 2 hours of operation (Ref. 10-6). Conversely, utilization of used oil over the past several years (concentrations up to 7 percent) in a 55-megawatt power plant showed no boiler deterioration or unusual maintenance problems (Ref. 10-7).

### 10.4.3 Erosion and Other Combustion Problems

The sedimentary material in waste oil is characteristically abrasive, leading to burner nozzle tip erosion and damage of pump seals. Generally, re-refiners have experienced low durability of the pumps used to transport used oil in the plant. Normally, a pump life of 6 months is obtained, compared to 5 years for pumps in other applications. Burner nozzle tip life has been estimated to be 6 months when spraying used oil blends, compared to a normal service life of 3 years (Ref. 10-4). With used oil blends, large amounts of sedimentary material are deposited in filters and strainers, requiring a substantial increase in the frequency of cleaning these components. While this procedure prolongs equipment life, it increases maintenance costs (Ref. 10-4).

Another potential problem related to combustion of used oil is the high water content of untreated used oil, which can result in a number of undesirable conditions, including fuel line freezing in cold weather operation, aggravated heat release rate fluctuations, and flame-out, particularly in smaller units.

## 10.5 ENVIRONMENTAL CONSIDERATIONS

### 10.5.1 Particulates

Particulate size is determined by reactions of the used oil ash constituents during combustion and subsequent secondary reactions between the ash particles formed and the gas stream. At the high temperatures existing in the flame zone, lead, zinc, and other trace metals undergo secondary reactions forming volatile species, which subsequently condense and appear in the flue gas as submicron particles. Other species such as calcium and phosphorus may melt and fuse within the oil droplets during combustion. After the hydrocarbons contained in the droplets are completely consumed, ash skeletons remain. Particle size distributions for the six predominant particulates emitted during the combustion of used oil are listed in Table 10-6. It is interesting to note the predominance of submicron-size lead particles (Ref. 10-6).

Table 10-6. Particle Size Distribution of Lead and Other Major Contaminants in Emissions from Waste Oil Combustion (Ref. 10-6)

| 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 |

The particulates formed in the combustion process are either emitted from the stack or retained within the boiler. Reference 10-6 postulates thermal diffusion as the mechanism for the distribution of these particulates, with the temperature difference between the gas stream and heat exchanger surfaces providing the driving force. Maximum particulate deposits occur at the locations of maximum temperature differential between the boiler surface and the flue gas.

### 10.5.2 Toxic Trace Metal Emissions

Of all the trace metal particulates emitted, lead is of principal concern with regard to health effects. The determination of the actual amount of lead emitted from combustion of used oil has been the subject of a number of tests. In general, it appears that less than 50 percent of the lead content exits the stack. This estimate is for flue gas transport without a downstream collection or control system. Of course, trace metal emissions would be reduced if used oil were burned only in plants containing control equipment.

Ambient air lead concentrations have been estimated in the vicinity of 11 coal-fired power plants which, it had been assumed, were converted to burn 100 percent used oil, with all of the particulates emitted from the stack (Ref. 10-8). As shown in Table 10-7, even in this extreme case, most plants were able to meet a proposed EPA lead emission standard of 5 micrograms per cubic meter. Some plants can even meet the California standard of

Table 10-7. Estimated Ambient Air Lead Concentrations Near Waste-Oil-Burning Power Plants (Ref. 10-8).

| Plant | Megawatt Equivalent | Maximum 90-Day-Average Lead Concentrations, $\mu g/m^3$ | | | |
|---|---|---|---|---|---|
| | | Jan to Mar | Apr to Jun | Jul to Sep | Oct to Dec |
| Lake Shore | 514 | 3.2 | 2.8 | 4.6 | 3.3 |
| North Oak | 500 | 2.3 | 3.0 | 3.5 | 2.8 |
| Ottawa | 82 | 0.4 | 0.3 | 0.3 | 0.2 |
| Philo | 500 | 4.3 | 6.3 | 3.3 | 3.0 |
| Miami Fort | 893 | 3.7 | 5.8 | 4.5 | - |
| Edgewater | 193 | 1.0 | 1.1 | 1.2 | 1.1 |
| Owensboro | 53 | 1.0 | 2.3 | 1.6 | 0.5 |
| Frank Ratts | 233 | 1.8 | 3.0 | 3.4 | 1.2 |
| Winon A | 26 | 0.9 | 0.3 | 0.5 | 0.9 |
| French Is. | 25 | 0.9 | 0.6 | 0.7 | - |
| Elmer Smith | 400 | 1.1 | 2.0 | 2.7 | 0.9 |

1.5 micrograms per cubic meter. Ambient air lead concentrations, shown in Table 10-8 for a number of burning tests, indicate substantially lower lead emissions than the above worst-case estimates. All but one of these facilities meet the California lead emission standard.

On a national basis, if all available crankcase oil (625 x $10^6$ gallons in 1975) were burned, a total of 9800 tons of lead would be emitted into the atmosphere per year, compared to about 180,000 tons emitted from automobiles (Ref. 10-9). While this comparison does not imply that lead emissions from burning used oil are satisfactorily low, it provides a perspective as to the relative magnitude of lead emissions from burning used oil. For toxicity reasons, other trace elements emitted in large quantities, including phosphorus and zinc, are also of concern.

### 10.5.3 Other Emissions

In addition to particulates and trace metal emissions, there is concern relative to the emission of polynuclear aromatics (PNA), known carcinogens. Tests conducted at the Bartlesville Energy Research Center indicate

## Table 10-8. Ambient Air Concentrations of Lead Near Various Facilities Burning Waste Oil as Fuel (Ref. 10-8)

| Test Sponsor[a] | Combustion Site | Type of Virgin Fuel | Total Fuel Feed Rate, gal/hr | Waste Oil in Feed, vol % | Lead Content of Waste Oil, wt % | Stack Height, ft | Soot Blowing | Maximum Ground-level Concentration, $\mu g/m^3$ | Concentration Measurement Classification[e] |
|---|---|---|---|---|---|---|---|---|---|
| Gulf Research and Development[b] | domestic oil burner | No. 2 fuel oil | 3 | 27 | 1.1 | 15 | no | 4 | 1-hr average (C) |
| County of Fairfax, VA[c] | hot water boiler | No. 5 fuel oil | 25 | 0 | -- | 27 | no | 0.2 | 24-hr sample (M) |
| County of Fairfax, VA[c] | hot water boiler | No. 2 fuel oil | 25 | 25 | 0.2 | 27 | no | 0.5 | 24-hr sample (M) |
| County of Fairfax, VA[c] | hot water boiler | No. 2 fuel oil | 25 | 50 | 0.2 | 27 | no | 0.3 | 24-hr sample (M) |
| County of Fairfax, VA[c] | hot water boiler | none | 25 | 100 | 0.2 | 27 | no | 0.1 | 24-hr sample (M) |
| Mobil Oil[b] | steam boiler | No. 6 fuel oil | 100 | 5 | 1.0 | 60 | yes | 1.0 | 30-day average (C) |
| Humble Oil[b] | steam boiler | none | 100 | 100 | unknown | 35 | yes | 0.05; (0.65)[f] | short-term sample (M) |
| Shell Oil[b] | steam boiler | No. 6 fuel oil | 374 to 476 | 75 to 100 | 0.5 to 1.0 | 130 | yes | 0.2 | 30-day average (C) |
| Hawaiian Electric Co.[b] | utility boiler | No. 6 fuel oil | 1,900 | 7 | 0.45 | 137 | yes | 0.11 | 1-hr average (C) |
| GCA/Technology Division[d] | municipal incinerator | none | 300 | 100 | 1.0 | 100 | no | 0.2 | 30-day average (C) |

[a] No control devices utilized.

[b] Adapted from Chansky, Steven, James Carroll, Benjamin Kincannon, James Sahagian, and Norman Surprenant, September 1974, Waste Automotive Lubricating Oil Reuse as a Fuel; prepared for the U. S. Environmental Protection Agency.

[c] Fairfax County Public Schools, March 18-April 12, 1974, Waste Lubricating Oil Burning Test, conducted by Fairfax County Public Schools and Fairfax County Health Department, Fairfax County, Virginia.

[d] Chansky, Steven, Billy McCoy, and Norman Surprenant, September 1973, Waste Automotive Lubricating Oil as a Municipal Incinerator Fuel, GCA Corporation, Bedford, Massachusetts, prepared for the U. S. Environmental Protection Agency.

[e] C = calculated; M = measured.

[f] From ambient sampling during soot blowing.

that combustion of re-refined used oil results in higher PNA formation than virgin oil. While this effect is believed to be related to incomplete combustion phenomena, much work remains to be performed to resolve this issue.

## 10.6 POTENTIAL DEMAND FOR USED OIL FUELS

The largest annual consumers of energy in the United States are the industrial and electric generation sectors. In 1975 these two sectors consumed 29.1 and 28.7 percent, respectively, of the nation's energy input (Ref. 10-10). Industrial installations obtained 18.6 percent of their energy requirement from coal, 27.0 percent from petroleum, and the remainder from natural gas, distributed electricity, and hydro power. Although private industrial firms are heterogeneous in character, requiring latitude in fuel logistics and utilization considerations, the option exists for any one industrial location to supplement its coal and oil derived energy requirements with used oil. Electric generation facilities obtained 43.3 percent of their input energy from coal, 16.0 percent from petroleum, and the remainder from natural gas, nuclear power, and hydro power. The trend in recent years with regard to fuels consumed by electric utilities has been influenced by environmental considerations, shifts in fuel availability and price, and legislated requirements such as the Energy Supply and Environmental Control Act of 1974 (ESECA). This trend demonstrates the flexibility of electric utilities relative to fuel switching, indicating that used oil might potentially be used by this industry.

Generally, large electric power plants are located in the vicinity of major metropolitan regions where supplies of used oil are ample, (Ref. 10-4). A regional breakdown of total coal and petroleum consumption, and the amount of used oil generated, is shown in Table 10-9. Although this breakdown represents the total energy consumption, including electrical power plants, an approximation of the amount utilized by the electric power generation sector may be obtained based on the statistic that electric generation accounts for 68.3 percent of total coal usage and 9.9 percent of total petroleum usage (Ref. 10-10). The energy available from used oil, as shown in Table 10-9, is a relatively small and nearly constant fraction of the total energy obtained from coal and petroleum sources.

Table 10-9. Comparison By Region of Energy Available from Used Oil to Total Oil and Coal Energy Consumption 1971 (Ref. 10-4)

| Region | Coal Consumption | | Petroleum Consumption | | Total Energy Consumption, quad | Used Oil Generated | | |
|---|---|---|---|---|---|---|---|---|
| | $10^6$ ton | Quad[a] | $10^6$ gal | Quad[b] | | $10^6$ gal | Quad[c] | Total, %quad |
| New England | 2.5 | 0.06 | 16,900 | 2.41 | 3.01 | 40.2 | 0.0053 | 0.176 |
| Middle Atlantic | 83.4 | 2.08 | 39,200 | 5.60 | 7.68 | 147.6 | 0.0196 | 0.255 |
| South Atlantic | 90.5 | 2.26 | 31,400 | 4.48 | 6.74 | 108.9 | 0.0145 | 0.215 |
| East South Central | 72.4 | 1.81 | 10,100 | 1.44 | 3.25 | 66.6 | 0.0089 | 0.274 |
| East North Central | 188.3 | 4.71 | 33,400 | 4.77 | 9.48 | 240.2 | 0.0319 | 0.336 |
| West North Central | 35.5 | 0.89 | 16,000 | 2.29 | 3.18 | 92.0 | 0.0122 | 0.384 |
| West South Central | 0.4 | 0.01 | 25,500 | 3.64 | 3.65 | 134.9 | 0.0179 | 0.490 |
| Mountain | 21.6 | 0.54 | 8,700 | 1.24 | 1.78 | 44.0 | 0.0059 | 0.331 |
| Pacific | 4.1 | 0.10 | 24,800 | 3.54 | 3.64 | 120.9 | 0.0168 | 0.462 |
| Total | 498.7 | 12.46 | 206,000 | 29.41 | 41.87 | 995.3 | 0.1330 | 0.318 |

[a] Based on 0.025 quad per $10^6$ ton coal.

[b] Based on 0.143 quad per $10^9$ gallon petroleum.

[c] Based on 0.133 quad per $10^9$ gallon used oil.

This distribution indicates that supplies of used oil are regionally available for potential users. Although the available energy from used oil is only about 0.3 percent of the total energy consumption, it amounts to about 1.1 percent of the energy obtained from coal, and to about 1.6 percent of the coal used by electric generating plants, which is not an excessive amount to blend safely as a supplemental fuel.

Section 2 of the Energy Supply and Environmental Control Act of 1974 provides, through the Federal Energy Administration (now DOE), for a coal conversion program to convert electric power plants and major fuel burning installations (MFBI) from oil or natural gas to coal (Ref. 10-11). This program is equally applicable to proposed as well as existing power plants. As of 30 June 1977, the FEA has issued, or has pending, conversion orders covering 322 units at 179 sites for utilities, and 200 units at 90 sites for MFBIs. This conversion program reduces the number of fuel users that can most easily utilize used oil, but adds those plants currently using natural gas to the list of potential users.

Currently, Allied Chemical Company, at its Solvay, New York, plant consumes over 1 million gallons of used oil by mixing it with pulverized coal prior to burning, and by spraying it on coal piles to alleviate the dust problem (Ref 10-4). It appears that the coal conversion program will not impede the utilization of used oil as a fuel, and may even enhance its use as demand for low cost dust pallatives increases.

The current trend of converting power plants to non-petroleum fuels is stimulated by the fact that petroleum products have more valuable applications, such as chemical feedstock. The transportation sector relies almost exclusively on the use of petroleum products, whereas home heating relies heavily on natural gas. For reasons of economics and convenience, and the current absence of alternative liquid and gaseous fuels, these sectors will continue to use petroleum and natural gas in the near to midterm. The preferred feedstock in the petrochemical industry is natural gas. However, the deteriorating natural gas situation in the United States is forcing the industry to turn to heavy feedstocks derived from crude, naphtha and gas oil (Ref. 10-12). It is expected that gas-based petrochemical feedstock will decline to 19 percent by 1990. Conversion of petrochemical feedstock to heavier hydrocarbons implies that used oil may be more readily acceptable for this application in the future. Although chemical feedstock is a small part of the United States energy picture (about 17 billion gallons petroleum equivalent per year in 1973), feedstock derived from waste oil (which amounted to about 1.4 billion gallons in 1975), could be used as a substitute. However, as pointed out in Section 11, the suitability of used oil as chemical feedstock is questionable due to ash forming constituents. Also, it is not known if a source of feedstock that only comprises about 8 percent of demand would be of sufficient interest to the industry to warrant development of techniques for its utilization.

## 10.7 REFERENCES

10-1 Final Report, Task Force on Used Oil Disposal, American Petroleum Institute, Washington, D.C. (May 1970).

10-2 Mobile Technical Bulletin: Heating With Waste Oils, JGW 0-93-007, Mobil Oil Corporation, New York (1970).

10-3 O. de Lorenzi, Editor, Combustion Engineering, Combustion Engineering Inc., Windsor Locks, Connecticut (1953).

10-4 S. Chansky, et al., Waste Automotive Lubricating Oil Reuse As A Fuel, EPA-600/5-74-032, U.S. Environmental Protection Agency, Washington, D. C. (September 1974).

10-5 Waste Oil Roundup... No. 3, Pub. No. 1587, Committee on Disposal of Waste Products, American Petroleum Institute, Washington, D.C. (September 1974).

10-6 G. Chappell, Waste Oil Reprocessing, 6722-41-100-4-73-CR, Exxon Research and Engineering Company, Linden, New Jersey (January 1973).

10-7 Energy From Used Lubricating Oils, 1588, Task Force on Utilization of Waste Lubricating Oils, American Petroleum Institute, Washington, D. C. (October 1975).

10-8 J. Gordon, et al., Lead Emissions from the Burning of Waste Automotive Crankcase Oil, WP-11834, The Mitre Corporation, Washington, D.C. (October 1976).

10-9 J.H. Prescott, "U.S. Oil Refiners Gird for Lead-in-Gasoline Cuts," Chemical Engineering (31 January 1977).

10-10 D.B. Shonka, et al., Transportation Energy Conservation Data Book: Edition 2, Oak Ridge National Laboratory, Oak Ridge, Tennessee (October 1977)

10-11 Coal Conversion Program: Environmental Impact Statement, DES-77-3, U.S. Federal Energy Administration, Washington, D.C. (February 1977).

10-12 "Light Feedstocks Declining Source For Chemicals," Chemistry and Engineering News (7 February 1977).

# SECTION 11

# ALTERNATIVES TO BURNING OR RE-REFINING

## 11.1 CURRENT PRACTICES

### 11.1.1 Road Oiling

In addition to burning, other important applications of used oil are for road oiling and dust control in rural areas. Currently, approximately 10 percent of the total used oil supply is utilized for these purposes. These applications have evolved in the past because used oil was readily available at little or no cost, and re-refiners or other users were often not readily accessible.

The life of used oil in road applications is relatively short in that used lube oils are low in asphaltics and, hence, form a poor bond with the treated surface. As a result, the oil, along with the metallic contaminants, tends to wash away, creating an environmental hazard.

### 11.1.2 Asphalt Manufacture

The manufacture of asphalt represents another application for used oil. Asphalt is manufactured from residual asphaltic or bitumen derived from crude oil refining. This residue is partially oxidized to dehydrogenate and polymerize the molecules. For specific applications, such as preparing macadamized pavement, asphalt is mixed with crushed gravel and a cutting stock (which can be used oil) to provide the correct mixing and handling characteristics (Ref. 11-1). It is generally believed that the metallic contaminants within the used oil are sufficiently coated with asphaltic materials to resist leaching into the environment (Ref. 11-2). Currently, approximately 8 percent of the available used oil is utilized in the manufacture of asphalt.

### 11.1.3 Miscellaneous Uses

Used oil is applied to wooden forms used in concrete construction work to serve as a parting agent. Other uses are in secondary lubricating applications, such as the cutting chains on chain saws (Ref. 11-3) or power chains on farm machinery. Occasionally, used oil is blended with diesel fuel for use in diesel engines. As reported in Reference 11-4, blends of up to 15 percent were evaluated. In general, a 5 percent blend provided the best results.

In these tests, a higher than normal deposit formation was noted, which poses a potential problem area. The specific fuel consumption reduction was less than the increase in the heating value of the fuel resulting from the addition of the lube oil, indicating a loss in combustion efficiency.

Fleet test data for a 3 percent lube oil and diesel fuel blend are presented in Ref. 11-5, indicating a 30 to 40 percent reduction in smoke, accompanied by stable HC and $NO_x$ emission levels. Subsequently, the engine manufacturer approved the use of filtered diesel engine lube drainings blended with diesel fuel. Currently, a one percent blend is used in the Coors truck fleet, which represents the total in-house supply of available used crankcase oil (Ref. 11-5).

## 11.2 POTENTIAL USES

### 11.2.1 Petrochemical Feedstock

Used oil, containing paraffinic compounds represents a potentially valuable feedstock for the petrochemical industry. In the production of ethylene, propylene, butene, and butadiene, which are important compounds for the manufacture of plastics, paraffinic molecules are steam-cracked and reacted to form polymers such as polyethylene and polypropylene (Ref. 11-2).

The ability to process used oils without pretreatment in conventional steam cracking tubular furnaces is questioned because of the presence of ash-forming materials. Phasing down the lead pool in gasoline lowers the ash content of used oil but has no effect on the other ash-forming constituents derived from oil additives. An alternative process based on high-temperature fluidized bed coking has been proposed for cracking untreated used oil. While this process has been used to crack heavy crudes into ethylene and other monomers (Ref. 11-2), no information is available regarding the use of this technique in conjunction with used oil.

### 11.2.2 Synthesis Gas

Used oil may be partially oxidized to carbon monoxide and hydrogen, forming synthesis gas, which is widely used in the production of many industrial chemicals such as ammonia and methanol. Industrial installations producing synthesis gas are equipped with scrubbing systems for the removal of fine carbon particles normally formed during partial oxidation of the hydrocarbon species (Ref. 11-2). Presumably, this system could also remove the metallic ashes formed from the used oil contaminants. The effects of these ash particulates on the hot refractory walls of the reactor are unknown.

### 11.2.3 Refinery Feedstock

Used oil may be utilized as a refinery feedstock, going either to cracking units for the production of light fuels or to lube oil feedstock. The latter use is more natural as the material is already lube oil. To prevent catalyst poisoning by the metallic contaminants of used oil, some degree of pretreatment of the oil might be required. Currently, there are no known refineries which process used oil. In addition to the potential problems associated with catalyst poisoning, the available amount of used oil is probably insufficient to be of interest to the refinery industry.

## 11.3 REFERENCES

11-1 W. Nelson, Petroleum Refinery Engineering, McGraw-Hill Book Company, New York, N. Y. (1958).

11-2 N. Weinstein, Waste Oil Recycling and Disposal, EPA-670/2-74-052, U.S. Environmental Protection Agency, Washington, D.C. (August 1974); prepared by Recon Systems.

11-3 J. Gordon and J. Cioffi, Lead Emissions from the Burning of Waste Automotive Crankcase Oil, WP-11834, The Mitre Corporation (October 1976).

11-4 R. Bechtold and S. Lestz, Combustion Characteristics of Diesel Fuel Blends Containing Used Lubricating Oil, SAE Paper 760132, Pennsylvania State University (February 1976).

11-5 "Coors, A Fleet Brewed to Perfection," Commercial Car Journal, Vol. 129, No. 6 (August 1975).

# SECTION 12

# RESOURCE CONSERVATION

## 12.1 GENERAL

Even if the importance of environmental pollution and the energy conservation aspects of waste oil recovery are discounted, two important considerations remain. First, the oil embargo of 1973 clearly demonstrated the strategic importance of oil and emphasized the value of re-refined oil as a strategic lube oil reserve. This is particularly true since several studies (Refs. 12-1 through 12-5) have projected an increasing future reliance on foreign oil. The second consideration has both longer-term and broader industrial implications. Independent of artificial (embargo) restrictions or wartime seizure of sources, depletion of world crude resources could be catastrophic to many industries including lube oil.

## 12.2 STRATEGIC IMPLICATIONS OF THE RE-REFINING INDUSTRY

Emphasis on the strategic importance of oil is not new (Refs. 12-6 and 12-7), and current attempts to create a national emergency oil storage reserve under Public Law 94-163 underscore those observations. At least two situations can be envisioned in which the re-refining industry would be a valuable national asset: an outright interruption of international oil supplies or a transient but rapid escalation of lube oil demand resulting from military action.

The market supply of lube oil is balanced against demand by increasing or decreasing production and through inventory changes. Historically, the oil industry has done an excellent job of balancing these variables. For many years, capacity has exceeded production and has provided an extra margin of safety. However, recent predictions indicate that between 1978 and 1981 worldwide lube oil demands might begin to overtax the capability of free-world lube production (Ref. 12-8). As shown in Figure 12-1, worldwide production demand has increased at a much faster rate than that of the domestic market. World capacity does not seem to be increasing at a rate adequate to meet demand; therefore, excess United States capacity could gradually be eliminated. Under such conditions, a sudden surge in domestic demand, as for military action, would be difficult to accommodate without

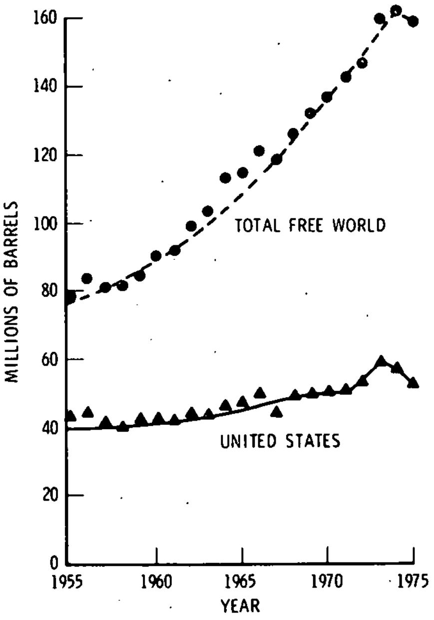


Figure 12-1. Total Free World and United States Base Oil Lubricant Demand (Ref. 12-8)

the extra capacity of a re-refining industry to supply the short fall. A similar but more drastic situation would be a repetition of the previous interruption of foreign oil supplies, perhaps even for a longer period. In that event, the re-refining industry could play a major role in the production of lube oils for transportation and industrial applications.

It has been variously estimated that half of the crankcase lube oil sold could be recovered, re-refined, and reused. Based on the currently predominant acid-clay process, this translates into a potential one-third increase in lube production capacity that could be committed to emergency use. While an adequate collection system would be required to support that capability, the critical element is the re-refining industry itself since, even if the oil were collected, it could not be processed by crude oil refineries without major dislocations in operation. Except for the collection problem, the same situation exists for industrial oil.

In its present condition, the re-refining industry is poorly equipped to respond to a call for emergency support. Most of its facilities are overaged, and there are no large-scale accumulation and collection procedures. In the case of crankcase oil, it is especially doubtful that a consistent supply of feedstock could be provided. If the re-refining industry is to be utilized as a strategic resource, then positive federal actions are necessary to (1) modernize and expand re-refinery facilities, (2) develop a dependable system of used oil collection, and (3) define lube oil base stock quality (not performance) by oil composition independent of source.

Such a supporting structure of advance activities would permit a flexible, rapid response to national emergencies and promote uninhibited interchangeability with virgin lube oil. The re-refining industry is experienced and established, it is widely dispersed geographically, which minimizes output distribution problems during emergencies. Further, it could have provided, at its present capacity level, the entire lube oil purchases of the United States government for the year 1976. During non-emergency periods, it could reduce military lube expenditures on an ongoing basis and perform ancillary public service by removing a large and growing source of environmental pollution while simultaneously conserving a valuable natural resource.

## 12.3 WORLD LUBRICATING OIL SUPPLIES

Various estimates of world crude oil reserves have been made, indicating proved reserves of the order of 600 billion barrels (Refs. 12-9 and 12-10). Petroleum reserves are classified according to the degree of assurance of their existence using the categories "measured, indicated, and inferred," with "measured" being the most certain. "Proved" reserves are the United States Geological Survey estimate of "measured" reserves.

World petroleum consumption in 1973 was 20.7 billion barrels. With no growth, that average consumption implies depletion of reserves in about 30 years. However, growth is probable. The Department of the Interior (DOI) estimates annual world demand for petroleum to be 29.2 billion barrels for 1990. At this compounded growth rate of 2.0 percent, depletion of current world reserves would be expected in 20 years or by 1997.

Although related to total crude supplies, the potential for depletion of lube crude is uniquely different. Importantly, only certain crudes are both chemically suitable as lube feedstock and also give acceptable product yields. Two basic types of crudes are used in the manufacture of lubricating oils: paraffinic and naphthenic. Under current conditions, preference is given to what are termed selected and premium grades. Currently, it is considered only marginally profitable to process a lube crude with less than 10 percent yield, and 18 to 20 percent is desirable. To compound the problem, paraffinic and naphthenic crudes are not equally plentiful.

Appropriate crude oil stocks from all parts of the world are made into what are commonly known as lubricating oil base stocks by various refining methods. These base stocks, both paraffinic and naphthenic, permit the production of lubricants possessing a range of viscosities by means of blending different oils together. The characteristics of some better known base oils are shown in Table 12-1. By tradition, the various paraffinic oils are known by names such as Solvent Neutral, Solvent, and Solvent Bright Stock. Bright Stock is a particularly viscous material as may be seen from the tabulated viscosity. These materials, together with various additives, are used to compound modern lubricants.

Table 12-1. Chemical and Physical Characteristics of Naphthenic and Paraffinic Base Oils (Modified from Ref. 12-13)

| Base Oil | Specific Gravity, 59°F | Color[a] | Flash Point, °F | Viscosity at 122°F, Centistokes | Viscosity Index[b] | Pour Point, °F |
|---|---|---|---|---|---|---|
| PARAFFINIC OILS | | | | | | |
| 100 Solvent Neutral | 0.865 | 1.5 | 392 to 428 | | 95 to 102 | 10 to 5 |
| 150 Solvent Neutral | 0.865 to 0.885 | 1.75 to 2 | 392 to 401 | 19 to 23 | 95 | 5 |
| 200 Solvent Neutral | 0.870 to 0.890 | 2 | 410 | 24 to 28 | 95 | 10 to 5 |
| 350 Solvent Neutral | 0.880 to 0.895 | 3.5 | 419 | 39 to 47 | 95 | 16 |
| 400 Solvent Neutral | 0.880 to 0.895 | 3.5 | 446 to 455 | 46 to 56 | 95 | 16 to 5 |
| 500 Solvent Neutral | 0.880 to 0.895 | 2.5 to 3.5 | 446 to 455 | 57.8 to 62.5 | 95 | 16 to 5 |
| 600 Solvent Neutral | 0.880 to 0.895 | 3.5 | 446 to 464 | 66 to 74 | 95 | 16 to 14 |
| Solvent Bright Stock | 0.890 to 0.920 | 4 to 7 | 527 to 554 | 243 to 290 | 95 | 18 to 14 |
| 350 Solvent | 0.885 to 0.900 | 3 to 4 | 410 | 39 to 47 | 85 | 16 |
| 500 Solvent | 0.895 to 0.925 | 3 to 4 | 392 to 428 | 49 to 57 | 65 to 70 | 10 to 5 |
| NAPHTHENIC OILS | | | | | | |
| V 4.5 | 0.895 to 0.910 | 2 to 2.5 | 374 to 392 | 29 to 35 | 35 to 45 | -13 |
| V 7.5 | 0.900 to 0.922 | 3 to 3.5 | 392 | 55.5 to 61 | 35 to 45 | -5 |
| V 18 | 0.900 to 0.928 | 3.5 to 4 | 464 to 473 | 122 to 137 | 30 to 45 | 16 to 5 |

[a] ASTM method D 1500.

[b] ASTM method D 2270.

When estimates of crude oil supplies and consumption are weighed, the evidence strongly indicates that a policy of conservation, at the international level, is required (Refs. 12-8, 12-10, 12-11, and 12-12).

Improvements in refinery processes and recovery can extend resources, but may result in rising prices. Therefore, an important part of any conservation plan should be the recovery and reuse of oil wherever possible. This suggests that the re-refining industry can also play an important role in overall conservation activities. Throughout the user market, accommodations to the supply shortages are already occurring, and more will be required within the next 5 years. The relative status of paraffinic and naphthenic crudes is discussed below.

### 12.3.1 Status of Paraffinic Crude Oils

Paraffinic-type crudes are used to manufacture high-viscosity index (HVI) oils. These oils are used for motor and bearing-type lubrication. The best domestic United States types are East Texas, West Texas Intermediate, and Pennsylvania. Texas supplies, however, are rapidly declining (Ref. 12-14). Outside the United States, suitable Persian Gulf crudes come from Saudi Arabia, Iraq, Qatar, Iran, Libya, and Algeria. The suitability of newer discoveries, such as those in Nigeria, Indonesia, and Alaska, for lube processing is debatable (Refs. 12-8, 12-12, and 12-14). The estimated production capacity for finished solvent neutral oils in the United States is 137,000 barrels per calendar day, based on the actual crude runs for 1976.

The viscosity index (VI), which is a measure of the change in viscosity with temperature, is an important characteristic for all lubricants which undergo a change in temperature during use. The VI is based primarily on an empirical scale derived from two lubricating oil fractions, one of which originates from a Pennsylvania crude and is arbitrarily assigned a viscosity index of 100; the other is from crude oil from the Gulf Coast which yields a lubricating oil assigned a viscosity index of 0. Higher VIs reflect less viscosity change with variation in temperature. The VI is calculated from the viscosities of these two standard materials at two temperatures, $100^{\circ}$ and $210^{\circ}$F. All other lubricating oils are compared with the viscosity variations of these two standardized reference samples by convention and not for technical reasons.

The VI of typical lubricating oil fractions produced by distillation of crudes varies considerably from source to source. Indexes may range from 0 for the Gulf Coast crudes to over 105 for the Persian Gulf crudes.

The VI of base oil fractions is not as important now as in the prior years because of the ability to use certain additives to impart the desired VI.

With domestic sources of desirable paraffinic lube crude declining, the United States oil industry must either begin development of sophisticated processing methods, such as severe hydrotreating to increase yields from stocks which are currently uneconomical, or bid against rising demand from the rest of the world for Mid-East supplies of the more select stock. A third alternative is to use lower grade United States crude and to increase the amount of additives to yield a compounded product equal to that obtained from a better crude. However, additives already constitute about 17 percent of the volume of a quart of multiviscosity motor oil and 50 percent of the cost (Ref 12-15). More important, the physical limit to the improvements obtainable by more and more additives is not known.

### 12.3.2 Status of Naphthenic Crude Oils

Naphthenic crudes are used to manufacture medium and low viscosity index (MVI and LVI) oils for industrial applications. The future supply of suitable naphthenic crude is even more questionable than that of paraffinic crude. Major domestic sources are the Gulf Coast (the A grade is most desirable) and Smackover Field in Oklahoma. However, beginning in the early 1980s, production is expected to decline. Even now, allowable characteristics are being relaxed from previous levels. Venezuela is the principal source outside the United States but its stock requires desulfurization, and the country is practicing conservation in extraction policies. No major discoveries elsewhere have been of the naphthenic type (Ref. 12-14). Naphthenic crudes are estimated to constitute less than 20 percent of the total supply of free-world crudes. The estimated United States production capacity for finished naphthenic-based lubes is 84,000 barrels per calendar day based on actual 1976 crude runs (Ref. 12-8).

Shell Oil pointed out in 1974 the conflict between rising industrial demand for lube and process oils and the limited supplies of naphthenic-type crudes which possess special characteristics (low pour point and high solvent power), particularly for process use, which are unobtainable from paraffinic stock (Ref. 12-12). In order to reserve naphthenic oils for process use, the domestic industry has been attempting to substitute paraffinic-based formulations for lubrication applications such as metal-working and diesel use.

Successful formulations have been derived for marine diesel lube, some cutting oils, and heat transfer oils. European railroad diesels converted to paraffinic oils years ago, and tests are under way for domestic United States railroads to convert to these oils. It is also possible that intermediate VI fractions of solvent extracts from paraffinic-based oils may be segregated, dewaxed, and hydro-treated to yield a naphthenic-type oil (Ref. 12-8). With the large anticipated growth in the electric utility industry, special attention should be directed toward supplies of electrical transformer oil.

In summary, there is a very real and increasing restriction of available naphthenic crude stock. There are unique lube applications, principally as process and specialty oils, for which only naphthenic is considered suitable. It appears that concerted efforts are necessary to convert all possible current uses of naphthenic-based lubes to paraffinic. Currently, naphthenic-based lubes are selling at about one-fourth less than the price of paraffinic (Ref. 12-16), but because of the increasing shortage the prices of naphthenic-based oils are expected to rise proportionately greater than for paraffinic oils. As with paraffinic oil, a corollary conservation and cost-cutting activity for nonprocess applications would be re-refining. Most lubricant experts believe that industrial oil can be recycled at least 10 times before it has to be discarded. If an oil is purified promptly and contaminants are not allowed to remain in it for long periods of time, its usefulness can be stretched over many years (Ref. 12-17).

## 12.4 REFERENCES

12-1 "Energy Use Rising by 6 Percent in 1977, says Gas Institute," Chemical Market Report (March 1977).

12-2 "U. S. Seen Relying Heavily on Arab Oil," The Oil and Gas Journal (5 January 1976).

12-3 W. G. Dupree, Jr., and J. S. Corsentino, United States Energy Through the Year 2000 (Revised), Bureau of Mines, Washington, D. C. (December 1975).

12-4 Waste Auto Lube Oil Reserves Fuel, EPA 600/5-74032, U. S. Environmental Protection Agency, Washington, D. C.

12-5 Energy Resources Report, Vol. 5, No. 16 (22 April 1977).

12-6 U. S. Energy Outlook -- A Summary Report of the National Petroleum Council, National Petroleum Council Committee on U. S. Energy Outlook (December 1972).

12-7 M. K. Udall, *America's Energy Potential: A Summary and Explanation* (October 1973).

12-8 E. M. Lee, "World Lubricant Supply/Demand -- Its Impact on the United States," Atlantic Richfield Company, Paper presented at the 1976 NPRA Annual Meeting, San Antonio, Texas.

12-9 Richard B. Mancke, *The Failure of U. S. Energy Policy*, Columbia University Press, New York (1974).

12-10 *Energy Perspectives 2*, U. S. Department of the Interior, Washington, D. C. (June 1976).

12-11 A. G. Goossens, R. F. Westerduin, and A. J. Suchanek, "Why Re-Refining of Spent Lubricating Oils," Gulf Science and Development Company.

12-12 C. R. Major and F. E. Winfield, "World Wide Availability of Lubricating Oils," Shell International Petroleum Company, Ltd., Paper presented at the NPRA 72nd Annual Meeting (31 March - 2 April 1974).

12-13 *Waste Oil Recovery Practices -- State of the Art (1972)*, Environmental Quality Systems, Inc., Washington, D. C., NTIS No. PB-229 801 (December 1972).

12-14 Personal communication: Dr. E. W. Nommensen, Exxon Oil Company, Houston, Texas (30 November 1976).

12-15 P. M. Cukor, et al., *A Technical and Economic Study of Waste Oil Recovery, Part III: Economic, Technical and Institutional Barriers to Waste Oil Recovery*, Teknekron, Inc., Berkeley, California (October 1973).

12-16 *Platts Oil Price Handbook and Oilmanac*, McGraw-Hill Book Company, New York (1977).

12-17 R. L. Oliverson, "Methods and Equipment for Inplant Reclamation of Used Lubricants," *Plant Engineering* (29 May 1975).

# PART II

# ENERGY CONSERVATION AND ECONOMICS

## PART II

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## PART II

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# SECTION 1

# INTRODUCTION

Part II is essentially a technical assessment of the economics of producing re-refined oil and of the energy conservation potential of re-refining.

Calculations are made of process energy requirements for re-refining and pretreating used oil, and for the manufacture of virgin lube oil. A detailed comparison is made of the manufacturing cost elements associated with seven processes for re-refining crankcase drain oil. The potential for profitability for re-refining is also examined.

The energy saving potential of used oil utilization is analyzed based on two different scenarios: (1) all used lube oil is re-refined; (2) all used oil is burned.

The major findings of the study are presented with regard to (1) used oil utilization options and their energy saving potential, (2) resource conservation, (3) environmental impact of the utilization options, (4) status of re-refining technology, (5) re-refining economics, and (6) factors governing expansion of the re-refining industry. Finally, recommendations for future DOE action are provided.

# SECTION 2

# PROCESS ENERGY REQUIREMENTS

## 2.1 GENERAL

With the growing awareness in recent years of the finite limits of our natural resources, and particularly energy reserves, a prime objective of this study has been the assessment of the energy saving potential of re-refining used oil relative to its alternative utilization as a fuel. The energy saving potential of re-refining is dependent on the process used for re-refining as well as the energy consumed in producing virgin lube oil. Therefore, the various re-refining processes currently used (of which acid-clay is predominant) or projected by industry were evaluated with respect to their energy requirements. In addition, production of virgin lube oil was addressed, with a refinery processing sequence typical of the industry used to assess energy intensity.

Two categories of energy usage connected with re-refining operations were considered early in the study. The more obvious source of consumption is the thermal and electric energy used directly in the process steps. A second and more indirect area of energy expenditure is associated with such peripheral activities as used oil collection, waste disposal, and the manufacture/transport of process chemicals. This latter category was examined for the acid-clay process and found to be a small energy consumer compared to the direct energy inputs. Consequently, with one exception for caustic treatment, the process energies presented in this section are confined to direct consumption values.

A few caveats are in order regarding the energy analysis for virgin lube oil. First, there is no single processing sequence or set of operating conditions universally descriptive of all virgin lubricating oil refineries. The reasons for this diversity include differences in crude feedstocks and product slates, plant size and age, degree of modernization, and company economics. Consequently, energy calculations have been based on typical, generic processing steps with the expectation that the results are indicative of general industry capability but do not necessarily apply to any one particular facility.

In the case of re-refining, a difficult problem was to define a reliable process yield, which has a major effect on energy requirements. For an existing process that has many practioners (i.e., acid-clay), a consensus yield could be obtained. Where only one or two plants are in operation, the data base for establishing the yield is limited; hopefully, the value selected is typical of the process. For newer processes in development, the only yield data available may have been derived from laboratory glassware experiments and may not be achieved in a full-scale plant; indeed, in some cases, there is a question whether the process will even work in an actual plant.

## 2.2 METHODOLOGY AND ASSUMPTIONS

Process energy inputs consist of heat, steam, and electricity in some combination. However, all requirements have been converted to fuel consumption values. That is, the efficiencies of electricity generation and transmission, steam production in the boiler, and furnace operation have been utilized in converting process energy into ultimate fuel usage values. The conversion factors have been taken primarily from Reference 2-1 and include:

Steam: For re-refining processes, energy equivalent to 1 lb was taken as 1170 Btu. This assumes approximately 100 psia saturated steam is generated, boiler feedwater is at 50°F, and no heat is recovered, all typical of the current re-refining industry. An overall efficiency of steam raising and utilization of 75 percent was applied, giving a conversion factor of 1560 Btu per pound of steam. For virgin lube oil production processes, steam energy was assumed to be 1000 Btu per pound, representing considerable heat recovery. With the same 75 percent generating efficiency, the conversion factor was 1333 Btu per pound of steam.

Electricity: To allow for generating plant and transmission efficiency, 1 kWh was assumed equal to 12,000 Btu.

Fuel: For input fuel requirements in Btu, no conversion factor is needed, of course. However, many data sources give heat requirements in terms of Btu's absorbed by the feed, and it is necessary to allow for the efficiency of the furnace, taken herein to be 75 percent.

Cooling Water: Although usually a minor contribution, cooling water pumping requirements were calculated on the basis of 3.7 Btu per gallon of cooling water circulated.

Energy calculations for each processing option are in units of Btu per barrel. The barrel has been defined in three ways in the presentation of results to permit maximum visibility and reader use. First is "Btu per barrel of charge," which is the energy requirement for each barrel of feed to the specific processing step, regardless of where that step fits in the refining or re-refining sequence. The next definition relates the energy requirement to a barrel of used oil feed to the re-refinery. For an initial process unit, e.g., dehydration, these first two numbers will be identical; for a final operation on the re-refined oil, e.g., fractionation, the second number will be smaller by a factor equal or close to the plant yield. Finally, the energy requirement is expressed in terms of a barrel of final base oil product from the refinery or re-refinery, not including any additives.

A standard used oil feed composition was selected, based on the data in Reference 2-2, representative of automotive crankcase drainings. It consisted of 7 percent water and 4.2 percent fuel dilution (light ends or naphtha). This feedstock was used for all re-refining process calculations. In a few instances noted later, published process data indicated slightly different feed compositions had been used; therefore, minor adjustments in the published material flows were necessary when the standard feed was introduced.

The used oil was assumed to have an average temperature of 60°F prior to processing. No energy requirement has been included for tank farm heating or steam tracing, as these quantities vary with plant location and are dependent upon specific equipment designs and layout. In the same vein, energy expenditures for non-process functions common to all refining and re-refining facilities, such as lighting and space heating/cooling, have been omitted from the calculations.

It is recognized that considerable plant energy conservation is achievable through process and equipment modifications. Usually, such improvements necessitate additional capital investments, e.g., thicker insulation, more heat exchangers, or recovery equipment for combustible by-products. These investments have historically not been feasible for the capital-poor re-refining industry. Indeed, until recently, even petroleum refineries stopped short of all-out energy conservation because fuel was inexpensive. In this study, no special effort has been made to achieve maximum energy conservation. For standard virgin oil process energies obtained from the literature, such as for solvent extraction, it is assumed that some degree of heat recovery has been included. In the case of many re-refining operations, such as dehydration or clay treatment, no energy conservation measures have been provided, closely approximating current practice. Consistent application of this approach should permit valid comparisons between processes even if there is some distortion of absolute values.

Flowsheet schematics for the various re-refining processes are presented in Figures 2-1 and 2-2, which also show operating conditions and material flows for the major steps. It should be noted that fractionation has been included in all processes to provide product base oils of several viscosities. While only a few advanced re-refining processes, and virgin lube production, contain a fractionation step, it has been added in all cases to facilitate comparisons among the several processes.

Energy requirements for some process steps were calculated in this study from simple thermodynamic principles and stream compositions (e.g. dehydration). In other cases, various literature sources were surveyed, compared, and values selected based on consensus or conservatism. The sources used are so specified in the text or tables.

The following subsections discuss the energy calculations for the acid-clay process and several of the more recent options that are either in commercial operation or under study for hardware implementation. A final entry is the energy requirement for manufacturing virgin lube oil, a necessary input in assessing the energy saving potential of re-refining vis-a-vis burning used oil, presented in Section 4.

## 2.3 RE-REFINING PROCESSES

### 2.3.1 Acid-Clay Process

For oil recovery using the acid-clay process, several product yield figures are given in the literature. Reference 2-6 states that "... greater than 70 percent yield is believed to be possible with careful operation, but a typical yield might be closer to 60-65 percent." These figures are based on total plant feed containing 10.5 percent water plus naphtha (light ends). In Reference 2-4, an overall yield of 72 percent was used in the energy recovery calculations (10 percent water plus light ends in the feed).

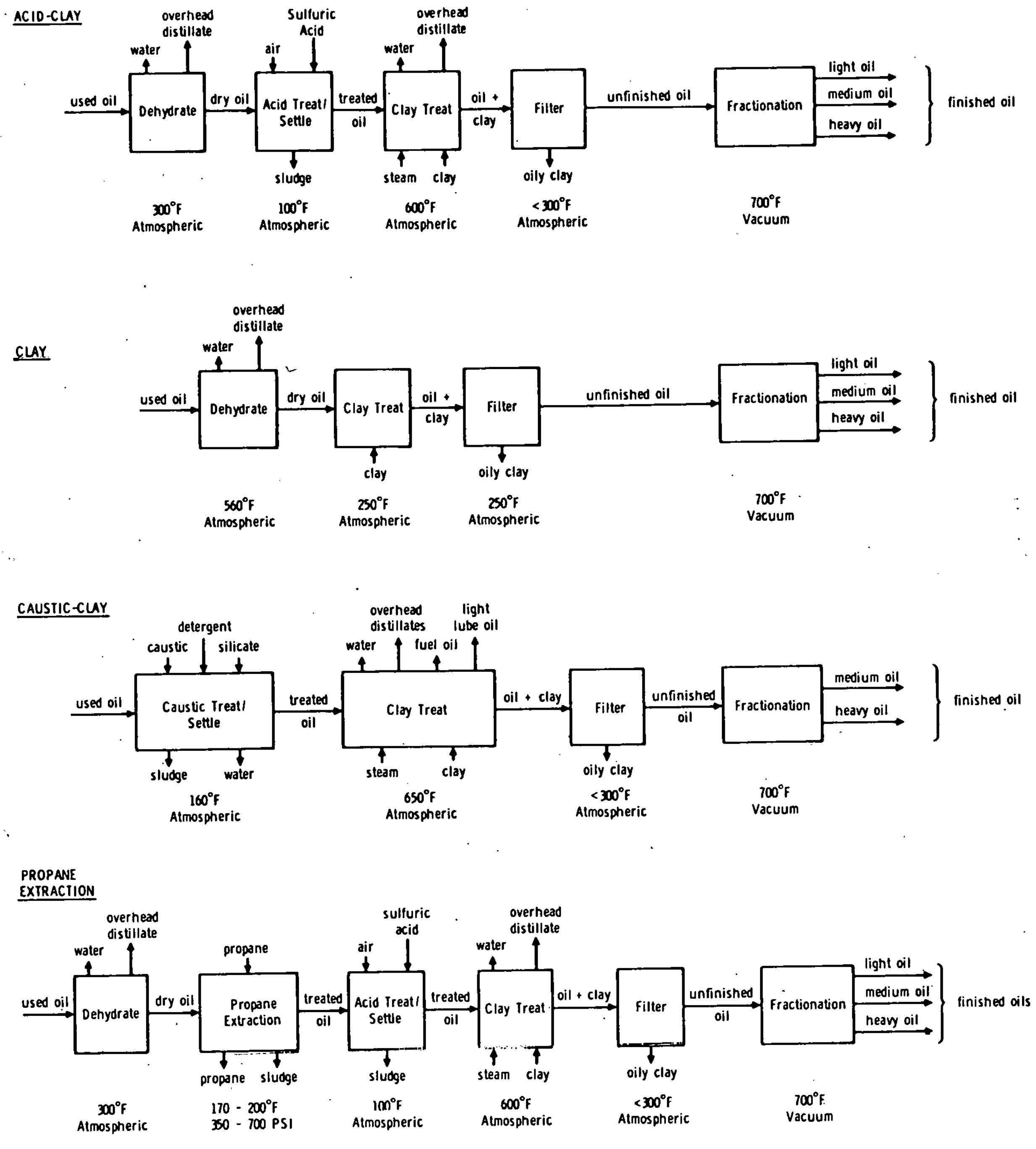


Figure 2-1. Summary of Flow Schemes for Various Lube Oil Re-Refining Processes

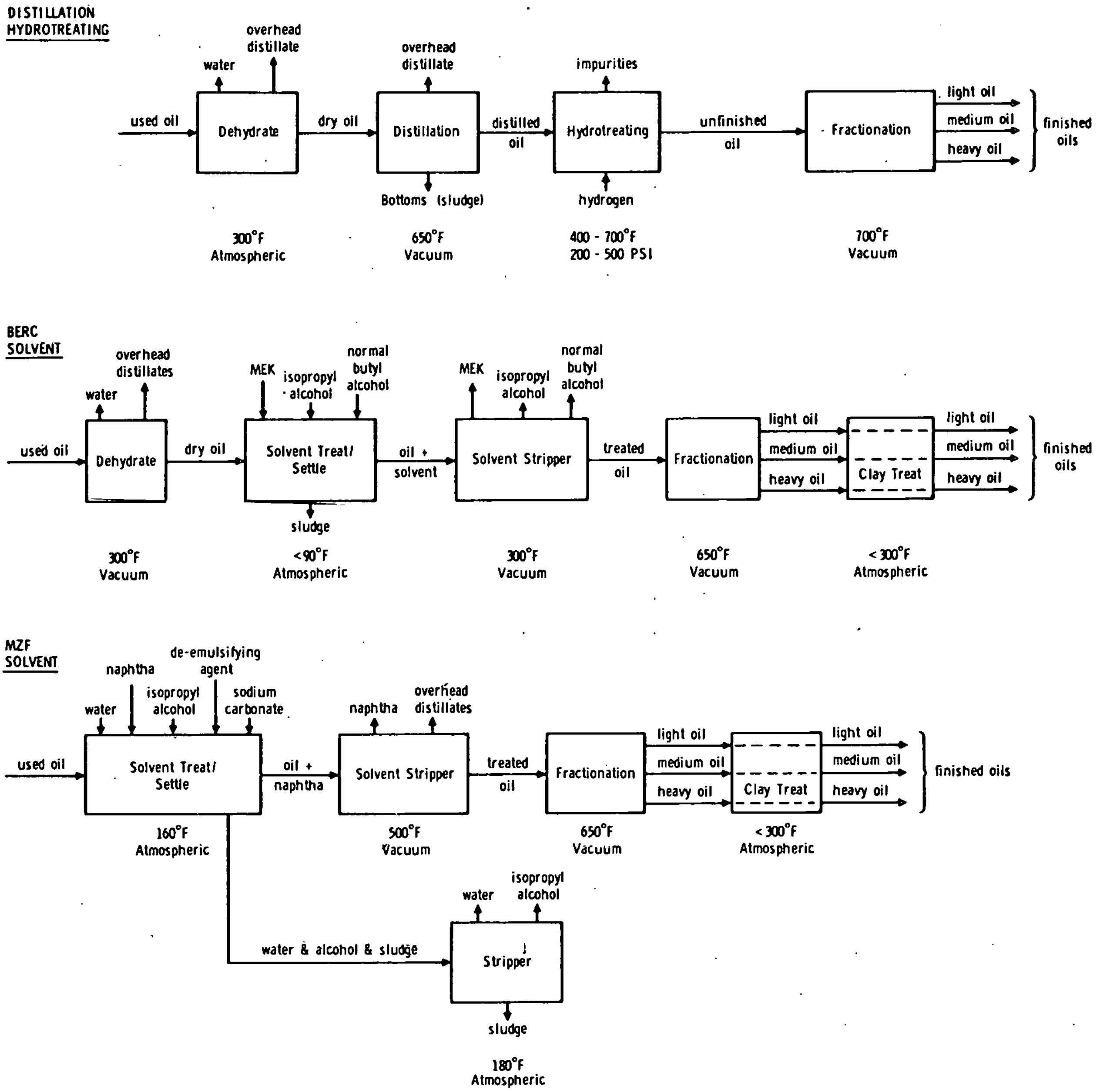


Figure 2-1. Summary of Flow Schemes for Various Lube Oil Re-Refining Processes (Continued)

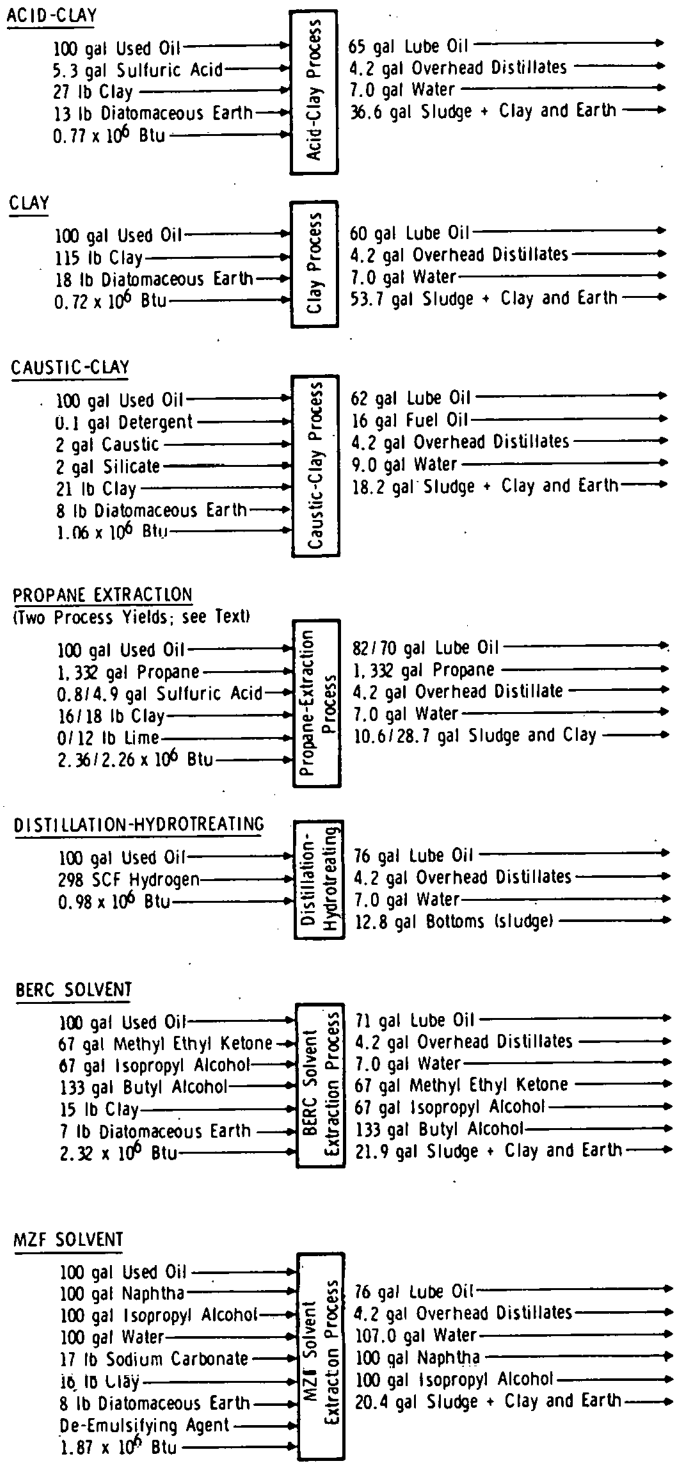


Figure 2-2. Summary of Material Balances for Various Lube Oil Re-Refining Processes

The acid-clay re-refiners contacted during the course of this study quoted overall feedstock yields ranging from 60 percent to 75 percent. A value of 65 percent appears to be near the average and was selected for the energy calculations in this study. For the standard feed utilized in the energy calculations, this value corresponds to a 73 percent yield on the oil content [i.e., 65 ÷ (1 - 0.07 - 0.042)].

The dehydration step primarily involves heating of the feedstock and vaporization of the water and light ends. A small amount of electricity (0.2 kWh) was added for pumps based on data from Reference 2-3. The input fuel energy for dehydration so calculated came to 102,600 Btu per barrel of used oil feed. Inasmuch as most of the re-refining processes start with dehydration, and the feedstock had been standardized, this value was generally applicable for the other processes studied.

Both acid treating, and clay treating with subsequent filtration, require primarily sensible heat inputs, particularly for the 600°F process temperature in the latter step. In fact, clay treating is the largest user of energy of any acid-clay process step.

Although none of the acid-clay plants visited include a product fractionation (vacuum distillation) step, it has been added in the calculations to facilitate later process comparisons. Where so added at the end of a process sequence, no product losses were assumed inasmuch as the purpose of such fractionation was not to remove contaminants. Energy requirements for vacuum distillation of petroleum fractions show a variation in the range from 100,000 to 175,000 Btu per barrel of charge (Ref. 2-3). For the fractionation of lube oils, the value given in Reference 2-1 of 122,300 Btu per barrel of charge appeared to be reasonable and was used throughout these calculations.

The result of this analysis of direct energy inputs to the acid-clay process is a requirement for 321,600 Btu per barrel of used oil feed or 494,800 Btu per barrel of product, based on a 65 percent yield. Two sources were available to obtain a check on the reasonableness of these numbers (Ref. 2-4 and 2-5). Teknekron (Ref. 2-4) used a yield of 72 percent, did not include fractionation, and assumed a slightly different used oil composition. The reported energy requirement was 196,000 Btu per barrel of used oil feed. Adding in the fractionation energy assumed in this study, the Teknekron value increases to 284,000 Btu per barrel of used oil feed or 395,000 Btu per barrel of product.

Energy estimates based on actual plant operations were obtained from Ref. 2-5. Values of 430,000 and 540,000 Btu per barrel of product were given by two plant representatives. These values are based on a 65 percent yield and do not include fractionation. When the 122,300 Btu per barrel fractionation requirement is added in, the above estimates become 552,000 and 662,000 Btu per barrel of product.

These values for the acid-clay process are shown in Table 2-1. It is apparent that there is considerable uncertainty in the energy numbers. Considering the many assumptions that must be made in the calculations, the estimates of this study appear to be in reasonable agreement with other sources.

Table 2-1. Summary of Energy Requirements for the Acid Clay Process

| Data Source | Reported Yield, % | Process Energy | |
|---|---|---|---|
| | | $10^6$ Btu Per Barrel Used Oil Feedstock | $10^6$ Btu Per Barrel Fractionated Product |
| Aerospace | 65 | 0.32 | 0.49 |
| Teknekron[(a)] | 72 | 0.28[(b)] | 0.40[(b)] [(c)] |
| Motor Oils[(d)] | 65 | - | 0.55/0.66[(e)] |

(a) Ref. 2-4.

(b) Adjusted for fractionation.

(c) Value would be approximately 0.44 x $10^6$ Btu, if yield were 65 percent.

(d) Ref. 2-5.

(e) Two values reported; includes adjustment for fractionation.

As mentioned earlier in this section, a brief evaluation was made of several indirect energy inputs to the acid-clay process. In particular, the items examined were sulfuric acid manufacture and transport, clay transport, and sludge hauling for disposal. Average values assumed for movement were (1) acid transported 50 miles by truck, (2) clay shipped 1000 miles by rail, 50 miles by truck, and (3) sludge hauled 30 miles by truck to dump. The total energy involved, including a minor amount for sulfuric acid production, was 12,400 Btu per barrel used oil feed or less than 4 percent of the total requirement of 321,600 Btu. Considering the uncertainty in the figure and its relatively small value, indirect energy was neglected for all processes except caustic treatment.

It should be noted that energy needed for the collection of used oil has also been omitted. To the extent that it can be estimated, the same energy value would have to be added to each used oil process and would serve little worthwhile purpose.

### 2.3.2 Clay Treatment

This is a straightforward process from an energy use standpoint, the primary load comprising the sensible heat to raise the used oil to 560°F and the latent heat of vaporization of the water and light ends. Total process energy, based on a reported yield of 60 percent (Ref. 2-7), was calculated to be 300,800 Btu per barrel of used oil feed or 501,300 Btu per barrel of fractionated product base oil, quite close to the acid-clay values.

### 2.3.3 Caustic Treatment

This process is claimed to have a 78 percent yield if the recovered diesel fuel fraction is added to the lube oil products (Ref. 2-8). The thermodynamic calculations for sensible and latent heat inputs are straightforward and need not be exhaustively treated here. It should be noted, however, that this process is one of two that does not include an initial dehydration step inasmuch as water solutions of caustic and silicate are added in the first mixer/settler tank. The total direct energy requirements are 322,200 Btu per barrel of used oil feed or 413,100 Btu per barrel of product.

However, unlike the other re-refining processes, indirect energy usage is significant here because both the sodium hydroxide (caustic soda) and sodium silicate used in the process require large quantities of energy in their manufacture. Sodium hydroxide is particularly an inefficient energy user because it is made electrolytically; it represents a fuel input of 88,700 Btu per barrel of used oil feed. Sodium silicate usage involves an energy input of 36,200 Btu per barrel of used oil feed. The total requirements for the process are then 447,100 Btu per barrel of used oil feed or 573,200 Btu per barrel of fractionated product.

### 2.3.4 Propane Solvent Extraction Process

The published yield for this process (Ref. 2-9) is 82 percent when slightly adjusted for the standard feed, and this value was used in the initial energy calculations. However, a recent (1977) visit to the operating plant near Milan, Italy, by a representative of the Bartlesville Energy Research Center, provided different data. According to the plant manager, the yield is only 70 percent. In lieu of trying to resolve these differences, energy calculations are reported for both yields.

Although the dehydration, acid and clay treatments, and fractionation steps are similar to those for other processes and relatively simple to calculate for energy usage, propane extraction per se presents several new problems. The extraction step is in reality a rather complex process in itself, involving a number of towers, drums, chillers and compressors, primarily associated with recovery of the propane. In addition, the particular operating conditions selected for used oil re-refining are not known. Thus, detailed energy calculations for each piece of propane extraction equipment were not feasible and another approach was selected.

Nelson (Ref. 2-3) provides energy requirements for propane extraction based on a 9:1 propane to oil volume ratio, viz, 140 pounds of steam, 110,000 Btu absorbed from fuel combustion, 2 kWh of electricity, and 40,000 Btu absorbed in cooling water. Using this study's conversion factors (Section 2-2), the energy input amounts to 390,700 Btu per barrel of oil extracted. However, Weinstein (Ref. 2-6) reports that a 15:1 propane ratio is used. Assuming that energy requirements scale linearly with propane ratio (a reasonable assumption inasmuch as most of the energy needed is for propane recovery and recycle), 651,200 Btu are required per barrel of oil extracted. Remembering that propane extraction is conducted on dehydrated used oil, this energy requirement translates to 578,200 Btu per barrel of used oil feed.

One other new energy consideration must be introduced at this point. Despite an elaborate propane recovery system, a small loss is almost unavoidable. Reference 2-10 reports that the loss amounts to 1.6 lb propane/barrel of oil extracted. This converts to 28,300 Btu per barrel of used oil feed, using a lower (net) heating value for propane of 19,940 Btu per pound.

The total energy input requirement for the 82 percent yield case came to 989,200 Btu per barrel of used oil feed or 1,206,000 Btu per barrel of product. The energy data in Reference 2-9, with the solvent loss of Reference 2-10, indicate a requirement for 904,300 Btu per barrel of used oil feed. The value derived in this study shows agreement within 10 percent, which is adequate for such calculations.

As mentioned above, energy requirements were also calculated for a 70 percent yield. In this case, 948,100 Btu per barrel of used oil feed or 1,354,000 Btu per barrel of product are needed for processing. As will be seen later, this is next to the highest energy requirement of any of the re-refining processes studied.

### 2.3.5 Distillation Process

The Kinetics Technology International (KTI) process, now being implemented in a demonstration plant in Germany, was selected as the basis for the energy calculations. A brief process description, including a claimed yield of 76 percent, was provided in Reference 2-11. The process was approximated by four idealized steps comprising dehydration, distillation, hydrogen treatment, and fractionation. Distillation was assumed to have the same energy requirement as fractionation. Hydrogen treatment was considered to be the same as for virgin lube oil, which is discussed at the end of this section.

The total energy requirement amounted to 412,600 Btu per barrel used oil feed or 542,900 Btu per barrel of product. It should be emphasized that these values do not include any pretreatment steps (other than dehydration) specifically aimed at removing particulates or metal contamination prior to distillation. Furthermore, because of the many process variations in this category, the calculated energy requirements may not correspond to any specific plant but are characteristic of this approach.

### 2.3.6 BERC Solvent Extraction Process

The Bartlesville Energy Research Center (BERC), a part of the Department of Energy, has developed a re-refining process using a mixed solvent consisting of one part (by volume) isopropyl alcohol, one part methyl ethyl ketone, and two parts butyl alcohol. The combination is used in a solvent to oil ratio of 3:1. The major process steps are (1) dehydration, (2) solvent extraction, including solvent recovery from the extract and raffinate, (3) vacuum distillation for additional contaminant removal and fractionation into several viscosity cuts, and (4) final clay treatment for color improvement and stabilization, although other finishing steps have been investigated.

Energy requirements were initially calculated on the basis of a 68 percent yield of used oil feedstock as reported in Reference 2-12. However, according to BERC, this yield value is too conservative. Laboratory testing has indicated that a yield of 71 percent may be expected and that value was used in the energy requirement calculations reported here.

The material flows used in Reference 2-12 were adjusted for the higher yield and the slightly different standard feedstock. The first approach used in the energy calculations was to almost totally ignore the detailed information in the Reference 2-12, basing the estimate primarily on generalized processing requirements. Thus, the BERC process was divided into four steps: dehydration, solvent extraction, fractionation, and clay treatment. The standard dehydration value used for most of the processes, 102,600 Btu per barrel of used oil feed, was also appropriate here. Solvent extraction energy was based on data in Reference 2-3 for phenol extraction. Inasmuch as the data was for a 2:1 phenol to oil ratio, it was multiplied by 1.5. In Reference 2-3, Nelson estimates the solvent loss at 0.07 percent of the solvent used per barrel of oil treated. For the BERC mixed solvent, this amounts to a loss in lower heating value of 8100 Btu per barrel of oil treated. The total solvent extraction energy came to 682,800 Btu per barrel of used oil feed.

Fractionation energy was based on the standard value used throughout this report. Clay treatment involved a simple sensible heat calculation for a 300°F process temperature. The total energy requirement using this approach and a 71 percent yield came to 972,500 Btu per barrel of used oil feed or 1,370,000 Btu per barrel of product.

To obtain some verification of the calculations, reference was made to the information in the Bigda report (Ref. 2-12). Since this is a report of a cost study, process energy per se was not specifically calculated. However, sizing calculations for all the heat exchangers are included from which the thermal input can be estimated. Solvent loss was given as 0.5 percent and converted to an energy input. Plant electrical costs were given from which energy input could be estimated. When all energies were converted to a fuel input basis, the requirement came to 999,800 Btu per barrel of used oil feed or 1,408,000 Btu per barrel of product. This latter value is within 3 percent of the estimate of this study using the more general approach and represents the largest energy requirement of any of the processes examined in this study.

It is worth noting at this point that the next highest energy value is for the propane solvent extraction process previously described, while third in order is the MZF solvent extraction process to be covered next. Solvent extraction processes are characteristically large users of energy because the solvent must be recovered to keep the process economically competitive and this requires relatively large expenditures of energy.

### 2.3.7 MZF Solvent Extraction Process

This advanced process, patented by Dr. M. Z. Fainman and Mr. C. McAuley (Ref. 2-13) uses an aqueous isopropyl alcohol solution, in conjunction with a small amount of alkali, as the solvent. The overall yield is claimed to be 76 percent of the used oil feed. It should be noted that claims for the process have not been verified and are based on a limited amount of small-scale laboratory experimentation. In addition to some question as to the reality of achieving a 76 percent yield in a production plant, there is a vital emulsion-breaking step which has not been completely revealed to the public. In the original patent (Ref. 2-13), centrifugation was used for the physical separation, a technique which requires relatively large amounts of energy. According to Dr. Fainman, an alternative method,which uses only a small amount of a low cost and abundant chemical, is being patented. The energy calculations have assumed no energy was needed to break the emulsion.

The MZF process, along with the caustic process described in Section 2.3.3, does not start off with a dehydration step because, in this case, water is added with the isopropyl alcohol as part of the solvent extractant. Energy inputs are needed for the mixer/settler, a vacuum stripper, solvent stripper, fractionator and clay treater. The total energy requirement for the 76 percent yield is 785,600 Btu per barrel of used oil feed or 1,034,000 Btu per barrel of product oil. As previously noted, this is the third highest energy requirement of any of the re-refining processes, although the lowest of the three solvent extraction processes.

The MZF process is the last of seven re-refining processes for which energy requirements were computed. The next section addresses the calculation of energy needed to pretreat used oil prior to burning.

## 2.4 PRETREATMENT PROCESSES

It is reasonable to assume that some degree of pretreatment will eventually be required prior to combustion of used oil in order to limit the emission of particulates and various other pollutants. Since the exact degree of cleanup that will be required is not presently known, three approaches were examined from the standpoint of energy requirements. The most effective treatment considered is based on the BERC solvent extraction process. However, the fractionation and clay treatment steps of that process are not required when the final product is a fuel rather than lube oil. The standard feed was used together with a 79 percent yield for the initial portions of the BERC process.

Using the approach selected in this study for the calculation of energy requirements for the BERC process (see Section 2.3.6), the pretreatment energy needed is 785,400 Btu per barrel of used oil feed or 994,200 Btu per barrel of product.

These energy requirements are understandably high, inasmuch as they include the most energy-intensive steps in the BERC process. Furthermore, they are probably unacceptable from a cost standpoint when one considers that the product is to be used as a fuel oil rather than a lube oil.

In an effort to reduce the energy requirements, the solvent to oil ratio in the BERC process was reduced from 3:1 to 1:1, the thought being that the used oil might still be cleaned sufficiently to be environmentally acceptable when burned. No data were available as to the expected yield for this solvent to oil ratio; a value of 84 percent was assumed. This yield is midway between that for dehydration only and that used above for a 3:1 ratio. The choice is based on the premise that incremental solvent effectiveness decreases as additional solvent is employed in the process.

For this case of a 1:1 solvent to oil ratio, the energy requirement drops to 330,200 Btu per barrel of used oil feed, or 393,100 Btu per barrel of treated product.

As an example of a low level, minimum energy pretreatment, a simple dehydration and filtration process was considered, perhaps with the addition of small amounts of caustic soda and a de-emulsifier to enhance settling of the solids. The energy requirement was just slightly greater than for dehydration alone to allow for pumping through the filter, and amounted to 102,800 Btu per barrel of used oil feed or 118,200 Btu per barrel of product, assuming a yield of 87 percent, which reflects the fact that such low-level treatment is not very effective in removing contaminants.

## 2.5 VIRGIN LUBE OIL PRODUCTION

An estimate was made of the energy consumed in producing a barrel of virgin lube oil. The calculated value is compared with data obtained from the literature or stated by petroleum and architect/engineer company personnel interviewed during the study. This virgin lube oil energy requirement is used in Section 4 in assessing the relative energy consumption of re-refining used oil versus burning it.

A flowsheet schematic is shown in Figure 2-3, which also indicates the volume of each process stream per 10,000 barrels of incoming reduced crude. The flows are typical for a Texas Mixed Base Crude with an API gravity of 31.7° (Ref. 2-14). Four major refining processes are involved: (1) propane

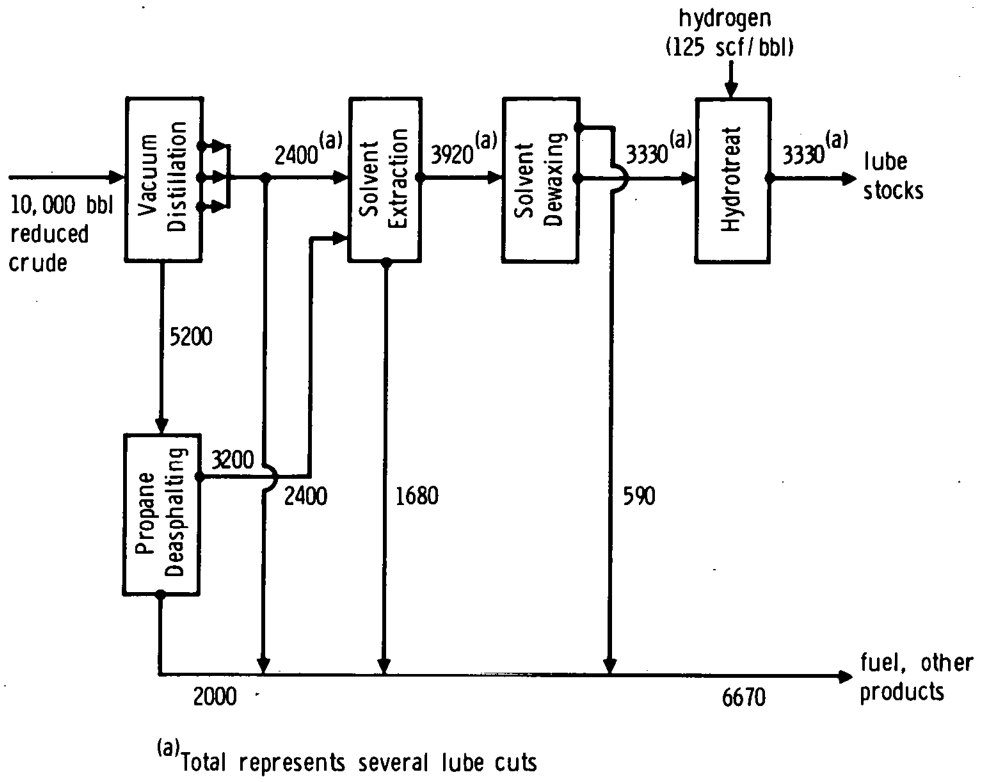


Figure 2-3. Flow Scheme for Virgin Lube Oil Refining Process

deasphalting of the vacuum distillation column bottoms; (2) solvent extraction of the lube fractions; (3) solvent dewaxing using methyl ethyl ketone (MEK), and (4) hydrotreating as the finishing operation. In accordance with the usual convention (Ref. 2-4), energy consumed in vacuum distillation is not included in the lube oil energy requirement inasmuch as this step would be carried out to recover other products even in the absence of lube production.

Energy calculations were based on actual refinery data from Reference 2-3, where fuel, steam, and power requirements are given for each of the four processes. Minimum, maximum, and average values are included for each process. The results, in terms of Btu's per barrel of charge to each process, are shown in Table 2-2. The spread in values reflects variations in the industry due to such items as plant design, age, and type of crude processed.

Table 2-2. Virgin Lube Oil Process Energy Requirements (Ref. 2-3)

| Process | Energy Requirement, $10^6$ Btu Per Barrel Process Charge | | |
|---|---|---|---|
| | Minimum | Average | Maximum |
| Solvent Extraction | 0.16 | 0.38 | 0.56 |
| Deasphalting | 0.16 | 0.32 | 0.49 |
| Dewaxing | 0.46 | 0.69 | 1.03 |
| Hydrofinishing | 0.06 | 0.08 | 0.12 |

Using the data in Table 2-2 and the material flows, it is straightforward to calculate the energy consumption per barrel of product. These values ranged from a low of 1.7 x $10^6$ Btu per barrel of lube oil to a maximum of 3.1 x $10^6$ Btu per barrel, with an average value of 2.1 x $10^6$ Btu per barrel.

Energy estimates were also obtained from several other sources. Teknekron (Ref. 2-4) reported a value of 3.09 x $10^6$ Btu per barrel, corresponding to the high estimate of this study. On the other hand, Reference 2-15 furnished a value of 1.3 to 1.5 x $10^6$ Btu, which did not include deasphalting. If the average energy requirement for deasphalting of 0.32 x $10^6$ Btu listed in Table 2-2 is added, the estimate for the four processes becomes 1.6 to 1.8 x $10^6$ Btu. Corresponding numbers furnished by Reference 2-16 are 0.8 to 1.7 x $10^6$ Btu. A representative of another major petroleum refining company gave a value of 1.5 x $10^6$ Btu. Among the architect/engineer organizations, Reference 2-17 furnished utility requirements they use for each of the four processes. With the conversion factors presented in Section 2.2, the total energy estimate amounts to 1.4 x $10^6$ Btu. Finally, Reference 2-18 furnished utility requirements for the solvent dewaxing and propane deasphalting processes. These values translate to energy requirements of 0.70 x $10^6$ Btu and 0.33 x $10^6$ Btu, respectively, confirming the average values for these processes listed in Table 2-2. It therefore appears that the value of 2.1 x $10^6$ Btu per barrel of product derived here is a reasonable, perhaps conservative, estimate of virgin lube oil processing energy.

The effect of this virgin oil value on the comparative energy savings due to re-refining is discussed in Section 4 and presented graphically in Figure 4-14. At the virgin lube oil process energy value of 2.1 x $10^6$ Btu per barrel, or 50,000 Btu per gallon, only the clay process shows an energy loss. If the virgin energy value is as high as 3.1 x $10^6$ Btu per barrel (74,000 Btu per gallon), all the re-refining processes show a substantial energy saving. Conversely, if the virgin oil can be produced at an energy expenditure near 0.8 x $10^6$ Btu per barrel (19,000 Btu per gallon), only the caustic-clay and distillation-hydrotreating processes would still show positive energy savings.

## 2.6 PROCESS ENERGY SUMMARY

Results of all the process energy calculations, including both those for re-refining of used oil and those for refining of virgin oil, are summarized in Table 2-3. Data basis or limitations are as indicated by the annotations shown in the Table.

Table 2-3. Summary of Process Energy Requirements(a)

| Process | Process(a) Yield, % | Process Energy: $10^6$ Btu per Barrel Used Oil Feedstock(b) | Process Energy: $10^6$ Btu per Barrel Fractionated Product(c) |
|---|---|---|---|
| Acid-Clay | 65 | 0.32 | 0.49 |
| Clay | 60 | 0.30 | 0.50 |
| Caustic-Clay | 62(d) | 0.45 | 0.57 |
| Propane Solvent Extraction(e) | 70<br>82 | 0.95<br>0.99 | 1.35<br>1.21 |
| Distillation- Hydrotreating | 76 | 0.41 | 0.54 |
| BERC Solvent Extraction | 71 | 0.97 | 1.37 |
| MZF Solvent Extraction | 76 | 0.79 | 1.03 |
| Pretreatment (3:1 Solvent to Oil Ratio) | 79 | 0.79 | 1.00 |
| Pretreatment (1:1 Solvent to Oil Ratio) | 84 | 0.33 | 0.39 |
| Pretreatment (Dehydration-Filtration) | 87 | 0.10 | 0.12 |
| Virgin Lube Oil | | | |
| Average | - | - | 2.10 |
| Minimum | - | - | 1.70 |
| Maximum | - | - | 3.10 |

(a) Barrels of product per barrel of used oil feedstock.
(b) Standard feedstock containing 7 percent water and 4.2 percent light ends, which is typical of automotive crankcase drainings.
(c) Product is base oil, and contains no additives.
(d) Process also produces a 16 percent fuel fraction.
(e) Two different yields have been reported (see text).

## 2.7 REFERENCES

2-1 *The Potential for Energy Conservation in Nine Selected Industries Vol. 2*, Federal Energy Administration, Washington, D. C. (1975).

2-2 M. L. Whisman, et al., *Waste Lubricating Oil Research: Part 4*, Report No. BERC/RI-7614, Bartlesville Energy Research Center, Bartlesville, Oklahoma (October 1976).

2-3 W. L. Nelson, *Guide to Refinery Operating Costs (Process Costimating)*, Second Edition, The Petroleum Publishing Company, Tulsa, Oklahoma (1970).

2-4 P. M. Cukor and T. Hall, *A Technical and Economic Study of Waste Oil Recovery, Part IV: Energy Consumption in Waste Oil Recovery*, Teknekron, Inc., Berkeley, California (October 1975).

2-5 Personal communication: B. Williams, Motor Oils Refining Company, McCook, Illinois (3 May 1977).

2-6 N. J. Weinstein, *Waste Oil Recycling and Disposal*, EPA-670/2-74-52, U. S. Environmental Protection Agency, Washington, D. C. (August 1974).

2-7 Personal communication: A. Warden, Warden Oil Company, Minneapolis, Minnesota (5 May 1977).

2-8 Personal communication: R. Mahler, Diamond Head Oil Refinery, Kearny, New Jersey (9 November 1977).

2-9 "Spent Lube Reclamation", *Hydrocarbon Processing*, p. 213 (September 1976).

2-10 D. V. Quang, et al., "Experience with the French Petroleum Institute Propane Clarification Process in Re-Refining Spent Crankcase Oils", *The Journal of Environmental Sciences*, pp. 18 - 20 (May/June 1975).

2-11 *KTI Technology in Refining of Spent Lubricating Oils*, Brochure supplied by Kinetics Technology International Corporation, San Marino, California (October 1976).

2-12 R. J. Bigda, *Predesign Cost Estimate for Re-Refined Lube Oil Plant*, Bartlesville Energy Research Center, Report No. BERC/RI-77/11 (June 1977).

2-13 M. Z. Fainman and C. McAuley, "Method of Purifying Lubricating Oils", U. S. Patent No. 3,819,508 (June 1974).

2-14 W. L. Nelson, *Petroleum Refinery Engineering*, McGraw-Hill Book Company, New York (1958).

2-15 Personal communication: Dr. E. W. Nommensen, Exxon Oil Company, Houston, Texas (30 November 1976).

2-16 Personal communication: J. J. Shook, Chevron Research Company, Richmond, California (12 July 1978).

2-17 Personal communication: R. Gialella, Stone & Webster Engineering Corporation, New York, New York (13 July 1978)

2-18 Personal communication: H. Hipkin, Bechtel National, Inc., San Francisco, California (13 July 1978).

# SECTION 3

# ECONOMICS OF CRANKCASE LUBE OIL RE-REFINING

## 3.1 GENERAL

Of the numerous potential processes for re-refining crankcase drain oil, seven were subjected to a detailed cost analysis. These are the (1) acid-clay, (2) clay, (3) caustic-clay, (4) propane extraction, (5) distillation-hydrotreating, (6) BERC solvent extraction, and (7) MZF solvent extraction processes. Although the clay process is usually associated with industrial oils, it is included here in that it is currently used by one re-refiner to process crankcase drain oil for the production of automotive lube oils (see Section 5.2.3 Part I). This group is believed to represent a reasonable cross section of available and proposed methods, and includes processes being considered for commercial scale applications. Cost analyses were not directed to any industrial oil processes or to processing crankcase oil for use as a fuel. A variety of simpler processes are applicable for industrial oil, while the degree of pretreatment required (if any) for crankcase oil prior to burning has not been established. However, if a high level of contaminant removal is required prior to burning crankcase oil, the treatment process may be similar to that for producing lube oil. That is, solvent extraction or distillation processes may be used, but the degree of purification and finish need not be as high as that required to produce quality base stocks suitable for compounding into an automotive lube oil.

In this section, specific attention is directed to a detailed comparison of the manufacturing cost elements associated with each process and the expected capital investment. To facilitate comparison of the processes, discussion is first directed to the production of base stock lube oils. Costs for additives, or performance improvers, and packaging for market sale, which are common to all processes, are incorporated in the discussion in Section 3.3. Overall costs and the potential for profitability are addressed in Section 3.4. While there may be some reservations regarding absolute costs, it is believed that this analysis does reflect relative cost differenees of competing processes. A summary of cost factors and assumptions are shown in Section 3.5 and, finally, the sensitivity of production costs to process yield is shown in Section 3.6.

Two sources of data were available for calculating production costs for the propane extraction process. These were the French Petroleum Institute's (IFP) published data for its Selectopropane process (Ref. 3-1) and the BERC reported data for the Pieve Fissiraga plant near Milan, Italy, which uses the IFP process (Ref. 3-2). These data sources indicate widely divergent process yields. Since these differences could not be resolved in an expeditious manner for inclusion in this report, analyses were conducted to reflect both data sets.

Ground rules common to the analysis of all processes are as follows:

1. The reference facility is one of 10 million gallons per year feedstock capability, based on operating 3 shifts per day for 250 days per year.
2. Collection and transportation costs for used oil feedstock are incorporated into a common 15 cents per gallon delivered price to the re-refinery.
3. Costs of process chemicals common to different processes are the same; no reduction for higher volume or optimal purchasing.
4. A fractionation step is included in all processes to provide lube oils of various viscosities.

## 3.2 PROCESS RELATED COST FACTORS

Certain cost factors, such as plant and equipment, chemical inventory, and energy requirements, are clearly and directly process related. Others, like maintenance, insurance, and taxes, are commonly estimated as a fixed percentage of investment. As such, they may be considered indirectly related to the chemical process. The impact of process yield on effective labor and feedstock cost may be considered either direct or indirect but is clearly process dependent. For this reason, these two cost factors are grouped and then sequentially integrated into the total cost calculations. Note should be taken that the terms "direct" and "indirect" are used in a logical sense, not that of conventional business economics.

### 3.2.1 Comparison of Plant and Equipment Investment

To normalize estimates of required plant and equipment investment as completely as possible, processing hardware was grouped into major categories, such as pumps, boilers, storage tanks, treating tanks, distillation towers, etc. These costs were then scaled and simplified, when required, to show dollars per unit capacity. For instance, pump costs per gallon per minute were generated on an average basis without consideration of cost factors attributable to specific operating requirements, such as pressure load. A major source of these data was the cost analysis of the BERC solvent process performed by R. J. Bidga & Associates (Ref. 3-3). Special equipment costs, such as for hydrotreating and propane extraction, were obtained from data provided in References 3-1 and 3-4. This special equipment is considered to be purchased as a complete unit and, for the hydrotreating section, the cost of a catalyst is assumed included in the price. Plant and equipment (P & E) estimates include a nominal $100,000 for land and site improvements. Detailed cost breakdowns for the seven processes considered in this study are shown in Table 3-1.

Several other investigators have also estimated P & E costs. These costs are presented along with estimates from this analysis and are shown in Table 3-2 for comparison and reference purposes. Although the design capacities differ in the various estimates, plants of 10 million gallons per year capacity are at a level where hardware costs are not very sensitive to size, as pointed out in Reference 3-3. That is, for a 30 percent additional cost, a 10 million gallon per year plant could be doubled to 20 million gallons per year. In this context, the data of Table 3-2 imply that a reasonable facility estimate for any of the processes would be between about 1.5 and 3.2 million dollars. It should be noted that these cost estimates do not include nonprocess related items that would be required for operating an actual facility, such as office furniture and equipment, lab equipment, storage bins, tools, spare parts, vehicles, etc.

## Table 3-1. Detailed Breakdown of Plant and Equipment Costs, Thousands of Dollars

| Equipment | Acid-Clay | Clay | Caustic-Clay | Propane Extraction | Distillation Hydrotreating | BERC Solvent | MZF Solvent |
|---|---|---|---|---|---|---|---|
| Storage Tanks | 264 | 236 | 261 | 257 | 393 | 259 | 244 |
| Feedstock Dehydration | 59 | 59 | - | 59 | 59 | 59 | - |
| Acid Treatment Section | 54 | - | - | 54 | - | - | - |
| Caustic-Clay Treatment Section | - | - | 57 | - | - | - | - |
| Propane Extraction Section | - | - | - | 1,350[a] | - | - | - |
| Solvent Treatment Section | - | - | - | - | - | 71 | 74 |
| Solvent Stripper | - | - | - | - | - | 194 | - |
| Naphtha Stripper | - | - | - | - | - | - | 127 |
| Alcohol Stripper | - | - | - | - | - | - | 124 |
| Water/Solids Separator | - | - | - | - | - | - | 5 |
| Vacuum Distillation (Purification) | - | - | - | - | 188 | - | 5 |
| Hydrotreating Section | - | - | - | - | 400[b] | - | - |
| Vacuum Distillation (Fractionation) | 214 | 214 | 182 | 214 | 214 | 219 | 214 |
| Clay Contacting | 53 | 106 | 121 | 53 | - | 53 | 53 |
| Clay Filtering | 50 | 150 | 50 | 50 | - | 200 | 200 |
| Steam Boiler | 92 | 72 | 92 | 92 | 40 | 176 | 136 |
| Hot Oil Furnace | 328 | 328 | 328 | 328 | 328 | 328 | 328 |
| Cooling Tower | 98 | 88 | 112 | 168 | 107 | 168 | 120 |
| Sludge Stripper | - | - | - | - | - | 32 | - |
| Additional Pumps | 12 | 12 | 12 | 12 | 12 | 23 | 23 |
| Waste Water-Oil Separator | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Total Equipment Cost[c] | 1,231 | 1,272 | 1,221 | 2,644 | 1,748 | 1,789 | 1,655 |
| Piping[d] | 234 | 242 | 232 | 246[e] | 256[f] | 340 | 314 |
| Land and Site Improvements[g] | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Buildings[h] | 40 | 80 | 40 | 40 | 40 | 40 | 40 |
| Subtotal Plant & Equipment Cost | 1,605 | 1,694 | 1,593 | 3,030 | 2,144 | 2,269 | 2,109 |
| Engineering Fee[i] | 160 | 169 | 159 | 168[e] | 174[f] | 227 | 211 |
| Total Plant & Equipment Cost[j] | 1,765 | 1,863 | 1,752 | 3,198 | 2,318 | 2,496 | 2,320 |

[a] Selectopropane unit obtained from IFP.

[b] Hydrofining unit obtained from Exxon.

[c] Equipment erected on site.

[d] Includes labor and material for piping, instrumentation, electrical distribution, compressed air, fire protection, painting, communications, yard and fence lighting. Computed at 19 percent of the total equipment cost.

[e] Propane extraction section cost excluded from this computation.

[f] Hydrotreating section cost excluded from this computation.

[g] Includes utilities to site (water, electricity, gas, and sewage), driveways, walkways, and fencing.

[h] Excludes furniture, office equipment, lab equipment, shelves, storage bins, racks, etc.

[i] Computed at 10 percent of subtotal plant and equipment cost.

[j] Excludes vehicles, spare parts, tools, inventory of feedstock and chemicals, etc.

Table 3-2. Summary of Plant and Equipment Cost Estimates, Thousands of Dollars

| Process | Aerospace | | Other | | |
|---|---|---|---|---|---|
| | Capacity[a] | Cost | Capacity[a] | Cost | Source (Ref) |
| Acid-Clay | 10 | 1.8 | 5 | 1.5[b][c] | 3-5 |
| Clay | 10 | 1.9 | - | - | - |
| Caustic-Clay | 10 | 1.8 | - | - | - |
| Propane Extraction | 10 | 3.2 | 5 | 1.8[b][c] | 3-5 |
| Distillation Hydrotreating | 10 | 2.3 | 5 | 1.8[b][c] | 3-5 |
| BERC Solvent | 10 | 2.5 | 10[e] | 2.0[d] | 3-3 |
| MZF Solvent | 10 | 2.3 | 6 | 1.5[f] | 3-6 |

[a] $10^6$ gallons used oil feedstock per year.

[b] Costs updated to 1975 ysing GNP deflator (Ref. 3-7) and from 1975 to 1977 using 10% (arbitrary).

[c] Includes land and site improvements.

[d] Excludes land and site improvements.

[e] Capacity based on 350 stream days per year. All other based on 250 days per year, except for MZF which is unknown.

[f] Land and site improvement not stated.

The cost of chemicals in inventory, in comparison to P & E, is not significant, as shown in Table 3-3 for a supply sufficient for two weeks of plant operation. Although process chemicals which are recycled might be considered a part of P & E, they are not included in this study's estimate. Whether this treatment is consistent with the "other" data of Table 3-2 is unknown. However treated, the cost of such chemicals does represent a capital requirement.

Estimated P & E costs for all processes considered are higher in this study than those estimated by others for several reasons. First, assumed plant capacity on a daily basis is larger in all cases. Second, a fractionation step is included in this study for all processes whereas only the BERC estimate in the "other" category includes this cost. Although the propane extraction process, as represented by the IFP Selectropropane process (see Section 5.2.4, Part I), includes fractionation, equipment cost for this step was not included in the Reference 3-5 analysis. Additionally, the cost of specialized equipment, particularly a propane clarification unit appears to have been underestimated in that reference.

Having identified P & E costs, manufacturing costs are now assessed in the following subsection to identify overall expenses associated with each process.

Table 3-3. Chemical Inventory Costs, Thousands of Dollars[a]

| Process | Acid-Clay | Clay | Caustic-Clay | Propane Extraction | Distillation Hydro-Treating | BERC Solvent | MZF Solvent |
|---|---|---|---|---|---|---|---|
| Inventory | 20.5 | 41.3 | 23.0 | 7.1[b] | 7.2 | 13.7[b] | 12.4[b] |

[a] Consumed chemicals sufficient for two weeks of plant operation.
[b] Does not include stock of solvents recycled during process operation.

### 3.2.2 Comparison of Process Costs

Production cost calculations performed use process yields reported in Section 2. As discussed in that section, reliable yield information is often difficult to obtain for a variety of reasons. For processes that are in commercial operation, this might be attributed to items such as variable feedstock and processing conditions. Where a process sees limited use, yield data may of necessity be limited to the experience of a single plant. Hopefully, its operation is typical of the process. For newer processes, there is a lack of adequate full-scale plant data. Yields quoted from laboratory glassware may not be achievable in an actual plant. Indeed, there are those who say that the process itself may not even work in an actual plant. This lack of firmness is unfortunate for, as will be shown in Section 3.6, production costs are sensitive to process yield.

The processes investigated vary greatly in their degree of implementation, and hence potential reliability of data. Data for the acid-clay process are based on many plants in commercial operation. For the clay and caustic-clay processes, the data are based on the operation of single plants. Although there are two propane extraction plants in operation, data are only available from one. As previously discussed, these data are available from two sources, which reported different yields. Results for both yields are included in this report. For distillation-hydrotreating, yields are based on a KTI proposed process and should be considered an idealized one. The BERC solvent process yield is based on laboratory and pilot plant work, while the MZF solvent process yield is only based on laboratory work.

#### 3.2.2.1 Direct Process-Related Costs

As previously explained, process costs are divided into direct and indirect costs for the purpose of categorizing how they enter the cost analyses. Direct costs are for make-up chemicals, process energy requirements, and waste disposal. A credit is given each process for the energy content of the overhead distillates contained in the used oil. For the caustic-clay process, the one re-refiner using this process takes a large fuel cut in addition to the overhead distillate. Credit for this fuel cut is included with that of the overhead distillate. For clarity, direct and indirect costs are discussed separately, with cost of labor and feedstock discussed subsequently. Both direct and indirect costs are summarized in cents per gallon of product in Table 3-4.

Table 3-4. Process Related Costs for Re-Refining Used Automotive Lube Oil

| Item | Costs Directly Attributable to Process[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Acid-Clay | Clay | Caustic-Clay | Propane Extraction | Distillation-Hydrotreating | BERC Solvent | MZF Solvent |
| Process Yield Used in Establishing Costs[b] | 0.65 | 0.60 | 0.62[c] | 0.82/70[d] | 0.76 | 0.71 | 0.76 |
| Source (Ref.) | Note (e) | (Ref. 3-8) | (Ref. 3-9) | (Refs. 3-1, 3-2) | (Ref. 3-10) | (Ref. 3-11) | (Ref. 3-12) |
| Basis | Many Plants in Operation | One Plant in Operation | One Plant in Operation | Two European Plants in Operation | Idealized Process | Laboratory Test and Pilot Plant Operation | Laboratory Test Only |
| Chemicals, ¢/gal Product | 7.88 | 17.21 | 9.25 | 2.17/4.90 | 2.38 | 4.82 | 4.06 |
| Energy, ¢/gal Product | 2.69 | 2.72 | 3.92 | 6.57/7.37 | 2.95 | 7.45 | 5.62 |
| Waste Disposal, ¢/gal Product | 5.63 | 3.58 | 1.17 | 0.91/2.87 | 0.67 | 1.23 | 1.07 |
| Credit for Overheads, ¢/gal Product | (2.07) | (2.25) | (10.46)[f] | (1.64/1.93) | (1.77) | (1.90) | (1.77) |
| Total | 14.13 | 21.26 | 3.88 | 8.01/13.21 | 4.23 | 11.60 | 8.98 |

| Item | Cost Indirectly Attributable to Process[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| Maintenance, ¢/gal Product[g] | 1.36 | 1.55 | 1.41 | 1.88/2.29 | 1.51 | 1.76 | 1.51 |
| Insurance and Taxes, ¢/gal Product[h] | 0.81 | 0.93 | 0.85 | 1.19/1.37 | 0.91 | 1.06 | 0.91 |
| Total | 2.17 | 2.48 | 2.26 | 3.07/3.66 | 2.42 | 2.82 | 2.42 |

(a) In cents per gallon of product.

(b) As provided by sources referenced.

(c) Process also produces 16% fuel. Fuel credit included with overheads.

(d) Reflects yields for the plant operating near Milan, Italy, as reported by the two referenced sources.

(e) Typical value reported by re-refiners contacted during this study.

(f) Includes credit for fuel fraction.

(g) Computed as 5% of P & E (Table 3-1).

(h) Computed as 3% of P & E (Table 3-1).

The propane, BERC, and MZF processes recycle process solvents. Chemical costs for the BERC and MZF processes are based on a 1/2 percent solvent loss, while losses for the propane process are assumed to be 0.038 lb per gallon of used oil feedstock (Refs. 3-1 and 3-3). In all other cases, process chemicals are either fully consumed or not economically recoverable. Values entered as chemical costs for all processes are based on the amount consumed per gallon of base oil produced. Process chemical costs and data sources are listed in Table 3-5. Quantities required for each process reflect the process descriptions shown in Section 5, Part I, and summarized in Figures 2-1 and 2-2 of Part II.

Hydrogen, which is required in the distillation-hydrotreating process, is available at widely varying prices which are related to the quantity purchased (Ref. 3-16). For example, the cost is about 9 cents per standard cubic foot (scf) when purchased in a cylindrical tank holding one pound of hydrogen gas (somewhat less than 200 scf), and about 1.75 cents per scf when purchased in tube trailers holding from 125,000 to 165,000 scf.

Larger quantities of hydrogen may be purchased in 9,000-gallon cryogenic tank truck loads (about 1 x $10^6$ scf) at a price of 0.8 cents per scf, assuming local availability. Since about 3 scf of hydrogen are required per gallon of re-refined oil, this represents about a 2-week supply, which is considered a normal inventory. Based on the quantity of hydrogen required, and the advantageous price associated with bulk purchase, a price of 0.8 cents per scf is used in this analysis. A cost of $150,000 to $200,000 for a cryogenic tank (Ref. 3-16) is included in the P & E cost of the re-refinery. It should be noted that the delivered price of hydrogen would increase as distance from an available supplier increases, at a rate of about 0.3 cents per scf per 500 miles.

Table 3-5. Process Chemical Costs

| Process Chemical | Cost | Data Source |
|---|---|---|
| Butyl Alcohol | $1.28/gal | Ref. 3-13 |
| Clay | $135/ton | Ref. 3-14 |
| Diatomaceous Earth | $138/ton | Ref. 3-15 |
| Hydrated Lime | $ 36/ton | Ref. 3-13 |
| Hydrogen | $0.008/scf | Ref. 3-16 |
| Isopropyl Alcohol | $1.08/gal | Ref. 3-13 |
| Methyl Ethyl Ketone | $1.41/gal | Ref. 3-13 |
| Naphtha | $0.40/gal | Ref. 3-13 |
| Propane | $0.30/gal | Ref. 3-17 |
| Richonate 60B | $0.34/lb | Ref. 3-18 |
| Sodium Carbonate | $ 57/ton | Ref. 3-13 |
| Sodium Hydroxide | $1.09/gal | Ref. 3-13 |
| Sodium Silicate | $0.42/gal | Ref. 3-13 |
| Sulfuric Acid | $ 48/ton | Ref. 3-13 |

No cost figures are shown in Table 3-5 for catalysts used in the distillation-hydrotreating process. Initial supply, as previously stated, is considered included in the P & E costs and the assumption is made that catalyst poisoning either does not occur or that the catalyst may be easily regenerated. This assumption results in a zero recurring cost for catalysts as it is not consumed in the process. Implications of this assumption are addressed in Section 3.5.

For the BERC and MZF solvent processes, the final finishing treatment uses 0.2 lb clay and 0.1 lb of diatomaceous earth per gallon of treated oil, or 50 percent of that required by the acid-clay process, because of the higher state of purification of the used oil charged to this step.

Total process energy was taken from Table 2-3. Although it is general practice to use overhead distillates to provide process energy, in the interest of normalizing comparison between competing processes, all energy was assumed to be purchased, with a credit given for these overhead distillates. Energy costs are based on 32.1 cents per gallon for No. 6 residual fuel oil (Ref. 3-19), with conversion assumed at $5.9 \times 10^6$ Btu per barrel. Results of these calculations are also shown in Table 3-4. The credit for overheads that is shown for the caustic-clay process also includes a credit for the 16 percent fuel cut taken.

Finally, the cost of process waste disposal was presumed to be related to its hazard. As explained in Section 5, Part I, disposal costs at the dump were found to vary from 4 cents to as high as 16 cents per gallon of sludge. Although these costs were dependent on local conditions, this analysis makes use of a variable cost for disposal to reflect the decreasing availability of suitable dump sites with increase in waste product toxicity. A cost of 10 cents per gallon was assigned to waste produced by the acid-clay process on the basis of its comparatively high toxicity and corrosivity. A cost of 4 cents per gallon was assigned to processes whose wastes do not contain acid. The propane process, which uses acid in smaller amounts, was assigned an intermediate cost of 7 cents per gallon. No costs were assigned for transportation to the dump in that these costs are dependent on the actual siting of the re-refinery relative to the dump. These disposal costs were then prorated by the amount of sludge produced by each process to arrive at the costs shown in Table 3-4. No process was given a credit for waste disposal even though its waste may be a saleable product, such as for use in the manufacturing of roofing asphalt (Ref. 3-20) or as a paint pigment (Ref. 3-21). The use of highly contaminated waste products for these various purposes has not been established as safe or environmentally acceptable, and is therefore not considered in this report.

#### 3.2.2.2 Indirect Process-Related Costs

Costs normally estimated as a percentage of P & E investment are maintenance, insurance, and taxes. Because investment is dependent upon process choice, these expense items are related to the type of process used. This report uses 5 percent of P & E costs for maintenance and 3 percent for taxes and insurance, which are considered typical for an industrial plant (Ref. 3-3), but may not be representative of the old re-refineries in current operation. It should be noted that due to some inherent difficulties associated with handling used oil, maintenance costs may run higher than shown in Table 3-4. Reporting these costs on an incremental basis provides a convenient means for the reader to adjust production costs, should higher maintenance costs be indicated.

### 3.2.3 Comparison of Feedstock and Labor Costs

Two additional sources of expenses in re-refining used oil are labor and the cost of feedstock. Used oil feedstock is commonly thought of as a direct expense. Whether or not the re-refiner collects it, its price in all published studies is quoted as though it were purchased at the plant gate like process chemicals. In fact, the yield of the re-refining process affects how much feedstock must be processed in the production of a gallon of finished base stock. In this sense, although each re-refiner may pay the same price for used oil, the effective cost increases with lower processing yields. Because of these complications, feedstock costs have also been separated from the previous discussions of direct and indirect process related costs. For all processes, a used oil feedstock price of 15 cents per gallon was assigned.

In this report, labor requirements were assumed to be the same for all processes: three in office administration at $60,000 per year total and ten plant personnel (two operators per shift plus one supervisor, one shipping clerk, and two maintenance personnel, on the day shift) at $156,000 per year total, including overhead. This labor force is considered to be the minimum number of persons capable of operating a re-refinery. An actual re-refinery could have a larger number of workers, particularly if other operations, such as packaging the product, were included. While the total labor cost is fixed for each process, the cost per unit of re-refined oil produced varies with process yield. Feedstock, labor, direct, and indirect costs are summarized in Table 3-6 to show the total production cost of re-refined oil. Costs for oil additives and product packaging for market distribution, which are assumed to be the same for all processes, are addressed in the following subsection.

Table 3-6. Summary of Base Oil Production Costs for Selected Automotive Lube Oil Re-Refining Processes(a)

| Process | Yield | Feed Stock(b) | Processing Indirect(c) | Processing Direct(c) | Labor(d) | Total(e) |
|---|---|---|---|---|---|---|
| Acid-Clay | 0.65 | 23.1 | 2.2 | 14.1 | 3.3 | 42.7 |
| Clay | 0.60 | 25.0 | 2.5 | 21.3 | 3.6 | 52.4 |
| Caustic-Clay | 0.62(f) | 24.2 | 2.3 | 3.9 | 3.5 | 33.9 |
| Propane Extraction(g) | 0.82 | 18.1 | 3.1 | 8.0 | 2.6 | 31.8 |
|  | 0.70 | 21.4 | 3.7 | 13.2 | 3.1 | 41.4 |
| Distillation Hydrotreating | 0.76 | 19.7 | 2.4 | 4.2 | 2.8 | 29.1 |
| BERC Solvent | 0.71 | 21.1 | 2.8 | 11.6 | 3.0 | 38.5 |
| MZF Solvent | 0.76 | 19.7 | 2.4 | 9.0 | 2.8 | 33.9 |

(a) All costs in cents per gallon of base oil produced.

(b) Effective cost due to process efficiency. All feedstock 15 cents per gallon at plant gate.

(c) From Table 3-4.

(d) Three office @ $20,000 each, ten plant @ $15,600 each (unit cost varies due to process efficiency).

(e) Profit, packaging, and additives not included.

(f) Process also produces 16 percent fuel.

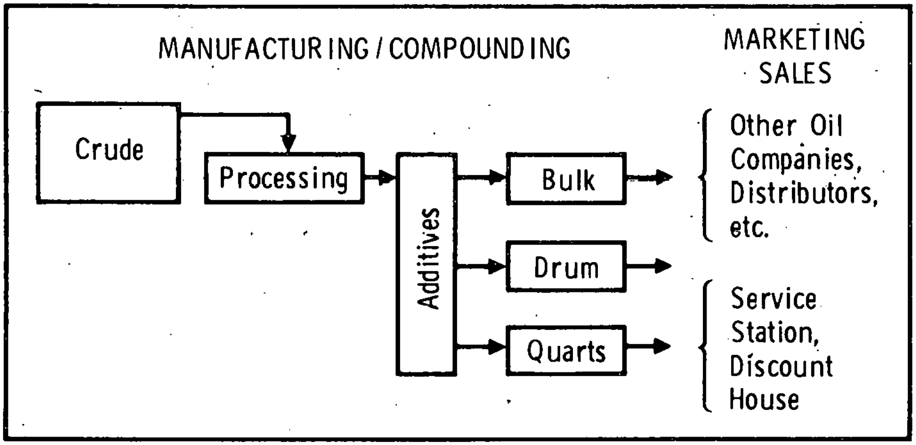
(g) Data shown for both reported yields.

## 3.3 MARKETING AND RELATED COST FACTORS

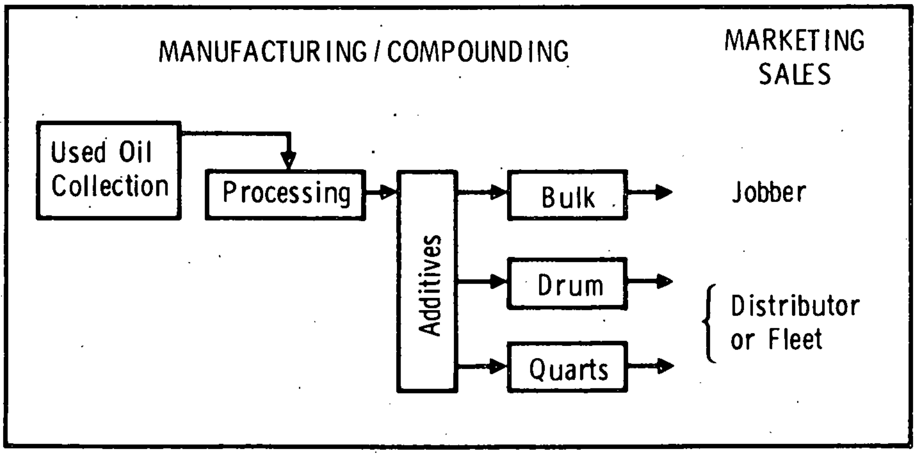
The manufactured bulk base oil product is distributed in a number of different ways. Re-refined automotive oil may be packaged in quart containers, may be sold in drums or tank truck lots to wholesalers, or may be sold in railroad tank cars to bulk distributors in a manner similar to virgin oil. The overall close parallelism in the manufacturing and marketing of both virgin and re-refined oil can be seen in Figure 3-1 (Ref. 3-22). Initially, all automotive oils were sold in bulk. Gasoline stations in the 1940's commonly dispensed oil from drums. In today's market structure, both the packaging of automotive oil and the addition of performance additives may be done either by the manufacturer or by a distributor/jobber. For re-refined oil, the additive package is commonly blended with the base oil by the re-refiner. Although there is some variation in these practices, both additive blending and product packaging are included in this report as an expense in the total cost of producing re-refined oil. Associating these costs with manufacturing facilitates later comparison at the consumer level of the price of virgin and re-refined oils and the potential profit margin available to a re-refiner.

### 3.3.1 Additives and Performance Improvers

The demanding operating conditions in a modern automotive engine require the use of oil performance improvers. Additives are blended with automotive lube base stock to (1) improve oxidation resistance, (2) improve the ability to carry particulates in suspension, and (3) alter temperature-viscosity characteristics. As might be expected, the more comprehensive the attributes of the finished oil, the more additives are required. For example, a single viscosity SAE 20W API service classification SE oil meeting recommended auto manufacturers' specifications requires about 7 (volume) percent additives, whereas a multi-viscosity SAE 10W40 API SE oil requires a combination of additives totaling nearly 12 (volume) percent. For the cost analysis in this report, a 6.5 percent additive package for a single viscosity SAE 20W API SE oil was assumed. This additive package was considered applicable for re-refined oil produced by any of the various processes investigated. This assumption is used, even though it is recognized that base oils



a. New Motor Oil Processing Chain



b. Re-Refined Motor Oil Processing Chain

Figure 3-1. New and Re-Refined Motor Oil Processing Chains (Ref. 3-22) produced by these processes may differ in quality and require different amounts of additives, because it is not possible to assign a different level of quality to the oils produced. Indeed, as discussed in Section 9, Part I, the question of lube oil quality and means of determination is a difficult and complex problem. Therefore, re-refined base stock from all processes was assigned the same additive package cost, which is separately identified so that the reader may substitute another value for an alternate package. Cost of the additive package, based on a price of $2.72 per gallon and a 6.5 percent dosage rate, is 18 cents per gallon of finished oil. The additive package for a multiviscosity SAE 10W-40 API SE oil would be about 26 cents per gallon of finished oil (Ref. 3-23).

### 3.3.2 Product Packaging Costs

Product packaging requirements for re-refined oil are not different from those of any other automotive oil. The nature of both the cost and type of packaging is dependent on the customer. If the oil is sold in bulk, it will most likely be in drums or tank-truck lots. The cost incurred for filling, loading and unloading, and cleaning and painting of the containers, amounts to as much as 25 cents per gallon for drums. For tank size lots, handling and cleaning costs are approximately 8 cents per gallon (Ref. 3-24). Even though it seems high, a cost of 25 cents per gallon for drums was used to develop total production costs for re-refined automotive lube oil. In comparison, 55-gallon steel drums can be purchased new in Los Angeles for $16.20 (29 cents per gallon), used for $11.25 (20 cents per gallon), and cleaned and painted for $4.85 (9 cents per gallon) (Ref. 3-24). Other parts of the country indicate lower prices. For instance, in Oklahoma, prices are $15.00 new (27 cents per gallon), $8.00 used (15 cents per gallon) and $2.65 for cleaning and painting (5 cents per gallon) (Ref. 3-11). Since the cost of packaging is used consistently for all processes, the relative production costs are unaffected. However, those interested in exact production costs should check the local price of drums and labor rates and make an adjustment to the data shown in Table 3-7.

When intended for sale to individual automobile owners, re-refined oil is usually packaged in quart-sized containers. At first, re-refiners were hesitant to adopt the quart container. Today, however, re-refined oil may be purchased in quart containers like any other oil. The actual packaging in quart containers may be done by either the re-refiner or a market intermediary. The cost for packaging by the quart was identified as 55 cents per gallon.

## 3.4 COMPARISON OF TOTAL COSTS AND PROFITABILITY

Each component expense in the manufacture of re-refined oil has been addressed in the preceding sections. Miscellaneous expenses of several types, such as advertising and distribution, were deliberately avoided because of possible wide variations and because they are not now large expenses within the industry. The cost analysis has been structured to permit incremental additions of such items without major recomputation.

The potential profitability of different processes is directly related to total production cost of the end product. Although this cost does not reflect overall profitability, it does reflect relative price competitiveness. Therefore, the previously calculated production costs for each process are summarized in Table 3-7.

Having addressed the potential profitability of the various re-refining processes relative to each other, it is now appropriate to review the potential profitability of re-refining. Virgin lube oils, equivalent to the drum packaged SAE 20W API SE oil that is shown in Table 3-7, were found to be selling for $1.47 to $1.85 per gallon on the West Coast (Ref. 3-26). Conversely a re-refined motor oil was selling for $1.18 in the Mid-West (Ref. 3-24). A comparison of the production cost data of Table 3-7 to the actual market price of re-refined and virgin lube oil indicates the potential profitability of re-refining by the various processes, and the potential for further profits if the price differential between re-refined and virgin lube oils disappears.

This comparison is shown in Table 3-8. While the main emphasis of this cost analysis was to maintain relative accuracy between the various processes to facilitate comparisons, it is believed that the absolute accuracy is sufficiently high to permit confidence in the magnitude of the potential profitability in re-refining used automotive lube oils.

Table 3-7. Summary of Production Costs for Re-Refined Lube Oil Compounded for Automotive SE Service (cents per gallon product)

| Process | Yield | Mfg Cost[a] | Performance Additives[b] | Pkg. Drums[c] | Total |
|---|---|---|---|---|---|
| Acid-Clay | 0.65 | 39.9 | 18.0 | 25.0 | 82.9 |
| Clay | 0.60 | 49.0 | 18.0 | 25.0 | 92.0 |
| Caustic-Clay | 0.62[d] | 31.7 | 18.0 | 25.0 | 74.7 |
| Propane Extraction[e] | 0.82 | 29.7 | 18.0 | 25.0 | 72.7 |
|  | 0.70 | 38.7 | 18.0 | 25.0 | 81.7 |
| Distillation-Hydrotreating | 0.76 | 27.2 | 18.0 | 25.0 | 70.2 |
| BERC Solvent | 0.71 | 36.0 | 18.0 | 25.0 | 79.0 |
| MZF Solvent | 0.76 | 31.7 | 18.0 | 25.0 | 74.7 |

[a] Total from Table 3-3, adjusted to provide for 0.935 gallons of base oil required to produce one gallon of finished product

[b] To produce an SAE 20W API SE oil, 0.065 gallons of additives are used

[c] Costs for cased quarts would be 55 cents per gallon; tank car lots, 8 cents per gallon

[d] Process also produces 16 percent fuel

[e] Data shown for both reported yields

## 3.5 SUMMARY OF PROCESS COST FACTORS/ASSUMPTIONS

The acid-clay process has high chemical costs, high waste disposal costs, and a low yield. These factors are sufficient to offset its low process energy requirement and result in high production costs. The clay process has the highest production cost of any process considered due to

Table 3-8. Potential Profitability of Various Re-Refining Processes, Cents per Gallon[a]

| Process | Acid-Clay | Clay | Caustic-Clay | Propane[b] Extraction | Distillation-Hydrotreating | BERC Solvent | MZF Solvent |
|---|---|---|---|---|---|---|---|
| Total Production Costs | 83 | 92 | 75 | 73/82 | 70 | 79 | 75 |
| Profitability Relative to Re-Refined Oils[c] | 35 | 26 | 43 | 45/36 | 48 | 39 | 43 |
| Profitability Relative to Virgin Oils[d] | 64 to 102 | 55 to 93 | 72 to 110 | 74/65 to 112/103 | 77 to 115 | 68 to 106 | 72 110 |

[a] Plant amortization and marketing/distribution costs not included.

[b] Data shown for both reported yields.

[c] Relative to selling price of $1.18/gal in bulk drum packaging.

[d] Relative to selling price of $1.47 and $1.85/gal in bulk drum packaging.

the large amounts of chemicals (clay) consumed, and the low yield obtained. As in the acid-clay process, the low energy requirement of the process are not sufficient to offset the high chemical costs.

The caustic-clay process is rather unique in that the one plant in production takes a 16 percent fuel cut. Although the lube oil yield is low at 62 percent, the recovered hydrocarbons are high at 78 percent. High process chemical costs are more than offset by the credit given for this fuel cut and the overhead distillates. Since process energy is relatively low, an overall low production cost results.

As stated before, production costs for the propane extraction process were developed for two sets of data reflecting different yields in that resolution of these disparate values was not reached during the course of this study. This process has relatively high chemical and energy costs, which indicate that its ability to produce oil economically rests on its being able to obtain high yields. For a process yield of 82 percent, as reported in Reference 3-1 (adjusted for the common used oil characteristics used in this report), production costs would be amongst the lowest. Should the yield be 70 percent, as reported in Reference 3-2, then it would be one of the more expensive processes. Due to conflicting data relative to this process, production costs should be used with caution.

Costs developed for the distillation-hydrotreating process were based on the idealized process described in Section 5, Part I, consisting of dehydration, distillation, light hydrotreating and fractionation. No cost allowance was made for pre-treatment steps designed to overcome the inherent difficulty in applying the distillation process to re-refining used oil; the tendency of distillation colums to foul and eventually clog. Use of a narrow distillation cut to minimize fouling, as discussed in Section 5, Part I, was not analyzed in that this would represent a plant producing a substantial amount of fuel in addition to lube oil. It should be pointed out that, due to the relatively high price of fuel oil, a plant structured along this line could be very profitable. Also, no cost allowance is made for replacement of the hydrotreating catalyst. This assumption implies that catalyst poisoning either does not occur, or that the catalyst can easily be regenerated. Researchers contacted during the course of this study did not indicate any particular concern relative to obtaining a suitable catalyst. KTI's demonstration plant under construction, and a letter of intent to build a 2500 BPSD plant for Haberland of West Germany, would indicate that progress is being made towards solving the problems of catalyst poisoning and column fouling (Ref. 3-27). However, it must be noted that this study failed to identify any catalyst that would resist poisoning or could be easily regenerated. Should development work fail to resolve these two problem areas, the production costs developed herein will not be applicable. Indeed, the viability of using the distillation-hydrotreating process for re-refining used oil would be in doubt.

The BERC solvent process has a moderately high production cost due to high energy requirements, relatively high chemical costs, and a slightly lower yield than the lower cost processes. High energy costs are inherent in this process due to the large volume of solvents that must be stripped from the purified oil.

Production costs for the MZF solvent process were calculated to be somewhat lower than the BERC solvent process, due in part to the use of lower cost chemicals and a lower energy requirement. However, costs developed for this process were based on the process described in Section 5, Part I, which indicates use of an undisclosed emulsion separation technique (such as settling in the presence of a small amount of an inexpensive de-emulsifying agent) that does not require the expenditure of energy as would centrifugation. Therefore, neither process energy nor P & E costs were assigned to this separation step. The P & E cost of this separation technique was assumed to be included in the standard cost of a solvent treating/separation tank. Should this new technique not work, centrifugation would be required and the costs developed herein would not be applicable. Also, no costs are assigned for the de-emulsifying agent, as none has been identified. It should be noted that production costs were based on process yields obtained from small scale laboratory experimentation. Although small scale experimentation implies that the process was not tested with a variety of feedstock, BERC research (Ref. 3-28) indicates remarkable consistency of feedstock throughout the United States. This leads one to believe that this lack of testing on a variety of feedstocks should not present a problem.

## 3.6 SENSITIVITY OF PRODUCTION COSTS TO PROCESS YIELD

Process yields claimed for various re-refining processes are not definitive for numerous reasons, including the amount of water and gasoline contamination in the feedstock and specific process operating conditions. For existing processes that have many practitioners, a consensus yield may be obtained. Where only one or two plants are in operation, a single data point may be used. Even this latter case is not straightforward: witness the different yields reported for the IFP Selectropropane process. For processes under development, data may be based on lab or pilot plant work, and may represent either an optimistic best case set of data or a conservative set that could be exceeded in actual plant operation. Therefore, to provide insight into process costs as affected by yield, a cost sensitivity analysis was conducted to show production costs as a function of process yield. Process cost data are shown in Figure 3-2 for the reported yield of each process, and for an approximate 10 percent change in yield. This figure illustrates the inherent cost difference of the various processes, reflecting different chemical costs, energy costs, and so on, and shows that at equivalent yields the processes generally will have different production costs. For example, yield from the distillation-hydrotreating process would have to drop from 76 percent to about 66 percent before the MZF solvent process would become cost competitive. As another example, yield from the acid-clay process would have to increase from 65 percent to about 72 percent to become competitive with the BERC solvent process, whose yield is 71 percent.

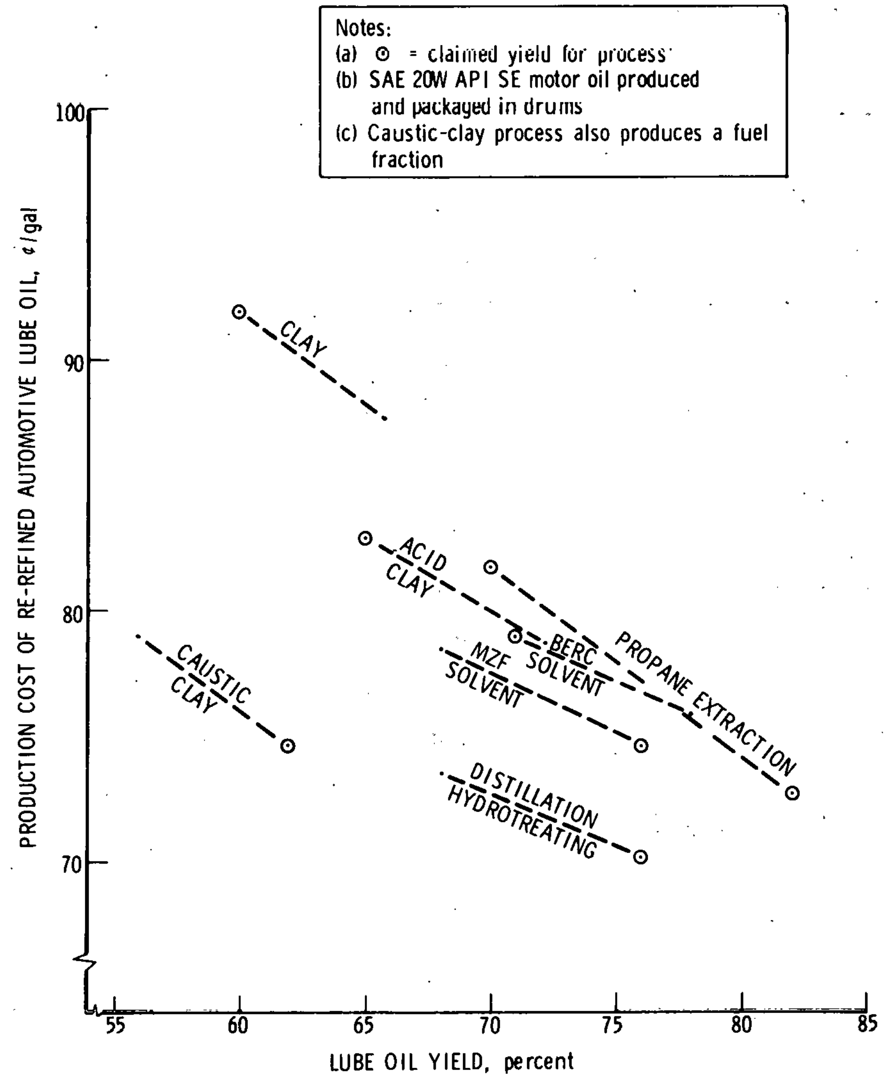


Figure 3-2. Sensitivity of Production Costs to Lube Oil Yield for Various Re-Refining Processes

## 3.7 REFERENCES

3-1 "Experience with the French Petroleum Institute Propane Clarification Process in Re-Refining Spent Crankcase Oils", The Journal of Environmental Sciences (May/June 1975).

3-2 M.L. Whisman, "Institut Francais du Petrole, Process for Regenerating Used Lubricating Oils", BERC, Bartlesville, Oklahoma (23 Sept 1977).

3-3 R.J. Bigda and Associates, Predesign Cost Estimate for Re-Refined Lube Oil Plant, BERC/RI-77-11 (30 July 1976).

3-4 Hydrocarbon Processing (September 1976).

3-5 "Waste Oil Study", Report to Congress, prepared by the U.S. Environmental Protection Agency (April 1974).

3-6 Personal Communication: Dr. M. Z. Fainman, MZF Associates, Los Angeles, California (17 May 1977).

3-7 Energy Perspectives 2, U.S. Department of the Interior (June 1976).

3-8 Personal Communication: Mr. A. Warden, Warden Oil Co., Minneapolis, Minnesota (5 May 1977).

3-9 Personal Communication: Mr. R. Mahler, Diamond Head Oil Refinery, Kearny, N.J. (9 November 1977).

3-10 KTI Technology in Refining of Spent Lubricating Oils, Kinetics Technology International Corp., San Marino, California (8 October 1977).

3-11 Personal Communication: Mr. M. L. Whisman, BERC, Bartlesville, Oklahoma (8 November 1977).

3-12 Letter from MZF Associates, Los Angeles, California, to The Aerospace Corporation, El Segundo, California (9 February 1977).

3-13 Chemical Marketing Reporter (6 February 1978).

3-14 Personal Communication: Mr. J. Knight, Sales Representative, The Filtrol Corporation, Vernon, California (22 February 1978).

3-15 Personal Communication: Mr. H. Blazina, Technical Representative, Johns-Mansville Inc., San Mateo, California (22 February 1978).

3-16 Personal Communication: Mr. K. Holden, Sales Representative, Air Products and Chemicals Corporation, Long Beach, California (8 September 1977).

3-17 Personal Communication: Sales Representative, Globe Gas Corporation, Long Beach, California (16 February 1978).

3-18 Personal Communication: Sales Representative, The Richardson Corporation, Des Plaines, Illinois (22 February 1978).

3-19 *Energy User News* (30 January 1978).

3-20 Personal Communication: Mr. L. Schurr, Berks Associates, Pottstown, Pa (11 October 1977).

3-21 Personal Communication: Ms. S. Bass, The Governor's Office, Raleigh, N. C. (26 October 1977).

3-22 *A Technical and Economic Study of Waste Oil Recovery,* Teknekron, Inc., Part III (October 1973).

3-23 Personal Communication: Mr. S. Gouta, Technical Sales, The Lubrizol Corporation, Los Angeles, California. (18 January 1978)

3-24 Personal Communication: Mr. B. Williams, Motor Oils Refinery, McCook, Illinois.

3-25 Personal Communication: Mr. M. Stull, Myers Drum Co., Subsidiary of Kaiser Steel Co. (7 December 1977).

3-26 Personal Communication: Sales Representatives of ARCO, Chevron, and Shell (15 February 1978).

3-27 Personal Communication between Dr. R.F. Westerduin, KTI, Zoetermeer, Netherlands, and Mr. M.L. Whisman, BERC, Bartlesville, Okalahoma (25 August 1977).

3-28 M.L. Whisman, et al, "A Summary of Composition Variations Among 30 Used Lubricating Oils Selected for Seasonal and Geographic Significance", *Waste Lubricating Oil: Part 4,* Bartlesville Energy Research Center, Bartlesville, Oklahoma (October 1976).

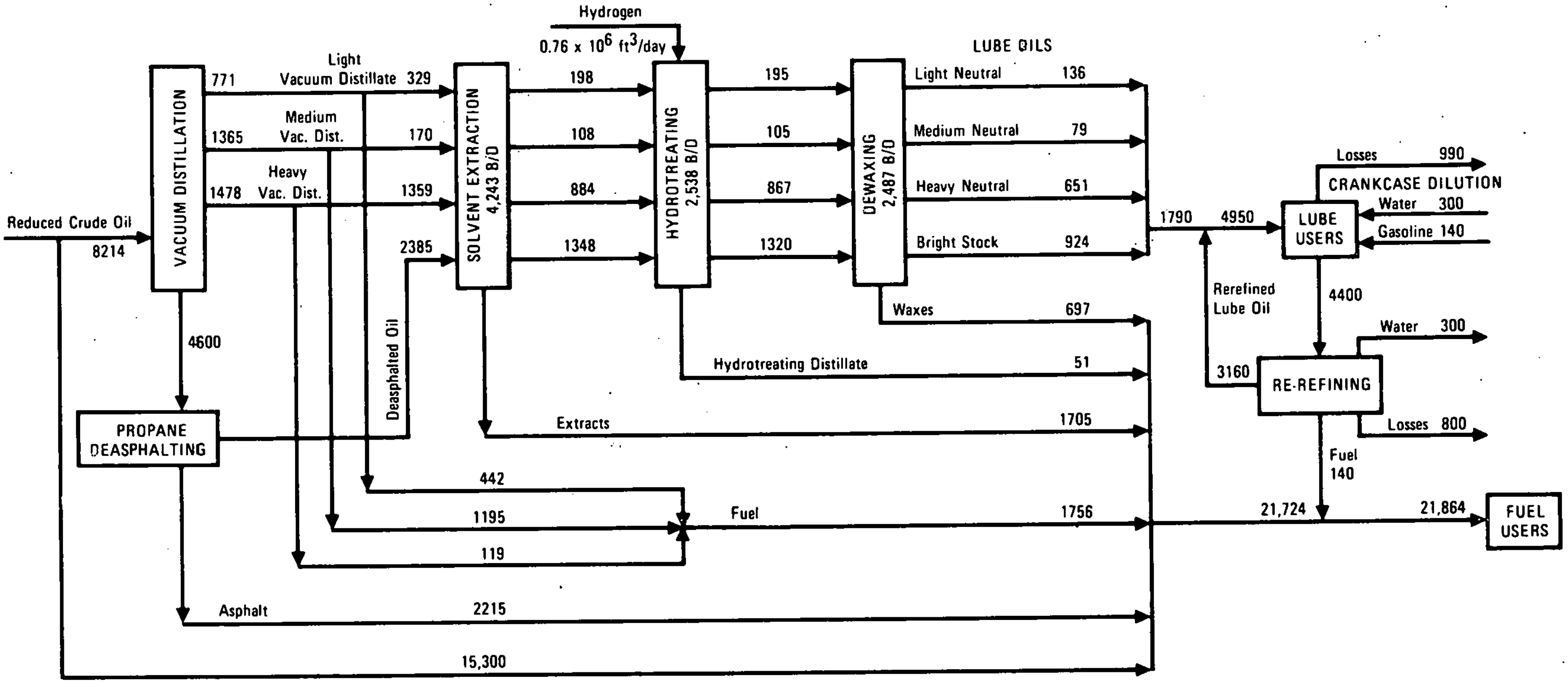
# SECTION 4

# ASSESSMENT OF USED OIL UTILIZATION

## 4.1 GENERAL

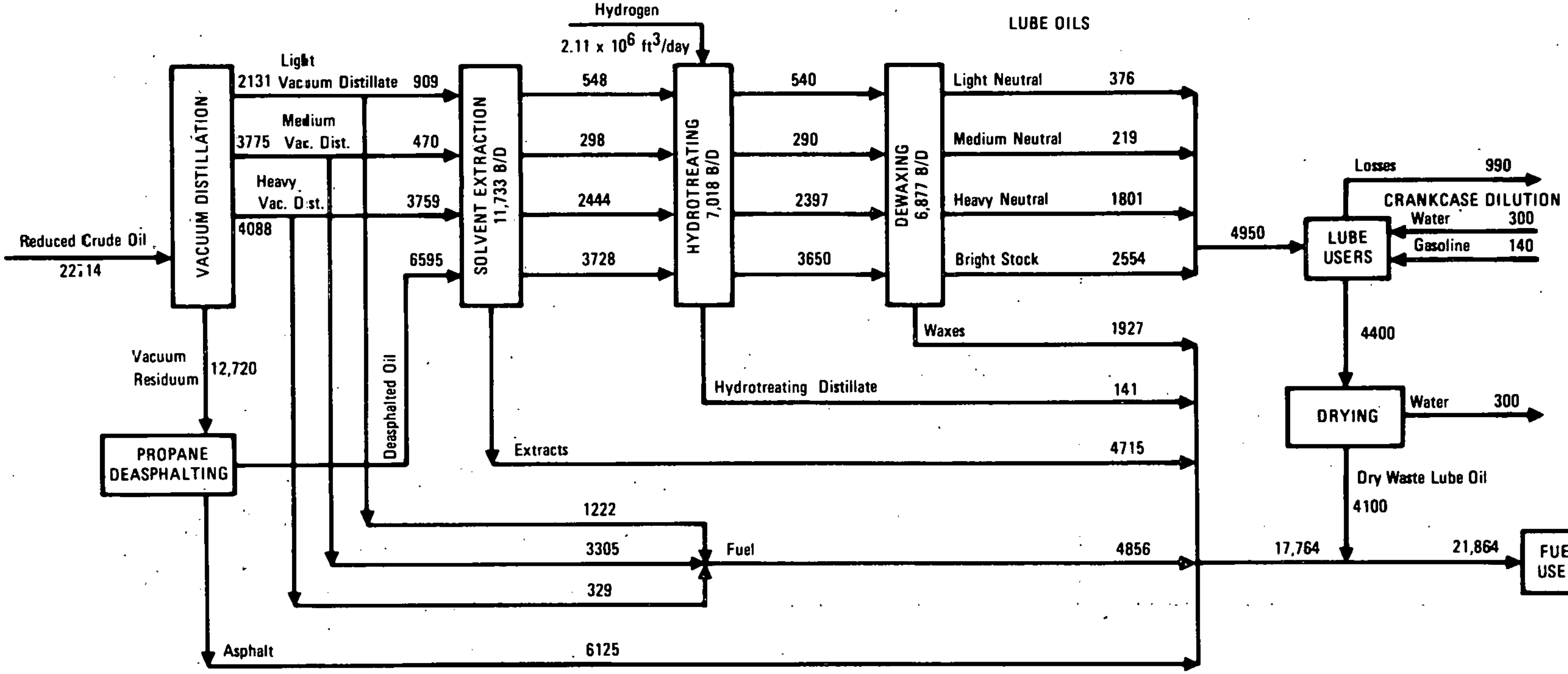
The subject of used oil utilization has been previously addressed by Teknekron, who assessed energy conservation aspects of re-refining used oil relative to burning (Ref. 4-1). Their approach made use of a refinery model which supplied fixed amounts of fuels and lubricants obtained from a constant supply of used oil and variable amounts of virgin crude. Schematics of this refinery operation for (1) re-refining used oil to lube oil, and (2) processing used oil to fuel have been extracted and are presented in Figures 4-1 and 4-2, respectively. In this model, used oil re-refining was based on the acid-clay process, with specific assumptions regarding process yield and energy. Virgin lube production made use of typical refinery processes, such as propane deasphalting, solvent extraction, hydrotreating and dewaxing, again with specific assumptions regarding process yield and energy. Also, Teknekron assumed dehydration of the used oil prior to burning, which resulted in an expenditure of about 1400 Btu per gallon of used oil feedstock. Based on the refinery model and assumptions used, a material and energy balance showed that re-refining used oil in lieu of burning resulted in an energy saving of 20,970 Btu per gallon of total lube oil demand. Since lube oil demand was assumed by Teknekron to be 12.5 percent higher than the available used oil feedstock, the energy based on the amount of used oil re-refined is 23,590 Btu per gallon of used oil feedstock.

Additionally, Teknekron performed a sensitivity analysis to show the effect on energy savings due to changing several parameters, including refinery process energy, process yield, and re-refinery losses. These effects are illustrated in Table 4-1 (Ref. 4-1).



Note: All throughputs expressed in barrels per stream day.

Figure 4-1. Refinery Model with All Used Oil Re-Refined to Lube Oil (Ref. 4-1)



Note: All throughputs expressed in barrels per stream day.

Figure 4-2. Refinery Model with All Used Oil Burned (Ref. 4-1)

Table 4.1. Energy Saving Sensitivities, (Ref. 4-1)

| Parameter & Magnitude Of Variation | Net Energy Savings, Btu per Gallon of Used Oil Feedstock | Percent Change in Net Energy Savings |
|---|---|---|
| Baseline | 23,590 | - |
| Virgin Lube Oil Refinery Process Energy | | |
| + 50% | 50,000 | +112 |
| - 55% | -0- | -100 |
| Virgin Lube Oil Refinery Yield | | |
| + 25% | 15,750 | - 33 |
| - 25% | 36,470 | + 55 |
| Used Oil Re-Refinery Losses | | |
| + 50% | 3,950 | - 83 |
| - 50% | 43,290 | + 84 |

## 4.2 PARAMETRIC ANALYSIS

### 4.2.1 Methodology

While Teknekron's sensitivity analysis is limited to three specific parameters, a parametric analysis was performed by The Aerospace Corporation which is broader in scope and considers the following five parameters over a wide range of numerical values:

1. Process energy for refining virgin lube oil.
2. Process energy for re-refining used oil.
3. Process yield of re-refined oil.
4. Process energy to pretreat used oil prior to burning.
5. Process yield of pretreated used oil to be used as a fuel.

In order to provide visibility into the elements affecting energy savings, these parameters are addressed as two groups. The first group contains those parameters related to the production of lube oil, both virgin and re-refined, whereas the second group, which is discussed in subsection 4.2.3, contains the parameters related to pre-treatment of used oil prior to burning. The energy balance for the case of re-refining in lieu of burning may be represented by the following two scenarios.

Scenario 1: Energy Balance for Re-Refining Used Oil

This energy balance consists of a summation of the energy required to re-refine used oil, plus the energy required to refine virgin lube oil needed to supply additional lube oil equal to re-refinery losses, plus the energy content of the virgin crude used in the manufacture of virgin lube oil, minus the energy content available from re-refinery by-products (overhead distillates).

$$E_{\text{re-refining}} = [E_{rr}] + [(1 - Y_{rr}) \times E_r] + [(1 - Y_{rr}) \times E_l] - [O_h \times E_{oh}] \qquad \text{(Eq. 4-1)}$$

where $E_{rr}$ = Re-refining process energy for used oil, Btu per gallon feedstock.

$Y_{rr}$ = Re-refinery yield, gallon product per gallon feedstock.

$E_r$ = Refinery process energy for virgin lube oil, Btu per gallon product.

$E_l$ = Heat content of virgin lube oil, Btu per gallon.

$O_h$ = Overhead distillate yield from used oil, gallon per gallon feedstock.

$E_{oh}$ = Heat content of overhead distillates, Btu per gallon.

Scenario 2: Energy Balance for Burning Used Oil

This energy balance consists of a summation of the energy requirements to refine virgin lube oil, plus the energy content of the virgin crude used in the manufacture of virgin lube oil, minus the energy content available from burning used oil.

$$E_{\text{burning}} = [E_r] + [E_l] - [E_{uo}] \qquad \text{(Eq. 4-2)}$$

where $E_r$ = Refinery process energy for virgin lube oil, Btu per gallon product.

$E_l$ = Heat content of virgin lube oil, Btu per gallon.

$E_{uo}$ = Heat content of used oil feedstock, Btu per gallon.

The net energy saving consists of the energy balance for re-refining used oil, minus the energy balance for burning. Subtracting the two energy balances yields the following expression for net energy saving:

$$E_s = [-E_{rr} + (Y_{rr} \times (E_r + E_l)) - E_{uo} + (O_h \times E_{oh})] \qquad \text{(Eq. 4-3)}$$

where

$E_s$ = Energy saving due to re-refining used oil, Btu per gallon used oil feedstock.

$E_{rr}$ = Re-refining process energy for used oil, Btu per gallon feedstock.

$Y_{rr}$ = Re-refinery yield, gallon product per gallon feedstock.

$E_r$ = Refinery process energy for virgin lube oil, Btu per gallon product.

$E_l$ = Heat content of virgin lube oil, Btu per gallon.

$E_{uo}$ = Heat content of used oil feedstock, Btu per gallon

$O_h$ = Overhead distillate yield from used oil, gallon per gallon feedstock.

$E_{oh}$ = Heat content of overhead distillates, Btu per gallon.

The validity of Equation 4-3 was checked by comparing results obtained from this equation for specific cases with the corresponding data published in Ref. 4-1. Equation 4-3 yielded numerically higher energy savings by approximately 1400 Btu per gallon used oil feedstock, which corresponds to the assumed amount of energy utilized to pretreat used oil prior to burning. Additional checks were then made after further analysis revealed that the results from the Teknekron refinery model could be reproduced exactly by Equation 4-4, shown below. Results obtained from Equations 4-3 and 4-4 showed agreement for a wide range of parameter values, except for the aforementioned difference of about 1400 Btu per gallon.

$$E_s = [\,-E_{rr} + (Y_{rr} \times E_r) - (L_{rr} \times E_{duo}) + E_{dh}\,] \qquad \text{(Eq. 4-4)}$$

where

$E_s$ = Energy saved due to re-refining used oil, Btu per gallon used oil feedstock.

$E_{rr}$ = Re-refinery process energy for used oil, Btu per gallon feedstock.

$Y_{rr}$ = Re-refinery yield, gallon product per gallon feedstock.

$L_{rr}$ = Re-refinery losses, gallon loss per gallon feedstock.

$E_r$ = Refinery process energy for virgin lube oil, Btu per gallon product.

$E_{duo}$ = Heat content of dehydrated used oil, Btu per gallon feedstock.

$E_{dh}$ = Energy required to dehydrate used oil, Btu per gallon feedstock.

### 4.2.2 Energy Savings Due to Re-Refining

Using Equation 4-3, parametric data were computed relating energy savings due to re-refining to the process energy requirement for the production of virgin and re-refined lube oil, and to re-refinery yield. The results of this analysis are presented in Figures 4-3 through 4-6 for re-refinery yields of 60, 70, 80, and 88.8 percent, respectively. An 88.8 percent yield is the limiting case in this parametric analysis because the used oil feedstock was assumed to include 4.2 percent overheads and 7.0 percent water. The net heating values of the various petroleum products used in the analysis are (1) 124,750 Btu per gallon for used oil, (2) 131,500 Btu per gallon for overhead distillates, and (3) 134,250 Btu per gallon for lube oil. Re-refining process energies of 0 to 25,000 Btu per gallon feedstock were considered in this analysis, encompassing estimated values of 7,500 Btu per gallon for the acid-clay process and 20,000 Btu per gallon for some solvent extraction processes. Virgin lube oil refinery energies of 25,000 Btu to 100,000 Btu per gallon of lube oil were considered. An example is included in Figure 4-3 for a virgin lube oil process energy of 65,000 Btu per gallon, a used oil re-refinery process energy of 7,000 Btu per gallon, and a re-refining process yield of 60 percent, resulting in a net energy loss due to re-refining of 6,700 Btu per gallon of used oil feedstock.

As indicated in Figures 4-3 through 4-6, for a given re-refinery yield, energy savings vary linearly with re-refining process energy and the product of refining process energy and re-refinery yield. Since refinery process energy requirements for virgin lube production are about 1/2 to 1 order of magnitude greater than re-refining process energy requirements for used oil, refinery process energy has a dominant effect on the energy-saving potential. Figure 4-7 is a composite of the preceding figures and illustrates the effect of re-refining yield on energy savings. Energy savings vary as a linear function of yield and the sum of refining process energy and heating value of lube oil. As shown in this figure, energy savings vary from about 1800 Btu per percent

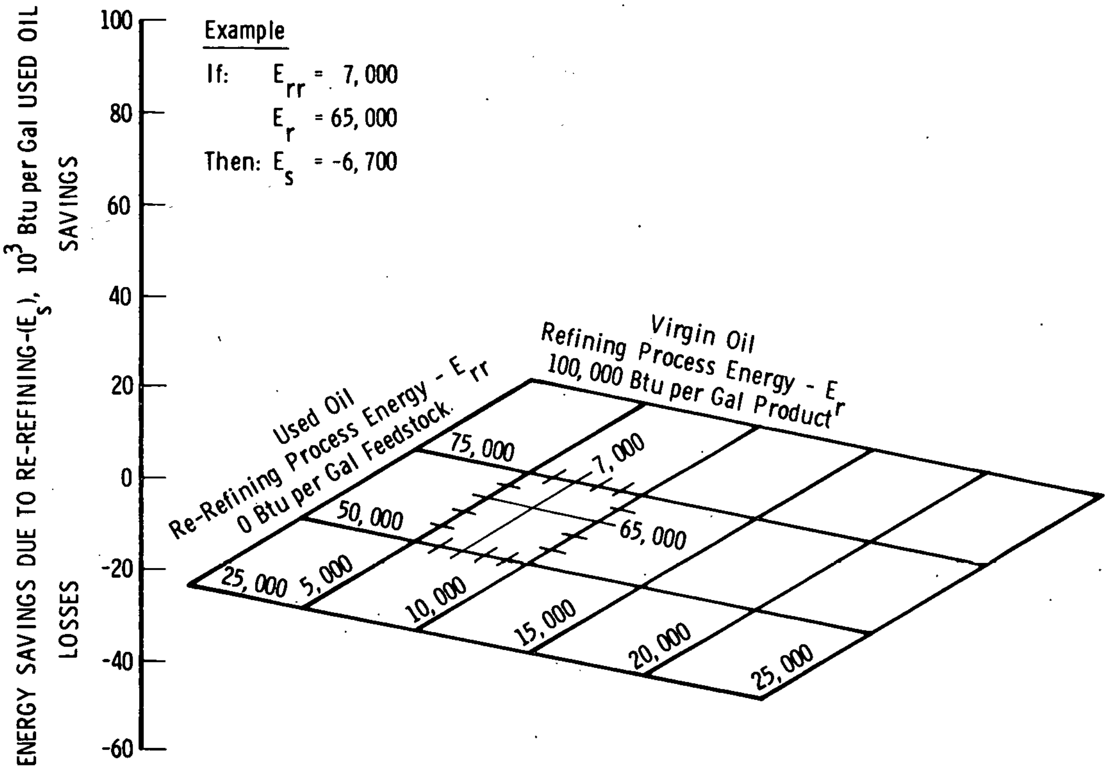


Figure 4-3. Energy Savings Due to Re-Refining for a 60 Percent Process Yield

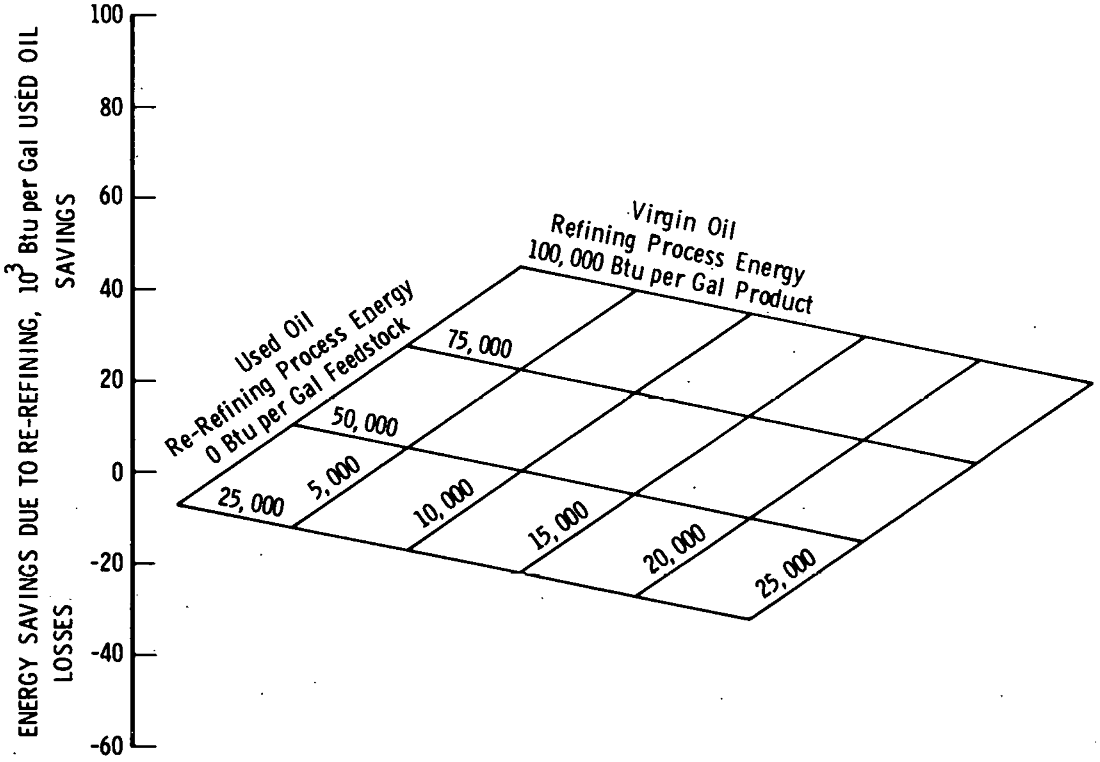


Figure 4-4. Energy Savings Due to Re-Refining for a 70 Percent Process Yield

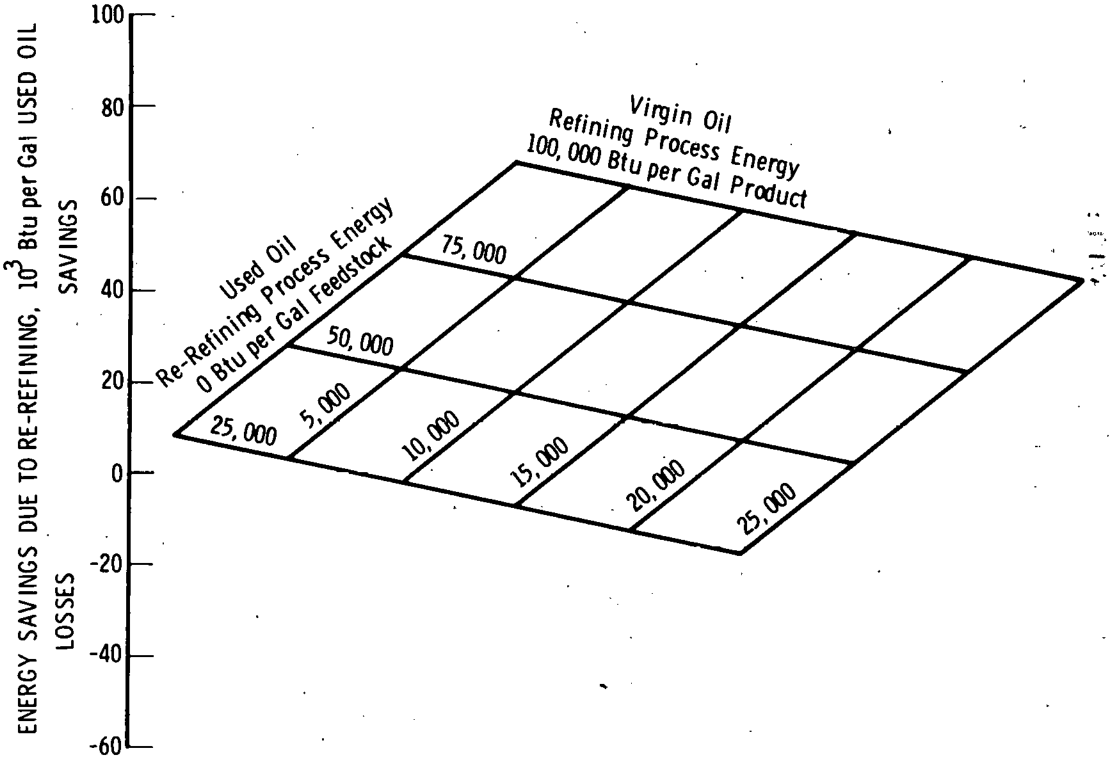


Figure 4-5. Energy Savings Due to Re-Refining, for an 80 Percent Process Yield

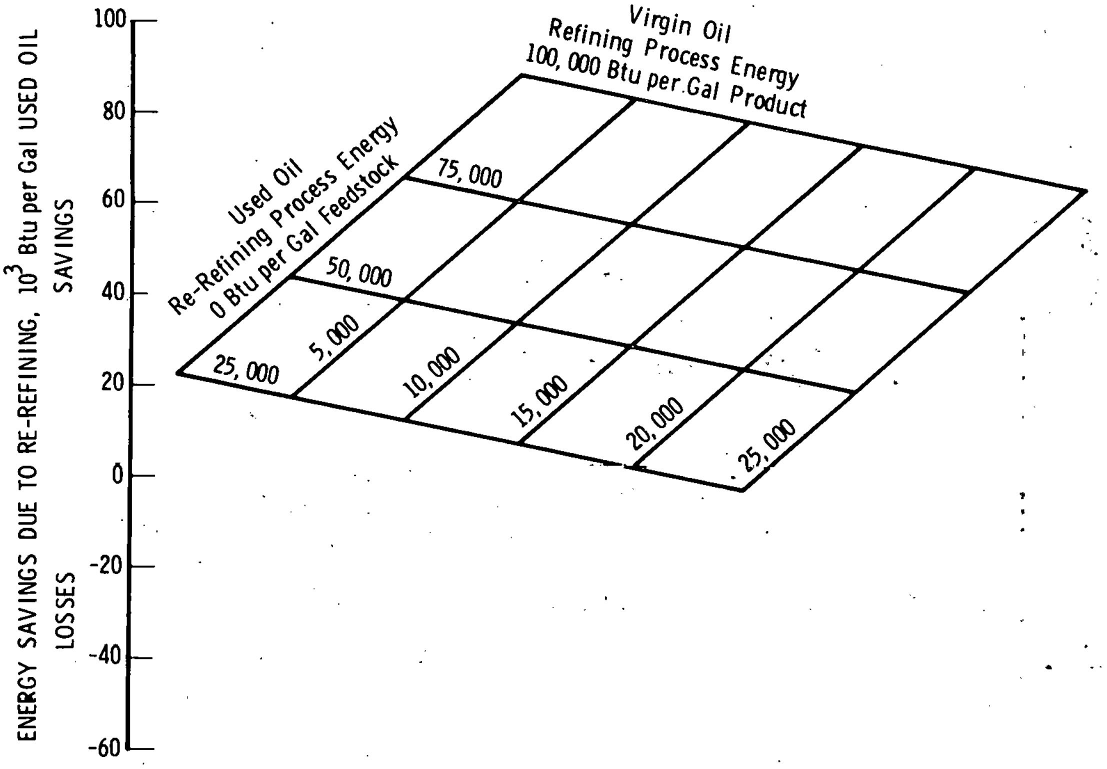


Figure 4-6. Energy Savings Due to Re-Refining, for an 88.8 Percent Process Yield

yield of re-refined oil for low values of refinery energy requirements to about 2400 Btu per percent yield at high values.

The data shown in Figures 4-3 through 4-6 are presented in Figure 4-8 in nomograph form, permitting direct interpolation for specific re-refinery energy values and process yield. The example included in Figure 4-8 is for a virgin oil refining process energy of 100,000 Btu per gallon of product, a used oil re-refinery yield of 76 percent and a used oil re-refinery process energy of 8,000 Btu per gallon of feedstock. These conditions produce a net energy saving of 50,500 Btu per gallon of used oil feedstock.

### 4.2.3 Incremental Energy Savings Due to Pretreatment Prior to Burning

The energy savings data shown in Figures 4-3 through 4-6 were computed without consideration of pretreating the used oil prior to burning. Conversely, the Reference 4-1 analysis assumed dehydration, which required an energy expenditure of about 1400 Btu per gallon of feedstock.

To account for pretreatment energy requirements and hydrocarbon losses, the parametric technique employed in this analysis involves the calculation of an incremental energy saving. This energy saving is then added to the energy saving due to re-refining, which is presented in Figures 4-3 through 4-6 for the case of burning used oil without pretreatment. Equation 4-3 was modified by changing the Scenario 2 energy balance for burning to reflect pretreatment process yields and energy requirements.

#### Scenario 3: Energy Balance for Burning Used Oil When Pretreatment is Required

This energy balance consists of a summation of the energy requirement to refine virgin lube oil, plus the energy content of the virgin crude that was manufactured into virgin lube oil, minus the energy content of the fuel oil obtained from the pretreated used oil, minus the energy content of the overheads obtained from the used oil, plus the energy requirement to pretreat the used oil.

$$E_{burning} = [E_r] + [E_l] - [Y_p \times E_{po}] - [O_h \times E_{oh}] + [E_p] \qquad \text{(Eq. 4-5)}$$

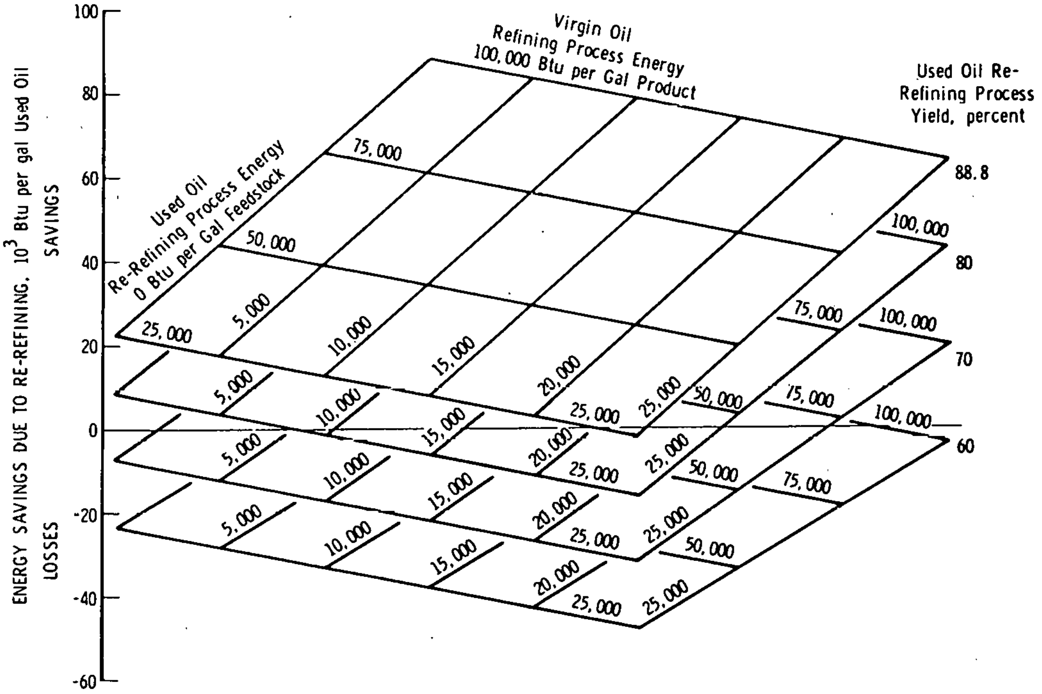


Figure 4-7. Energy Savings Due to Re-Refining for Various Process Yields

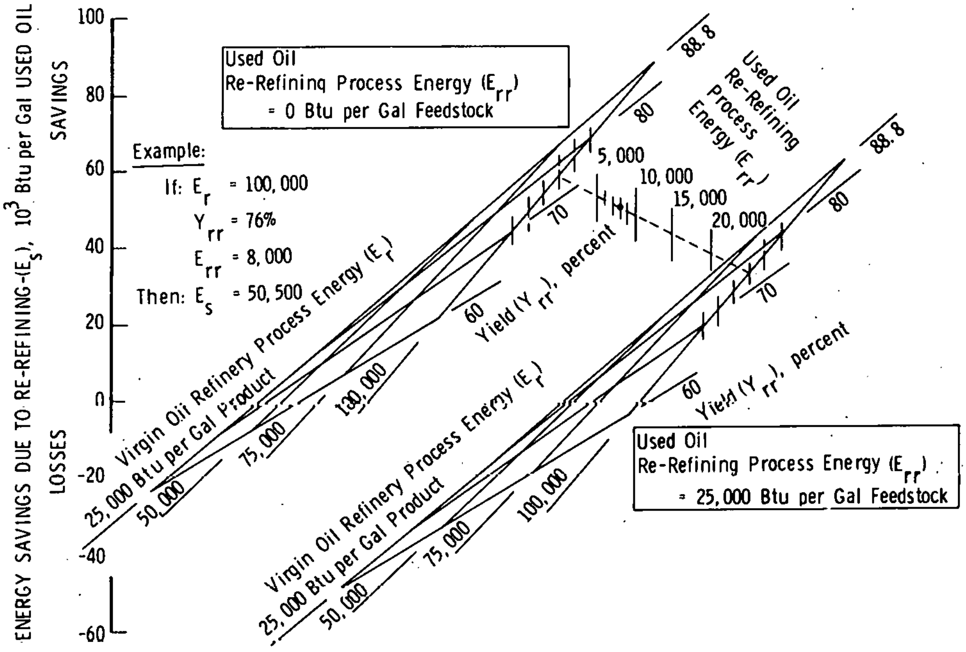


Figure 4-8. Nomograph Showing Energy Savings Due to Re-Refining

The net energy savings, when pretreatment is required prior to burning, then consists of the previously shown energy balance for re-refining used oil, minus the newly developed energy balance for burning with pretreatment. By subtracting the new equation formed (not shown here) from Equation 4-3, the following relationship for the incremental savings due to re-refining is obtained:

$$\Delta E_s = [E_{uo} - (O_h \times E_{oh}) - (Y_p \times E_{po}) + E_p] \qquad \text{(Eq. 4-6)}$$

where

$\Delta E_s$ = Incremental energy savings due to re-refining used oil when considering pretreatment prior to burning, Btu per gallon used oil feedstock.

$E_{uo}$ = Heat content of used oil feedstock, Btu per gallon.

$O_h$ = Overhead distillate yield from used oil, gallon per gallon feedstock.

$E_{oh}$ = Heat content of overhead distillates, Btu per gallon.

$Y_p$ = Pretreatment yield of fuel from used oil, gallon product per gallon feedstock.

$E_{po}$ = Heat content of pretreated used oil, Btu per gallon.

$E_p$ = Pretreatment process energy, Btu per gallon feedstock.

Results obtained from Equation 4-6 are presented in Figure 4-9, showing data for a range of pretreatment yields of 60 percent to 88.8 percent, and a range of pretreatment process energy requirements of 0 to 25,000 Btu. The 88.8 percent yield and 0 Btu case corresponds to no pretreatment based on the assumed 11.2 percent water and overhead content of the used oil, which was also used for the parametric energy savings calculations previously discussed. Figure 4-9 illustrates the rapid increase in energy savings due to re-refining as the yield of burnable fuel decreases with the decline in pretreatment yield. Each percent loss of yield increases the advantage of re-refining over burning by about 1300 Btu per gallon of used oil feedstock. The incremental change in energy savings due to pretreatment process energy requirements is one-to-one.

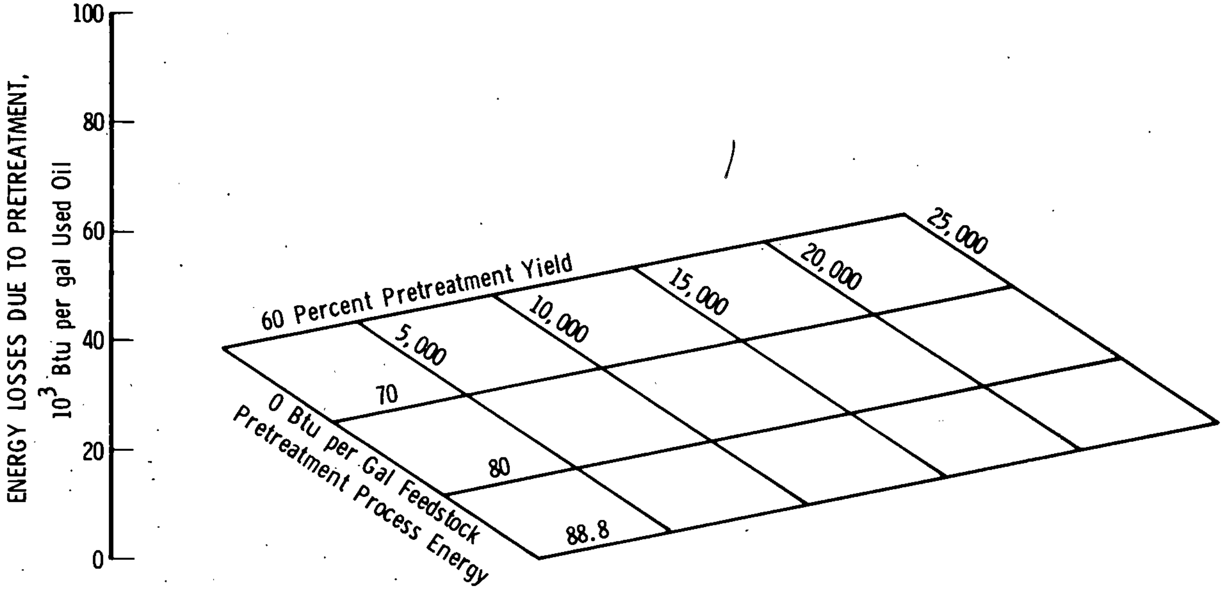


Figure 4-9. Energy Losses Due to Pre-Treating Used Oil Prior to Burning

## 4.3 CLOSED LOOP ENERGY ANALYSES

The parametric data shown in the previous subsections provides insight into the variation of energy savings due to the various refining, re-refining, and pretreatment parameters. However, to accurately assess the effect of re-refining at the national level it is necessary to examine the overall petroleum production system and to determine the net change in total energy requirements. The following subsections assess energy savings as measured by changes in the total petroleum energy input of the refineries to satisfy a fixed demand for fuels and lubricants.

### 4.3.1 Methodology

This analysis makes use of a closed loop energy model which provides for a fixed demand for lubes, fuels, and other petroleum products. This demand is satisfied with products obtained from virgin crude and used oil sources. The significant difference of this approach relative to the parametric analysis described in Section 4.2 and the method used by other investigators is that it accounts for all energy expenditures related to changes in refinery operations. This is important because certain refinery operations are traditionally not assigned in terms of energy consumption to any specific product. This is supported by Reference 4-1, which states that "Although atmospheric and vacuum distillation of crude oil are energy intensive processes, it is quite difficult to justify assigning a given portion of the energy consumed to the manufacture of lube oil . . . . Hence, energy consumed in the atmospheric and vacuum distillation steps has been omitted from the present calculation." Energy for these steps has been included in this analysis, which effectively recognizes that it requires more than one Btu of energy input into a refinery to produce a Btu of output. On an overall basis, approximately 10 percent more Btu's enter a refinery than leave as products.

In the basic energy model developed here crude oil enters the refinery and is subjected to (1) atmospheric fractionation, (2) vacuum fractionation, (3) lube oil refining processes, and (4) other refining processes. The process energy requirements of each step are apportioned to each product produced on the basis of the energy content of the product. That is, if 20 percent of the product (on a Btu basis) from vacuum fractionation goes to lube oil and 80 percent to fuel oil, then the energy required for fractionation is distributed on a 20/80 basis to lube oil/fuel oil. Output from this refinery goes to satisfy (1) lube oil demand, (2) fuel oil demand, and (3) other petroleum demand.

Total product demand is constant and satisfied in accordance with three scenarios. These are:

Scenario 1: Dumping

All used oil generated is disposed of by dumping. Lube and fuel demands are satisfied from virgin sources.

Scenario 2: Burning

All used oil generated is subjected to pretreatment for contaminant removal and then utilized as a fuel. The remaining fuel requirement, and all lube oil demand, is supplied from virgin sources.

Scenario 3: Re-Refining

All used oil generated is re-refined and is re-used as a lube oil. The remaining lube requirement, and all fuel demand (except for that portion provided by the overhead distillates obtained from re-refining), is supplied from virgin sources.

The three closed loop energy models are shown in Figures 4-10 through 4-12. Energy flows are shown on each figure, with a list of symbols shown in Table 4-2. Also shown in Figures 4-10 through 4-12 are analytical expressions for the total volumetric amounts of petroleum utilized and for the incremental fuel and lube demands supplied from used oil.

For each scenario, the total energy used is the sum of the energy flows Ⓐ through Ⓗ, as shown in the figures. By summing these terms and subtracting the resultant for each scenario from one another, expressions are obtained for assessing the utilization of used oil. The basic equations are as follows:

Dumping

$$E_{total} = [E_r \times L_d] \times [E_l \times L_d] + [E_v \times L_d] + [E_v \times F_d] + [E_{rc} \times F_d] + [E_a \times P_{total}] + [E_{op} \times P_{od}] = [E_{od} \times P_{od}] \quad \text{(Eq. 4-7)}$$

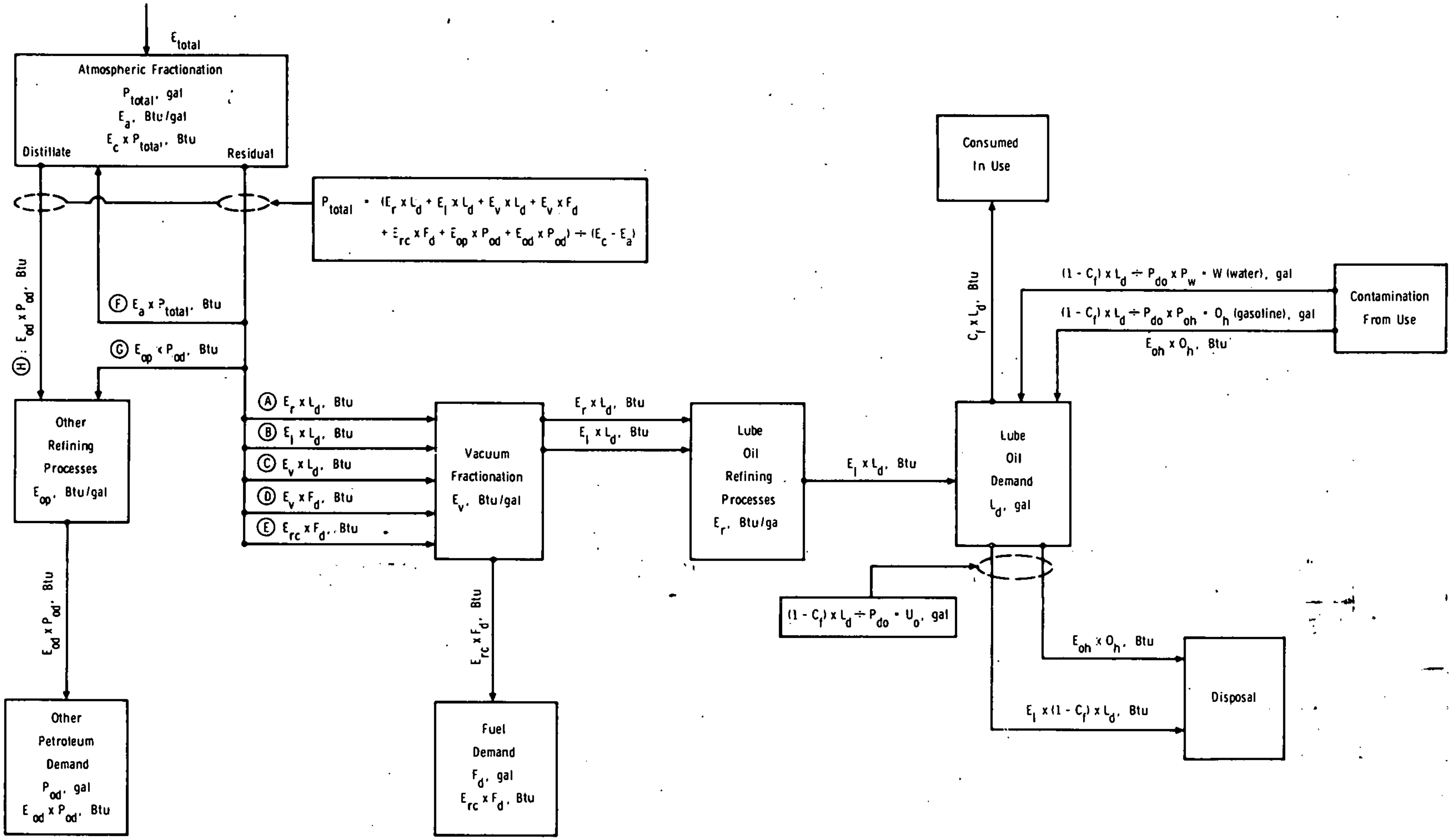


Figure 4-10. Closed Loop Energy Model for Disposal of Used Oil by Dumping

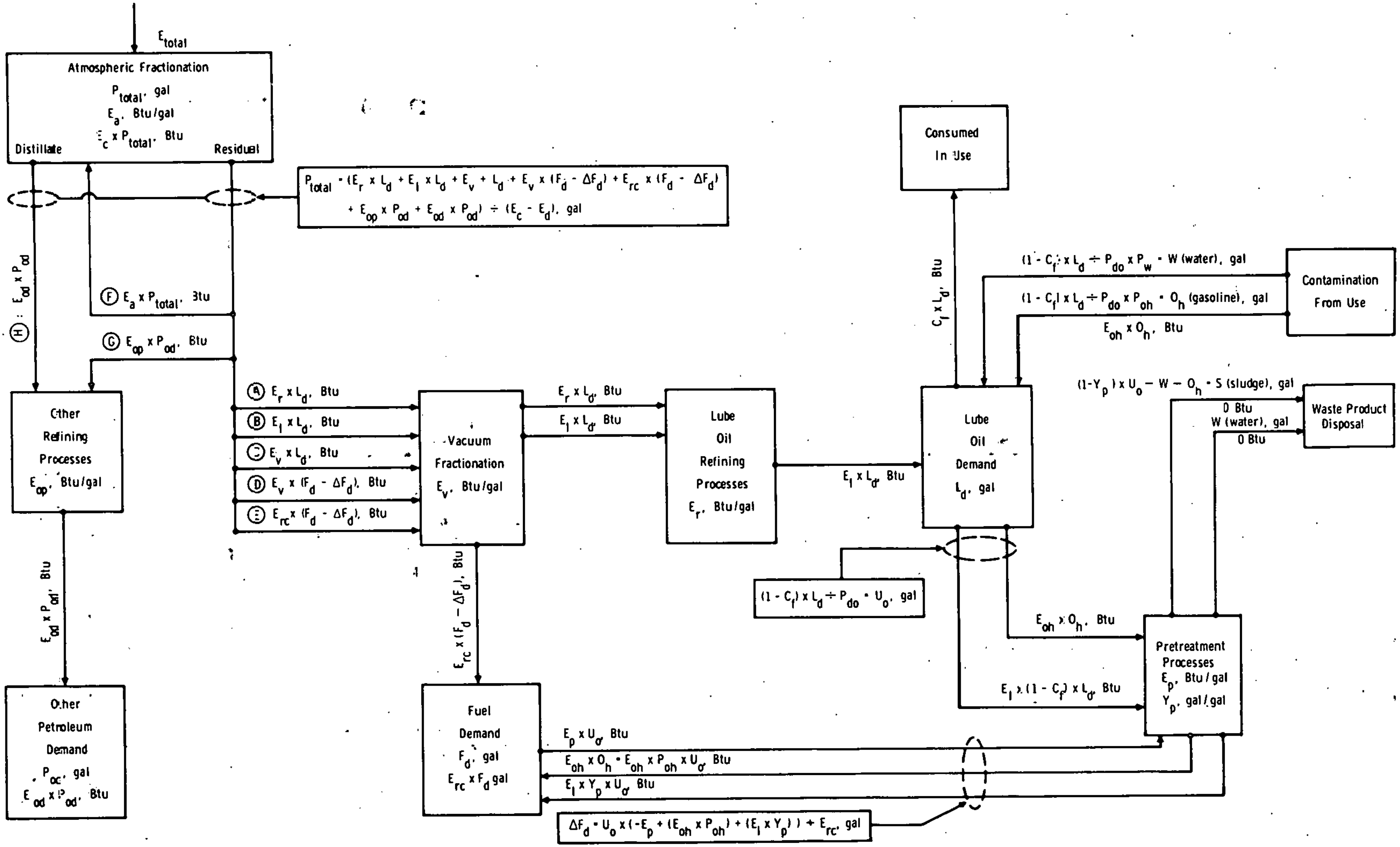


Figure 4-11. Closed Loop Energy Model for Utilization of Used Oil by Burning

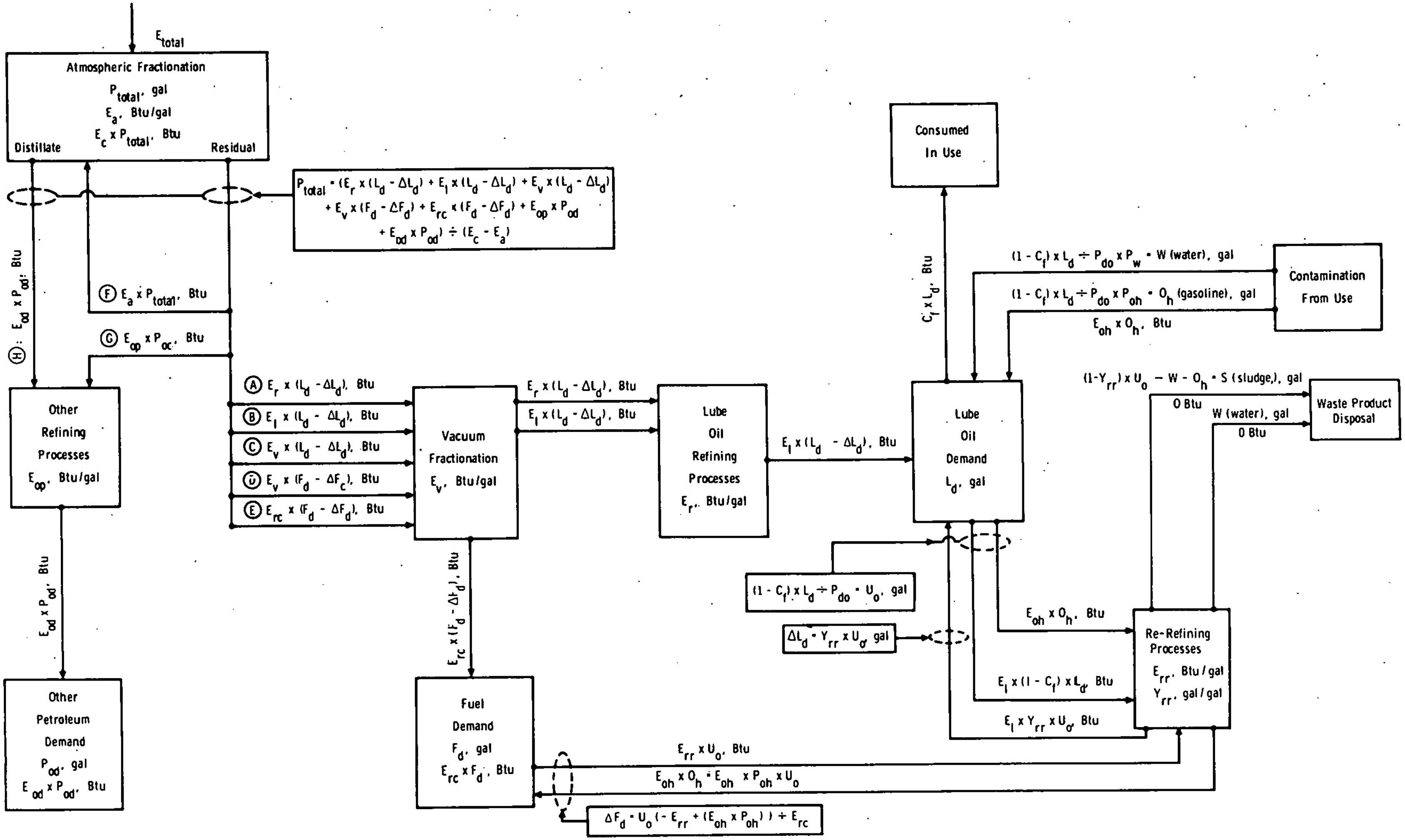


Figure 4-12. Closed Loop Energy Model for Utilization of Used Oil by Re-Refining

Table 4-2. List of Symbols for Closed Loop Energy Model

Ⓐ = Total process energy consumed in the production of virgin lube oil, excluding atmospheric and vacuum fractionation, Btu.

Ⓑ = Total energy content of virgin lube oil, Btu.

Ⓒ = Total process energy for vacuum fractionation of lube oil portion of total charge stock, Btu.

Ⓓ = Total process energy for vacuum fractionation of fuel oil portion of total charge stock, Btu.

Ⓔ = Total energy content of virgin fuel oil, Btu.

Ⓕ = Total process energy for atmospheric fractionation of crude oil, Btu.

Ⓖ = Total process energy for processing atmospheric fractionation distillates into other petroleum products, Btu.

Ⓗ = Total energy content of atmospheric fractionation distillates, Btu.

$C_f$ = Lube oil fraction consumed in service, gallon consumed per gallon demand.

$E_a$ = Process energy required for atmospheric fractionation of crude petroleum, Btu per gallon charge.

$E_c$ = Energy content of crude petroleum, Btu per gallon.

$E_l$ = Energy content of lube oil, Btu per gallon.

$E_{od}$ = Energy content of other petroleum products produced from atmospheric fractionation distillate, Btu per gallon.

$E_{oh}$ = Energy content of overhead distillates obtained from re-refining used oil, Btu per gallon.

$E_{op}$ = Process energy required for producing other petroleum products from atmospheric fractionation distillate, Btu per gallon charge.

$E_p$ = Process energy required to pretreat used oil prior to burning, Btu per gallon product.

Table 4-2. List of Symbols for Closed Loop Energy Model (Continued)

$E_r$ = Process energy required to produce virgin lube oil, Btu per gallon product.

$E_{rc}$ = Energy content of reduced crude obtained from atmospheric distillation, Btu per gallon.

$E_{rr}$ = Process energy required to produce re-refined lube oil, Btu per gallon charge.

$E_{total}$ = Total energy content of all crude petroleum processed, Btu.

$E_v$ = Process energy required for vacuum fractionation of reduced crude obtained from atmospheric distillation, Btu per gallon charge.

$F_d$ = Total fuel demand, gallons.

$L_d$ = Total lube oil demand, gallons.

$O_h$ = Total overhead distillate (gasoline contaminants) contained in used oil, gallons.

$P_{do}$ = Lube oil fraction contained in used oil (dry oil content), gallons per gallon.

$P_{oh}$ = Gasoline contaminant fraction contained in used oil (overheads), gallons per gallon.

$P_w$ = Water contaminant fraction contained in used oil, gallons per gallon.

S = Total amount of waste petroleum products (sludge) produced by pretreating and re-refining processes, gallons.

$U_o$ = Total amount of used oil generated, gallons.

W = Total water contaminants contained in used oil, gallons.

$Y_p$ = Yield of fuel oil from pretreatment process, gallons per gallon charge.

$Y_{rr}$ = Yield of lube oil from re-refining process, gallons per gallon charge.

$\Delta F_d$ = Total change in virgin fuel oil demand due to availability of fuel from used oil, gallons.

$\Delta L_d$ = Total change in virgin lube oil demand due to availability of lube oil from used oil, gallons.

where:

$$\begin{aligned}P_{total} = \Big[&[E_r \times L_d] + [E_l \times L_d] + [E_v \times L_d] \\ &+ [E_v \times F_d] + [E_{rc} \times F_d] + [E_{op} \times P_{od}] + [E_{od} \times P_{od}]\Big] \\ &\div \Big[[E_c - E_a]\Big]\end{aligned} \tag{Eq. 4-8}$$

Burning

$$\begin{aligned}E_{total} = &[E_r \times L_d] + [E_l \times L_d] + [E_v \times L_d] + [E_v \times (F_d - \Delta F_d)] \\ &+ [E_r \times (F_d - \Delta F_d)] + [E_a \times P_{total}] + [E_{op} \times P_{od}] \\ &+ [E_{od} \times P_{od}]\end{aligned} \tag{Eq. 4-9}$$

where:

$$\begin{aligned}P_{total} = \Big[&[E_r \times L_d] + [E_l \times L_d] + [E_v \times L_d] \\ &+ [E_v \times (Fd - \Delta F_d)] + [E_r \times (F_d - \Delta F_d)] + [E_{op} \times P_{od}] \\ &+ [E_{od} + P_{od}]\Big] \div \Big[[E_c - E_a]\Big]\end{aligned} \tag{Eq. 4-10}$$

and:

$$\begin{aligned}\Delta F_d = \Big[&U_\sigma \times [ - E_p + (E_{oh} \times P_{oh}) + (E_l \times Y_p)] \\ &\div [E_{rc}]\Big]\end{aligned} \tag{Eq. 4-11}$$

Re-Refining

$$\begin{aligned}E_{total} = &[E_r \times (L_d - \Delta L_d)] + [E_l \times (L_d - \Delta L_d)] + [E_v \times (L_d - \Delta L_d)] \\ &+ [E_v \times (F_d - \Delta F_d)] + [E_{rc} \times (F_d - \Delta F_d)] \\ &+ [E_a \times P_{total}] + [E_{op} \times P_{od}] + [E_{od} \times P_{od}]\end{aligned} \tag{Eq. 4-12}$$

where:

$$\begin{aligned}P_{total} = \Big[&[E_r \times (L_d - \Delta L_d)] + [E_l \times (L_d - \Delta L_d)] \\ &+ [E_v \times (L_d - \Delta L_d)] + [E_v \times (F_d - \Delta F_d)] \\ &+ [E_{rc} \times (F_d - \Delta F_d)] + [E_{op} \times P_{od}] \\ &+ [E_{od} \times P_{od}]\Big] \div \Big[[E_c - E_a]\Big]\end{aligned} \tag{Eq. 4-13}$$

and:

$$\Delta F_d = \Big[U_o \times [ - E_{rr} + (E_{oh} \times P_{oh})] \div [E_{rc}]\Big] \tag{Eq. 4-14}$$

By subtracting the total energy requirement for burning from that for dumping, the net energy saving due to burning used oil in lieu of disposal by dumping is obtained. The resultant equation is:

$$E_{net_{d-b}} = \left[\left[\frac{E_c}{E_c - E_a}\right]\right] \times \left[[U_o]\right] \times \left[\left[\frac{E_v \times E_{rc}}{E_{rc}}\right] \times [-E_p + (E_{oh} \times P_{oh}) + (E_l \times Y_p)]\right] \qquad \text{(Eq. 4-15)}$$

In a similar manner, the net energy saving due to re-refining in lieu of disposal by dumping is given by:

$$E_{net_{d-r}} = \left[\left[\frac{E_c}{E_c - E_a}\right]\right] \times \left[[U_o]\right] \times \left[\left[\frac{E_v + E_{rc}}{E_{rc}}\right] \times [(E_{oh} \times P_{oh}) - E_{rr}] + [Y_{rr} \times (E_r + E_l + E_v)]\right] \qquad \text{(Eq. 4-16)}$$

Again, in a similar manner, the net energy saving due to re-refining in lieu of utilization by burning is given by:

$$E_{net_{b-r}} = \left[\left[\frac{E_c}{E_c - Ea}\right]\right] \times \left[[U_o]\right] \times \left[\left[\frac{E_v + E_{rc}}{E_{rc}}\right] \times [E_p - (E_l \times Y_p) - E_{rr}] + [Y_{rr} \times (E_r + E_l + E_v)]\right] \qquad \text{(Eq. 4-17)}$$

An examination of Figure 4-10 shows that disposal of used oil by dumping results in an energy waste, as shown in equation form below. It should be noted that dumping used oil not only results in the loss of the energy content of the used lube oil, but also in the loss of the energy contained within the gasoline diluent. From Figure 4-11, we have

$$E_{waste_d} = [E_{oh} \times O_h] + [E_l \times (1 - C_f) \times L_d] \qquad \text{(Eq. 4-18)}$$

or, by substitution:

$$E_{waste_d} = [U_o] \times [(E_{oh} \times P_{oh}) + (E_l \times P_{do})] \qquad \text{(Eq. 4-19)}$$

### 4.3.2 Energy Savings Due to Utilizing Used Oil

The above equations for assessing the energy-saving potential related to the utilization of used oil were applied to the two disposal methods, burning and re-refining, and to the seven re-refining processes discussed in Section 5, Part I; (1) acid-clay, (2) clay, (3) caustic-clay, (4) propane extraction, (5) distillation-hydrotreating, (6) BERC solvent, and (7) MZF solve

In this analysis, BERC's used oil composition, published in Ref. 4-2 and discussed in Section 2, and lower heating values as determined in Ref. 4-3, were used. Also, the assumption was made that pretreatment of used oil prior to burning is required. An intermediate level of pretreatment was assumed to provide an adequate level of contaminant removal to meet potential future requirements relative to environmental protection. Process energy requirements for atmospheric and vacuum fractionation of crude petroleum were taken from Nelson (Ref. 4-4), while virgin lube oil process energy was obtained from Section 2. Numerical values of these constants are shown in Table 4-3.

Table 4-3. Numerical Values of Constant Parameters Used in Assessing Used Oil Utilization

| Used Oil Composition, %[a] | |
|---|---|
| Overhead Distillates | 4.2 |
| Water | 7.0 |
| Lube Oil | 88.8 |
| **Heating Value (Lower) of Petroleum Products, Btu/gal[b]** | |
| Used Oil | 124,750 |
| Overhead Distillates | 131,500 |
| Lube Oil | 134,250 |
| Reduced Crude | 142,350 |
| **Pretreatment Prior to Burning, Process Parameters[c]** | |
| Yield | 84 % |
| Energy | 7,850 Btu/gal |
| **Refinery Energy for Crude Fractionation, Btu/gal Charge Stock[d]** | |
| Atmospheric | 3,150 |
| Vacuum | 4,000 |
| **Refinery Energy for Virgin Lube Oil Production, Btu/gal product[e]** | |
| Energy | 50,000 |

(a) BERC, (Ref. 4-2), with outlier data removed.

(b) Teknekron (Ref. 4-1), adjusted with Mobil Oil Data (Ref. 4-3)

(c) Section 2, for 1:1 oil-solvent ratio extraction.

(d) Nelson, (Ref. 4-4), average API gravity.

(e) Section 2, Texas mixed base crude.

The assessment of utilizing used oil relative to dumping uses Equations 4-15 and 4-16 (without the term $U_O$, to obtain data on a per unit basis) to calculate energy savings. Results are shown in Table 4-4. As would be expected, all utilization methods provide large energy savings relative to dumping used oil, amounting to well over 100,000 Btu per gallon. However, the magnitude of the energy savings is dependent upon the specific process utilized, showing a variation in savings of 28,020 Btu per gallon between the most efficient use, re-refining with the distillation-hydrotreating process, and the least efficient use, re-refining with the clay process.

Even though burning without pretreatment appears to be an efficient method of utilizing used oil, three of the re-refining processes are better (it could be four, depending on the "real" yield for propane extraction), and only one re-refining process is less efficient than burning with pretreatment.

The second assessment of utilizing used oil compares re-refining to burning. This is the more meaningful comparison because used lube oil dumping is a disposal method rather than a utilization technique, which has diminished since the rise in the cost of energy. Energy savings for the seven re-refining processes were calculated from Equation 4-17 (once again without the term $U_O$) and are shown in Table 4-5. In comparison to the large energy savings previously shown relative to dumping, energy savings relative to burning used oil are much more modest. Indeed, the clay process even indicates a small energy loss.

The acid-clay process has low process energy requirements, but also has a relatively low yield. As a result, only moderate energy savings of about 7000 Btu per gallon are obtained. Although not explicitly stated in the closed loop energy model, process waste products are disposed of with no credit given for energy recovery. In this study process wastes from all re-refining processes are considered hazardous and environmentally unacceptable for use in alternate applications such as recovery of hydrocarbons.

The clay process has a lower yield than the acid-clay process, resulting in an energy loss. While process energy requirements are lower than for any other process shown in Table 4-5, this feature could not compensate for the low yield.

## Table 4-4. Comparison of Energy Savings for Various Used Oil Utilization Methods Relative to Disposal by Dumping

| Method and Process | Process Parameters | | | Energy Savings, Btu/gal used oil | Status of Operations |
|---|---|---|---|---|---|
| | Yield, % used oil | Energy, Btu/gal used oil | Confidence Level* | | |
| Burning | | | | | |
| Without pretreatment for contaminant removal | 89[a] | 0 | HIGH | 131, 210 | Common Practice |
| With pretreatment for contaminant removal | 84 | 7, 860 | MED[b] | 116, 160 | Not in Use |
| Re-refining | | | | | |
| Acid-Clay | 65 | 7, 660 | HIGH | 122, 960 | Extensive Commercial |
| Clay | 60 | 7, 160 | MED | 113, 850 | Limited Commercial |
| Caustic-Clay | 62[c] | 10, 640 | MED | 135, 900 | Limited Commercial |
| Propane Extraction | 70[d] | 22, 570 | LOW[e] | 116, 900 | Limited Commercial in Europe |
| | 82[d] | 23, 550 | LOW[e] | 138, 980 | Limited Commercial in Europe |
| Distillation-Hydrotreating | 76 | 9, 820 | LOW[f] | 141, 870 | Pilot in Construction |
| BERC Solvent | 71 | 23, 150 | MED | 118, 210 | Pilot Plant |
| MZF Solvent | 76 | 18, 700 | LOW[f] | 132, 520 | Laboratory Glassware |

(a) Represents lube oil content of used oil.

(b) For a medium level of pretreatment using solvent extraction process.

(c) Process also produces 16 percent fuel oil.

(d) Based on References 4-6 and 4-5, respectively.

(e) Conflicting yield data reported

(f) Inadequate data to substantiate yields.

*Degree to which Aerospace has confidence in the reported process parameters.

## Table 4-5. Comparison of Energy Savings for Various Re-Refining Processes Relative to Utilization by Burning(a)

| Re-Refining Process | Process Parameters | | Energy Savings, Btu/Gal Used Oil |
|---|---|---|---|
| | Yield, % Used Oil | Energy, Btu/Gal Used Oil | |
| Acid-Clay | 65 | 7,660 | 6,780 |
| Clay | 60 | 7,160 | - 2,330 |
| Caustic-Clay | 62(b) | 10,640 | 19,720 |
| Propane Extraction | 70(c) | 22,570 | 720 |
| | 82(c) | 23,550 | 22,810 |
| Distillation Hydrotreating | 76 | 9,820 | 25,690 |
| BERC Solvent | 71 | 23,150 | 2,040 |
| MZF Solvent | 76 | 18,700 | 16,350 |

(a) Used oil pretreated for contaminant removal prior to burning

(b) Process also produces 16% fuel oil

(c) Based on References 4-6 and 4-5, respectively

The caustic-clay process, which is in current use by one re-refiner, exhibits sizeable energy savings. Although the lube oil yield is only 62 percent the process generates a sizable fuel cut, amounting to about 16 percent of the feedstock. Therefore, the overall yield of petroleum products is high at 78 percent. This high yield, combined with the relatively modest energy requirements results in considerable energy savings. Of course, the fuel cut is not considered a waste product and full credit is given in the analysis for its energy content. This credit was calculated separately and added to the results obtained from the closed loop energy equations, which do not consider a fuel cut.

Two sets of numerical values are shown for the propane extraction process, reflecting yields of 70 and 82 percent. These data, which are based on the IFP Selectropropane process, were obtained from two sources. As previously discussed in Section 2, the differences in yields could not be resolved in the course of this study. Therefore, results for the propane extraction process should be used with caution. The propane extraction process has high energy requirements and requires a high yield to achieve energy savings. While substantial energy savings are obtained if a yield of 82 percent could indeed be achieved, the lower yield (70 percent) results in minimal energy savings amounting to less than 1000 Btu per gallon.

The BERC solvent process has high energy requirements which are offset by its relatively high yield of 71 percent. As a result, small savings of about 2,000 Btu per gallon are obtained.

The MZF solvent process also has relatively high energy requirements which are again offset by the high yield claimed, resulting in a relatively large energy saving of about 16,000 Btu per gallon.

### 4.3.3 Sensitivity Analysis for Energy Savings

As discussed in Section 3, yields claimed for various re-refining processes are not definitive for numerous reasons including (1) uncertainties in the amount of water and gasoline contamination in the feedstock, (2) uncertainties in process operating conditions, and (3) limited process development which has not progressed beyond the laboratory stage for many processes. Therefore, to provide insight into energy savings as affected by yield, a sensitivity analysis was conducted to show energy savings as a function of process yield. Energy savings data are shown in Figure 4-13 for the reported yield of each process and for a 10 percent change in yield. This figure illustrates the inherent difference in energy savings potential of the various processes, reflecting differences in process energy requirements. For example, yield for the distillation-hydrotreating process would have to drop from 76 percent to about 71 percent before the MZF solvent process would become an equivalent energy saver. As another example, the yield of the BERC solvent process would have to increase to almost 74 percent before it becomes equivalent to the acid-clay process.

Because of a lack of definitive data a sensitivity analysis was performed to show the effect of virgin lube oil process energy on energy savings. Figure 4-14 presents energy savings for the virgin lube process energy requirement determined in this study, and for a plus and minus 25 percent change in energy requirement. In terms of energy saving, not all re-refining processes investigated in this study are superior to the use of the used oil as a fuel. For example, if virgin lube oil process energy is as low as 19,000 Btu per gallon, as claimed by one lube oil manufacturer (see Section 2), then only the caustic-clay and distillation-hydrotreating processes would produce energy savings. The propane extraction process would also be included in this category if its real yield was indeed 82 percent, as claimed by IFP.

### 4.3.4 Potential for Future Petroleum Savings

Based on the lube oil demand projections of this study (Figures 8-1 and 8-2 of Part I) and the assumption that one-half of the total lube oil demand is available for re-refining (the other half is consumed in service) energy savings were computed to the year 2000. As shown in Figure 4-15, the widely used acid-clay process results in energy savings in the year 2000 of about 2.5 million barrels of petroleum equivalent, while the most efficient process, distillation-hydrotreating, saves about 9.5 million barrels per year. At the current price of foreign oil of about $12.70 per barrel, these savings correspond to a balance of payment savings of about 32 and 121 million dollars, respectively. The magnitude of the savings illustrates the desirability for developing new, efficient re-refining processes.

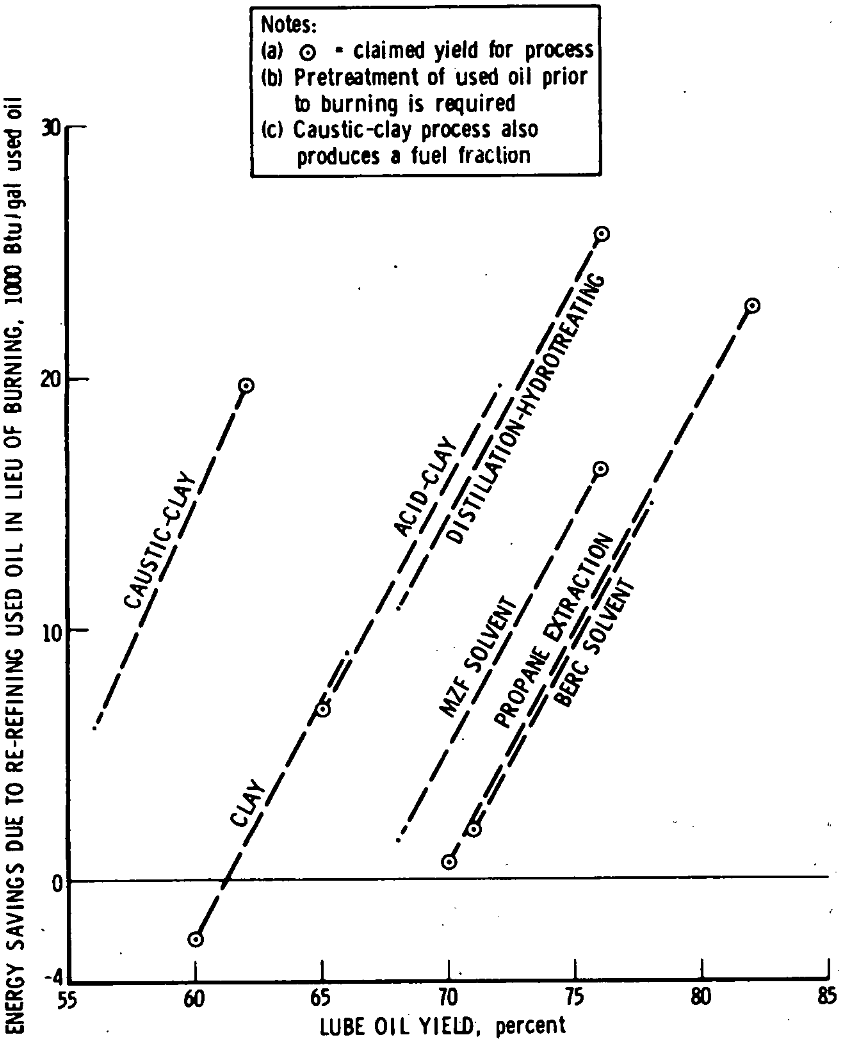


Figure 4-13 Sensitivity of Energy Savings to Process Yield for Various Re-Refining Processes

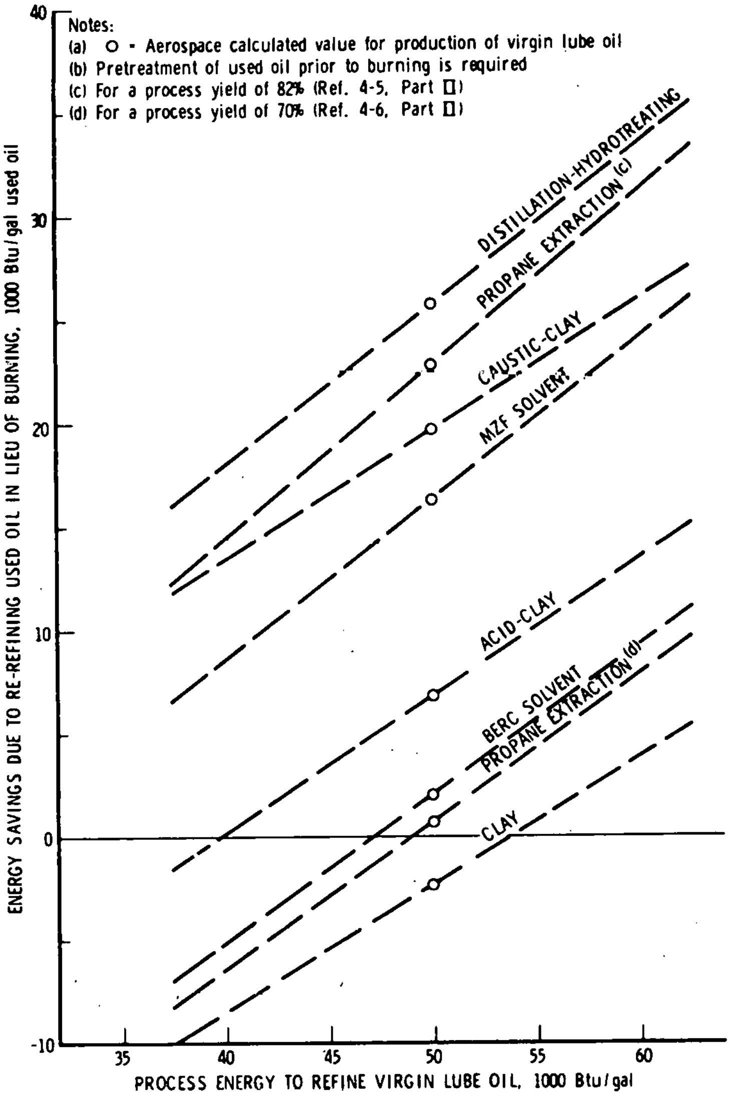


Figure 4-14. Sensitivity of Energy Savings to Virgin Lube Oil Process Energy for Various Re-Refining Processes

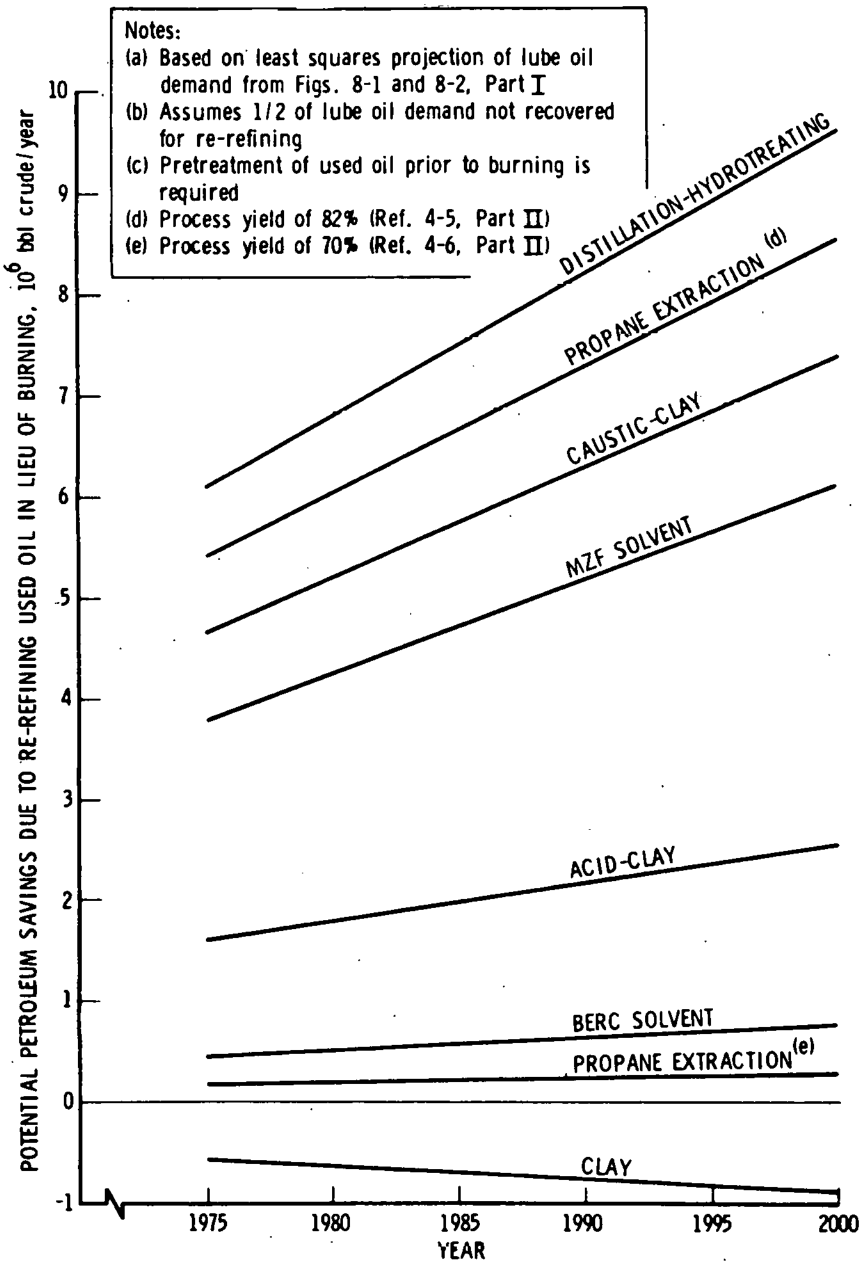


Figure 4-15. Potential Petroleum Savings to the Year 2000 for Various Re-Refining Processes

## 4.4 REFERENCES

4-1 P. Cukor, et al., A Technical and Economic Study of Waste Oil Recovery, Part IV, Energy Consumption in Waste Oil Recovery, Teknekron, Inc., Berkeley, Calif., Report No. EEED109, (25 October 1975).

4-2 M. L. Whisman, et al., Waste Lubricating Oil Research; Part 4, Report No. BERC/RI-7614, Bartlesville Energy Research Center, Bartlesville, Oklahoma (October 1976).

4-3 Mobil Technical Bulletin: Heating With Waste Oils, JGW 0-93-007, Mobil Oil Corporation, New York.

4-4 W. L. Nelson, Guide to Refinery Operating Costs, Second Edition, The Petroleum Publishing Corporation, Tulsa, Oklahoma (1970).

4-5 "Experience with the French Petroleum Institute Propane Clarification Process in Re-Refining Spent Crankcase Oils", The Journal of Environmental Sciences (May/June 1975).

4-6 M. L. Whisman, "Institute Francais du Petrole, Process for Regenerating Used Lubricating Oils", BERC, Bartlesville, Oklahoma (23 September 1977).

# SECTION 5

# MAJOR FINDINGS AND RECOMMENDATIONS

## 5.1 MAJOR FINDINGS

This section presents major findings developed from data acquired and analyses performed during the course of this study. These findings are structured to address (1) used oil utilization options, (2) energy-saving potential of utilization options, (3) resource conservation, (4) protection of the environment, (5) re-refining technology, (6) re-refining economics, and (7) factors governing expansion of the re-refining industry.

### 5.1.1 Used Oil Utilization Options

Two utilization options were considered in this study, (1) burning used oil as a fuel, and (2) re-refining used oil for recycling as a lube oil.

#### 5.1.1.1 Used Oil Generation and Disposal

Large amounts of lube oil are used in the transportation and industrial sectors, amounting to about 1.3 and 1.6 billion gallons, respectively, in 1975.

Oils degrade in service and must be periodically replaced, with recovery factors estimated at 57 percent for automotive lube oil and 43 percent for industrial oils. As a result, approximately 1.4 billion gallons of lube oil requiring disposal were removed from service in 1975.

About 75 percent of the total available amount of used oil is utilized in some manner. About 50 percent is used as fuel, 5 percent is re-refined, and 20 percent is used in various applications, including asphalt manufacture and road oiling. The remainder, about 25 percent, is dumped into the environment.

#### 5.1.1.2 Utilization as a Fuel

Some used oil is burned as a fuel for recovery of its heat content. Generally, it is added to virgin fuel oil in small amounts, about 5 percent, without any prior pretreatment for contaminant removal. Settling for removal of free-standing water is commonly done.

Pretreatment processes which could be used for contaminant removal range from simple steps such as dehydration and filtration for the removal of bound water, volatile hydrocarbons, and coarse solids, to sophisticated processes such as solvent extraction processes, which also remove soluble metallic contaminants contained in the used oil.

Pretreatment technology is related to lube oil re-refining, although product quality is of lesser importance. Additional costs incurred for pretreatment have prohibited its general use and have stifled development of suitable processes.

Potentially, future governmental regulations may require used oil to be pretreated prior to burning. Although the burning option considered in this study assumes that pretreatment for removal of soluble metallic contaminants is required, pretreatment processes are of little interest unless pretreatment is required prior to burning and re-refining is not utilized for some reason, such as a lack of market demand for the product.

#### 5.1.1.3 Recycling by Re-Refining

A number of different re-refining processes are in current use or have been proposed for implementation. Existing processes for re-refining, which were identified for inclusion in the analysis of utilization options, are (1) acid-clay, (2) clay, (3) caustic-clay, and (4) propane extraction. Among the numerous advanced processes proposed, three were selected for detailed analysis. These are the (1) distillation-hydrotreating, (2) BERC solvent, and (3) MZF solvent processes. Other advanced processes, such as the Phillips Re-Refined Oil Processes (PROP), were excluded because of a lack of process data required in the analysis.

All processes considered in this study are capable of re-refining automotive crankcase drainings for recycling as an automotive lube. This capability was determined either by actual use of the process in the production of automotive lube oil, or by virtue of process potential. As a result, the clay process, which is normally considered to be useful only for treating industrial oils, is also included.

Projections for advanced re-refining processes rely on data which are either not verified or not firmly established. Accurate yield data are lacking, particularly for propane extraction, indicating that a degree of caution should be exercised in reaching conclusions related to specific results.

### 5.1.2 Energy Savings Potential of Utilization Options

The energy savings potential related to burning of used oil, either with or without pretreatment, and re-refining used oil with any of the seven processes considered, was addressed in this study relative to (1) non-utilization disposal methods (dumping), and (2) utilization as a fuel with pretreatment for contaminant removal prior to burning. Savings were computed by use of a closed loop energy model which accounts for the overall change in energy consumption resulting from the specific utilization options employed. Effectively, the energy required by refineries for the production of the different petroleum products is considered.

### 5.1.2.1 Pretreatment Energy Requirements

Pretreatment processes consume energy and suffer additional energy losses in the form of discarded hydrocarbons, expressed in terms of process yield. Pretreatment process energies and yields are shown in Table 5-1 for a common used oil composition consisting of 89 percent lube oil and 11 percent water and gasoline contaminants.

Table 5-1. Process Energy and Yield for Several Levels Of Used Oil Pretreatments

| Level | Representative Process | Yield, % | Energy, Btu/Gal Feedstock |
|---|---|---|---|
| None | - | 89 | 0 |
| Low | Dehydration, Filtration | 87 | 2,400 |
| Medium | Solvent extraction at 1:1 solvent to oil ratio | 84 | 7,900 |
| High | Solvent extraction at 3:1 solvent to oil ratio | 78 | 18,800 |

### 5.1.2.2 Re-Refining Energy Requirements

Similar to pretreatment processes, re-refining processes also consume energy and lose a portion of the processed oil. Process energies and yields for the several processes considered are shown in Table 5-2, with data included for the two propane extraction yields reported in the literature.

Table 5-2. Process Energy and Yield for Several Re-Refining Processes

| Process | Yield, % | Energy, Btu per Gallon Feedstock |
|---|---|---|
| Acid-Clay | 65 | 7,700 |
| Clay | 60 | 7,200 |
| Caustic-Clay | 62 | 10,600 |
| Propane Extraction | 82/70 | 23,600/22,600 |
| Distillation-Hydrotreating | 76 | 9,800 |
| BERC Solvent | 71 | 23,200 |
| MZF Solvent | 76 | 18,700 |

### 5.1.2.3 Comparison of Utilization Options

Table 5-3 shows energy savings computed by means of a closed loop energy model, using as inputs the process energies and yields for the various utilization options, lower (net) heating values for fuels, actual refinery process energy for crude fractionation, and a process energy of 50,000 Btu per gallon for the production of virgin lube oil. Also shown in Table 5-3 are the potential petroleum savings which would accrue if all used oil generated (1.4 billion gallons in 1975) would be utilized in this manner.

Table 5-3. Comparison of Energy Savings for Various Used Oil Utilization Methods Relative to Disposal

| Method and Process | Energy Savings, Btu/ gal used oil | Potential Petroleum Savings, Millions of Barrels per Year |
|---|---|---|
| Burning | | |
| Without any Pretreatment for Contaminant Removal | 131,210 | 31.1 |
| With Medium Level of Pretreatment for Contaminant Removal | 116,160 | 27.5 |
| Re-Refining | | |
| Acid-Clay | 122,960 | 29.2 |
| Clay | 113,850 | 27.0 |
| Caustic-Clay | 135,900 | 32.2 |
| Propane Extraction | 116,900/138,980 | 27.7/33.0 |
| Distillation-Hydrotreating | 141,870 | 33.7 |
| BERC Solvent | 118,210 | 28.0 |
| MZF Solvent | 132,520 | 31.4 |

All used oil utilization methods and processes show substantial energy savings relative to disposal without energy recovery. As shown in Table 5-3, burning without any pretreatment for contaminant removal is an effective means of energy recovery. However, burning is less efficient than the best re-refining processes.

Burning without pretreatment is often considered environmentally unacceptable, and may be prohibited in the future. Therefore, utilization by burning with some pretreatment was used as a baseline to evaluate the various utilization methods, as shown in Table 5-4. For reference, burning without pretreatment is also included in Table 5-4.

Table 5-4. Comparison of Energy Savings for Various Used Oil Utilization Methods Relative to Burning with Pretreatment

| Method and Process | Energy Savings, Btu/ gal used oil | Potential Petroleum Savings, millions of barrels per year |
|---|---|---|
| Burning | | |
| without any pretreatment for contaminant removal | 15,000 | 3.6 |
| with medium level of pretreatment for contaminant removal | Baseline | Baseline |
| Re-Refining | | |
| Acid-Clay | 6,800 | 1.6 |
| Clay | -2,300 | -0.5 |
| Caustic-Clay | 19,700 | 4.7 |
| Propane Extraction | 700/22,800 | 0.2/5.4 |
| Distillation-Hydrotreating | 25,700 | 6.1 |
| BERC Solvent | 2,000 | 0.5 |
| MZF Solvent | 16,400 | 3.9 |

Actual energy savings achievable by re-refining are uncertain because the savings are highly dependent on process energy requirements for the production of virgin lube oil. Available data on virgin lube oil process energy show wide variations, ranging from 19,000 to 73,800 Btu per gallon.

For the lower value, 19,000 Btu per gallon, only the caustic-clay and the distillation-hydrotreating processes provide energy savings amounting to 0.05 and 0.4 million barrels per year. For the higher value, 73,800 Btu per gallon, all processes provide energy savings, ranging from a high of 10.5 million barrels per year for the distillation-hydrotreating process to a low of 2.9 million barrels per year for the clay process.

Additional energy savings would accrue in the case of re-refining if environmentally acceptable uses could be found for the process waste streams, such as the hydrocarbon rich acidic sludge produced by the acid-clay process (which is in predominant use). Other benefits related to sludge utilization include:

1. Elimination of dumping sludge into the environment.
2. Conversion of a process cost into an operating profit.
3. Permitting activation of those re-refineries which had been shut down due to nonavailability of approved dump sites, and permitting construction of new re-refineries to be built in such areas.

### 5.1.3 Resource Conservation

Resource conservation is an important criterion for the evaluation of utilization options because the molecular makeup of lube oil is uniquely suited for its intended purpose, that of lubrication, whereas many other molecules are suitable for fuel purposes, including nonpetroleum products.

Re-refining could serve as a strategic resource by providing lube oil for vital applications in case of insufficient virgin crude supplies, particularly from foreign sources, during times of emergency.

Available lube cut quantities from new petroleum discoveries such as Nigeria, Indonesia, and Alaska are lower than from older sources. In addition, a reduction in lube cut has the following implications relative to energy conservation.

1. Process energy requirements for virgin lube oil production increase with decreasing yield.
2. An increase in virgin lube oil process energy enhances the energy conservation aspects of re-refining used oil.

Relative to the acid-clay process the higher yields of a number of advanced processes increase the amount of re-refined oil which can be made available from a given supply of used oil, thus enhancing resource conservation.

## 5.1.4 Protection of the Environment

Historically, the disposal of used oil has created environmental problems, which remain largely unresolved. To provide an overall assessment of merit, environmental aspects of the various utilization options (burning, re-refining, or alternate uses) must also be considered.

> Burning used oil without pretreatment results in the emission of lead, trace metals, and particulates into the environment. As much as 9800 tons of lead per year would be emitted into the atmosphere if all used automotive lube oil would be burned. Compared to the 180,000 tons currently emitted from automobiles this is a relatively small quantity, amounting to less than 6 percent, but may pose significant point source problems. Also, polynuclear aromatics, known carcinogens which require temperatures above 2000°F for decomposition, are of concern.
>
> Frequently, other used oil utilization and disposal methods result in contaminants entering the environment. The degree of pollution varies from probably none for asphalt manufacture, to substantial for road oiling, and to severe for indiscriminate dumping.
>
> Re-refining minimizes the amount of used oil entering the environment by recycling it and concentrating the contaminants for controlled disposal. While the currently favored acid-clay process generates additional waste streams, consisting of acidic sludge and oily clay, a number of known new re-refining processes have fewer and less toxic waste products. Emissions and effluents from re-refineries can be controlled with simple and currently available technology.

## 5.1.5 Re-Refining Technology

The commonly used acid-clay process is capable of producing quality lube oil, but is seriously deficient because it has a low lube oil yield and produces large amounts of toxic waste products.

> Many replacement processes have been proposed, investigated, and patented over the past 20 years.
>
> A number of candidate replacement processes which have claimed or demonstrated advantages over the acid-clay process are under development, under investigation, or in limited use. These include (1) propane extraction, (2) distillation, and (3) other solvent extraction processes.
>
> Salient features of all processes investigated in this study are shown in Table 5-5 in terms of (1) degree of implementation, (2) product quality, (3) process yield, (4) process energy requirements, and (5) process complexity.

## Table 5-5. Salient Features of Various Re-Refining Processes

| Process | Implementation | Product Quality | Process Yield | Process Energy Requirements | Process Complexity | Other |
|---|---|---|---|---|---|---|
| Existing Processes | | | | | | |
| Acid-Clay | Widely used | Can produce a quality lube oil | Low (65 percent) when processing used automotive lube oils | Low (12,000 Btu per gallon of product) | Simple, and adapted to small volumes and batch operations. Can be adapted to semi-continuous operations | Produces acidic sludge and oily clay waste products |
| Clay | Limited use, one known plant producing automotive lube oil | Questionable for highly contaminated oils, acceptable for industrial oils | Low (60 percent) for automotive lubes and high (90 percent) for industrial oils | Same as acid-clay (12,000 Btu per gallon of product | Very simple | Produces oily clay waste product |
| Caustic-Clay | Limited use, one known plant producing automotive lube oil | Although thought questionable for highly contaminated oils, production of a quality lube oil is claimed | Low lube oil yield (62 percent) offset by concurrent production of fuel oil (16 percent) | About 40 percent higher than acid-clay (17,000 Btu per gallon product) if all energy is charged to lube production | Comparable to acid-clay process | Produces caustic sludge and oily clay waste product |
| Propane Extraction | Newly developed process with two European plants in production | Can produce a quality product | Yield unresolved. High yield (82 percent) claimed by process developer. Moderate yield (70 percent) reported by plant operator | Very high, more than 2 x acid-clay (28 to 32,000 Btu/gallon of product) | Relatively complex and suited to large scale operations. Propane section operates on a continuous basis. The acid-clay finishing step can be either batch or semi-continuous | Requires an acid-clay finishing step |
| Proposed/Under Development | | | | | | |
| Distillation - Hydrotreating | Several variations of process exist. Two distillation (no hydrotreating) plants in production. Demonstration plant under construction in W. Germany, and small pilot plant in operation in the U. S. | Should be capable of producing a quality lube oil | Significantly higher than for acid-clay (76 percent) | Slightly higher than for acid-clay (13,000 Btu per gallon of product) | Somewhat complex and suited to large scale continuous operations | Requires solution of distillation column fouling and catalyst poisoning problems |
| BERC Solvent | Pilot plant operation has produced re-refined oil for engine sequence and field tests | Producing high quality oil that nearly passed all engine sequence tests for an SE oil rating (and probably would have with slightly larger quantities of certain additives) | Higher than acid-clay (71 percent) | Highest of any process evaluated due to need to recover large volumes of solvent (33,000 Btu per gallon of product) | Relatively complex. Currently engineered for semi-continuous operation. Could be used for batch operations | Product lube oil currently undergoing vehicle field testing |
| MZF Solvent | Laboratory (test tube) stage. Process evaluation based on this data. Has least development work of processes reported | Laboratory data reports good removal of metallic contaminants, which should produce quality lube oil after undergoing subsequent fractionation and clay contacting | Significantly higher than acid-clay process (76 percent) | About 2 x acid-clay (25,000 Btu per gallon of product) | Should be comparable to other solvent extraction processes, and suited for semi-continuous or batch operations | Emulsion separation by centrifugation replaced by use of an undisclosed de-emulsication agent, who's cost is claimed to be low |

Pertinent information on the status of selected advanced processes and their ultimate feasibility is provided here for emphasis:

1. Propane Extraction: The Selectropropane process is currently in commercial operation in Europe, with two plants operating in Italy. License agreements are available from IFP, the French Petroleum Institute.
2. Distillation-Hydrotreating: This process has been under development for years with major efforts directed towards solving column fouling problems. These steps are commonly used in petroleum refining, but have yet to be successfully adapted to re-refining used automotive oils. However, distillation with a caustic pretreatment and a clay finishing step is used by one re-refiner. Periodic plant closures are required for column cleaning.
3. BERC Solvent: A lube oil pilot plant is operational. Limited engine testing has been conducted, and a fleet test program is currently being conducted by the State of Iowa.
4. MZF Solvent: This process has not progressed beyond the laboratory stage of development. There is concern relative to breaking emulsions when the process is operated at commercial production rates with feedstock from different sources.

### 5.1.6 Re-Refining Economics

Regardless of the potential energy savings that may be attributable to re-refining, re-refining must be economically feasible to achieve widespread implementation, unless sponsored under subsidy. Factors affecting re-refining economics are summarized in the following paragraphs.

#### 5.1.6.1 Production Costs

Plant and equipment costs of the various processes investigated do not differ greatly. For a 10 million gallons per year feedstock plant, the projected costs vary from 1.8 to 3.2 million dollars. Currently, only one re-refining plant in the United States exceeds 10 million gallons per year capacity, while a number of European plants fall into that category.

Chemical inventory costs for the various processes differ widely. However, on an absolute basis, these costs constitute only a small fraction of plant and equipment investment, amounting to less than three percent of the total investment cost.

Used oil feedstock costs for producing a given amount of finished product differ for the various processes as a result of the different yields obtained.

Used oil feedstock prices have escalated drastically in recent years, reflecting the price increases of both virgin crude and residual fuels. Typically, used oil sold for fuel purposes commands about 17 cents per gallon while used oil for re-refining (based on what re-refiners are willing to pay) sells for about 10 to 15 cents per gallon.

Total projected manufacturing costs for the different processes vary from 29 cents per gallon for the distillation-hydrotreating process to 52 cents per gallon for the clay process. It should be noted that these cost figures are sensitive to process yield, which lacks substantiation for some of the processes investigated in this study.

A comparison of production cost factors of the various processes investigated, as indicated by investment, chemical inventory, and manufacturing costs, is shown in Table 5-6.

### 5.1.6.2 Profitability

To meet service requirements, re-refined base oils require additives, particularly for automotive applications. Additive cost to produce a single viscosity API service SE oil amounts to about 18 cents per gallon, and constitutes 35 to 65 percent of the total manufacturing cost of the base oil.

Packaging, particularly in quart containers, represents a significant cost, about 55 cents per gallon, which exceeds total manufacturing cost of the uncompounded base oil. Bulk packaging is less costly, amounting to about 8 cents per gallon for tank car loads. This cost accounts for cleaning and handling but does not include amortization of the tank car.

Re-refined oil can be profitably transported long distances via tank truck if used oil is hauled back on the return trip. Current practice involves distances as great as 650 miles each way, with an estimated cost per gallon of about one cent for each thirty miles of trip radius.

An illustration of profitability, based on total production cost and the difference between production cost and the current $1.18 per gallon selling price of a comparable SAE 20W API SE re-refined lube oil, is shown in Table 5-7. For comparison, the bulk selling price of an equivalent virgin lube on the West Coast ranges from $1.47 to $1.85 per gallon.

Table 5-6. Comparison of Production Cost Factors for Selected Automotive Lube Oil Re-Refining Processes[a]

| Process | Plant and Equipment Investment Millions of Dollars[b] | Chemical Inventory, Thousands of Dollars[c] | Total Manufacturing Costs, Cents per Gallon Product[d] |
|---|---|---|---|
| Acid-Clay | 1.8 | 20 | 43 |
| Clay | 1.9 | 41 | 52 |
| Caustic-Clay | 1.8 | 23 | 34 |
| Propane Extraction | 3.2 | 7[e] | 32/41[f] |
| Distillation-Hydrotreating | 2.3 | 7 | 29 |
| BERC Solvent | 2.5 | 14[e] | 38 |
| MZF Solvent | 2.3 | 12[e] | 34 |

[a] Plant capacity of 10 million gallons per year used oil feedstock.

[b] Excludes inventory of feedstock, chemicals, vehicles, spare parts, office furniture, etc.

[c] Consumed chemicals for two weeks of plant operation.

[d] Lube oil base stock (uncompounded).

[e] Does not include stock of solvents recycled during process operation.

[f] Reflects reported yields of 82/70 percent.

### 5.1.7 Factors Governing Industry Expansion

Until recently, survival, rather than expansion, was uppermost in the minds of re-refiners. Profits disappeared in the face of increased costs and competition from low priced virgin products. Escalation of crude oil prices has reversed this trend, and product demand is currently outstripping re-refining capacity. Production is limited because of the non-availability of economically priced used oil feedstock. Aside from non-availability of adequate quantities of feedstock, production capacity has not expanded because of a lack of investment capital.

Table 5-7. Potential Profitability of Various Re-Refining Processes, Cents per Gallon[a]

| Process | Acid-Clay | Clay | Caustic-Clay | Propane Extraction[b] | Distillation-Hydrotreating | BERC Solvent | MZF Solvent |
|---|---|---|---|---|---|---|---|
| Total Production Cost | 83 | 92 | 75 | 73/82 | 70 | 79 | 75 |
| Potential Profitability[c] | 35 | 26 | 43 | 45/36 | 48 | 39 | 43 |

[a] Plant amortization and distribution costs not included.

[b] Reflects reported yields of 82/70 percent.

[c] Relative to current selling price of $1.18 per gallon in bulk drum packaging.

### 5.1.7.1 Feedstock Availability

Availability of used oil feedstock for re-refining is related to the price competition between re-refiners and other used oil users. Currently, those who utilize used oil for fuel purposes are outbidding the re-refiners.

A large fraction of the used oil generated, about 25 percent, is not available for re-refining or other uses. This amount is presumably discarded into the environment.

Recent environmental legislation, depending on EPA interpretation, may place controls over the collection, transportation, and disposal of used oil. These regulations could have the effect of shifting the supply of used oil towards re-fining.

Legislated markets for re-refined oil, and the resultant price that may be charged, should increase potential profitability sufficiently for re-refiners to outbid other users for available used oil supplies.

### 5.1.7.2 Capital Availability

Difficulties in obtaining loans from the private sector for plant expansion, modernization, and/or construction are related to (1) the lack of familiarity with the re-refining industry, (2) an apprehension in investing in an industry that does not have an assured supply of feedstock, (3) wariness of new, untried processes, and (4) fears that market demand for the product does not exist.

Availability of outside capital for process development, testing, and demonstration appears nonexistent. Most re-refiners are not capable of generating sufficient capital internally for these activities.

The ability of re-refiners to raise capital for expansion/conversion of processes is currently limited to those who are either part of a larger corporate structure which can provide capital from internal sources, or have demonstrated profitability.

The ability to generate capital from the private sector will increase as fears of lending institutions relative to re-refining are removed. This situation may occur due to (1) improved profitability of existing operations, and (2) government involvement through such programs as the setting of quality standards, purchase of re-refined products, and investment credits or loan guarantees.

### 5.1.7.3 Product Acceptance

Major impediments to acceptance of re-refined oil by the private sector are related to uncertainties in product quality, and lack of recognition of brand names belonging to local re-refiners, in contrast to the heavily advertised virgin lube oil products marketed on a national basis.

In the past, specific government regulations have served as impediments to marketing re-refined oil products. These include:

1. Military specifications specifically prohibit the use of re-refined oil. These constraints reach beyond the military in that most federal agencies and many state, local, and private agencies utilize Mil-Spec requirements in their purchase orders.
2. Requirements to label the origin of re-refined oil as coming from used oil results in a connotation of product inferiority.
3. Internal Revenue Service prohibition of tax rebates on the virgin lube oil portion blended with re-refined oil, when used in off highway service, results in a price disadvantage of re-refined oil relative to virgin oil.

Current government legislation relative to energy conservation should eliminate past impediments and stimulate the use of re-refined oil through the following actions:

1. The question of re-refined oil quality should be resolved through tests formulated by the NBS to show substantial equivalency to virgin products.
2. Labeling requirements will be limited to those that state acceptable end use of the product, and may not be worded so as to connotate product inferiority.
3. Regulations prohibiting the use of recycled products by federal agencies will be changed.
4. Federal agencies will purchase recycled products at the maximum extent feasible, even if price is not competitive with virgin products.

Government leadership in using re-refined lube oil products should set an example to stimulate its use in the private sector.

## 5.2 RECOMMENDATIONS

Even though the magnitude of potential energy savings achievable through re-refining is not very large, this form of conservation should be used as part of the nation's overall effort to conserve petroleum. Therefore, DOE is encouraged to take an active role in re-refining activities in order to maximize energy savings. Recommendations are provided in the following subsections.

### 5.2.1 Process Evaluations

As a stimulus to the development and commercialization of energy efficient re-refining processes in the private sector, it is recommended that the DOE undertake a program to evaluate, verify, and otherwise demonstrate, the technical feasibility of proposed processes. Then, by means of publications, workshops, and other methods of communication, knowledge of this technology will be transfered to industry, who may then implement it in accordance with product demand and other economic factors. This program could be structured as follows:

a. Evaluate proposed re-refining processes relative to their technical merit, economic feasibility, and potential for energy conservation, based on claims made by the inventor(s) or proponent(s).

b. For candidate processes which satisfactorily pass this initial screening, verify claims by laboratory tests.

c. Evaluate process effectiveness by characterizing the purified oil with regard to metal content, carbon residue, acid number, and so on.

d. Determine product quality by means of bench tests for foam, oxidation resistance, wear, corrosion, and so on.

e. Verify process feasibility in conjunction with used oil obtained from diverse sources, particularly from commercial collectors.

f. Scale up process testing to pilot plant size sufficiently large for evaluation of commercial feasibility.

g. Verify the quality of the re-refined oil by means of engine sequence tests.

For the purpose of initiating this program, it is recommended that this evaluation be initially performed for two of the more energy efficient processes investigated in this study, the caustic-clay and MZF solvent processes. The most energy efficient process, distillation-hydrotreating, is excluded from this recommendation because its feasibility is related to distillation column design to prevent coking, and innovative hardware designs are not available for testing. Also, the propane extraction process, which has the potential of large energy savings, is excluded because it is commercially available from the developers, with plants in operation to demonstrate all facets of the process to candidate users.

### 5.2.2 Sludge Utilization

As a near term enhancement of energy savings from re-refining, it is recommended that uses be developed for the waste products of re-refining processes, particularly for the sludge from those processes which are rich in hydrocarbons, such as acid-clay. Utilization of products manufactured from this sludge in place of those produced from virgin hydrocarbons increases the energy conservation aspects of re-refining and, in addition, converts a process cost into a profit. A program to develop uses for re-refinery sludge products could be structured as follows:

a. Initiate liason with re-refiners who are currently involved in the development of applications for sludge.

b. Characterize sludge as to its constituent elements for purpose of determining the variability of these characteristics for different regions and seasons.

c. Investigate methods of selectively extracting desirable hydrocarbons from the sludge.

d. Investigate methods of treating sludge so that it may be used safely in its entirety in selected applications, such as the manufacture of paving materials, or waterproofing compounds.

e. Investigate the possibility of recovering the heat content of sludge through combustion in an environmentally acceptable manner.

f. Perform a cost/benefit analysis to evaluate the various sludge uses developed during the course of this research program.

g. Initiate a pilot plant demonstration of the selected utilization method.

### 5.2.3 Program Implementation

It is recommended that the program outlined be carried out by reputable organizations with experience in the areas of lubricating oils and chemical processes. The Bartlesville Energy Technology Center,[*] of Bartlesville, Oklahoma, and the Southwest Research Institute, of San Antonio, Texas, are two facilities which fall into this category.

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[*] Formerly the Bartlesville Energy Research Center.

# APPENDIX A

## VISITS AND CONTACTS

During the course of this study, the following organizations were visited or contacted by telephone.

| Organization | Primary Contact |
|---|---|
| **Universities** | |
| University of Oklahoma<br>Norman, Oklahoma | Prof. Critchlow |
| Pennsylvania State University<br>University Park, Pennsylvania | Prof. Tewksbury |
| University of Tulsa<br>Tulsa, Oklahoma | Prof. Graves |
| **Government Agencies** | |
| Bartlesville Energy Research Center<br>Bartlesville, Oklahoma | Mr. C.J. Thompson<br>Mr. M.L. Whisman |
| California State Resources Conservation and Development Commission<br>Sacramento, California | Mr. S. Castle |
| Federal Energy Administration<br>Los Angeles, California | Mr. H. Dotson |
| Maryland State Environmental Services<br>Annapolis, Maryland | Mr. M.T. Long |
| National Bureau of Standards<br>Gaithersburg, Maryland | Mr. D.A. Becker |
| State of North Carolina<br>Office of the Governor<br>Raleigh, North Carolina | Ms. S. Bass<br>Mr. M. Davis |
| U.S. Army Fuels and Lubricants Laboratory<br>San Antonio, Texas | Mr. E. Farmer<br>Mr. S. Letz |
| U.S. Army Fuels and Lubricants Laboratory<br>Fort Belvoir, Virginia | Mr. T. Bowen<br>Mr. M.E. Lepera |
| U.S. Bureau of the Census<br>Washington, D.C. | Mr. R. Sweeney |
| U.S. Bureau of Mines<br>Washington, D.C. | Mr. J. Diehl |

| Organization | Primary Contact |
|---|---|
| U.S. Environmental Protection Agency<br>Washington, D.C. | Mr. H.B. Kaufman<br>Mr. L. McEwen |
| Wright Patterson AFB<br>Dayton, Ohio | Mr. Bean |
| **Industry and Research Organizations** | |
| Air Products and Chemicals Corporation<br>Long Beach, California | Mr. K. Holden |
| American Petroleum Institute<br>Washington, D.C. | Mr. H. Tiffnay<br>Ms. M.A. Wilkenson |
| Association of Petroleum Re-Refiners<br>Washington, D.C. | Mr. D.K. Ekedahl |
| Atlantic Richfield Company<br>Los Angeles, California | Mr. E.M. Lee |
| Bayside Oil Corporation<br>San Carlos, California | Mr. R. Banks<br>Mr. P. Odegard |
| Bechtel National Inc.<br>San Francisco, California | Dr. H. Hipkin |
| Berks Associates<br>Pottstown, Pennsylvania | Mr. L. Schurr |
| Bonus Refinery Division<br>Bonus International Corporation<br>Salt Lake City, Utah | Mr. J.B. Hancock<br>Mr. J.R. Mastelotto |
| Chevron Research Company<br>Richmond, California | Mr. F. Sam<br>Mr. J.J. Shook |
| Custom Refining Company<br>Denver, Colorado | Dr. J.S. Corlew |
| Dearborn Refining Company<br>Dearborn, Michigan | Mr. B. Horton |
| Diamond Head Oil Refinery<br>Kearny, New Jersey | Mr. R. Mahler |
| Double Eagle Refining Company<br>Oklahoma City, Oklahoma | Mr. C.L. Kerran<br>Mr. M. Kerran |
| ECO-Separator Division<br>A. Johnson and Company, Inc.<br>Ventura, California | Mr. E.H. Palmason |
| Edwin Cooper, Inc.<br>Paramount, California | Mr. W. Runkle |
| Exxon Oil Company<br>Baytown, Texas | Mr. D. Bosniack |
| Exxon Oil Company<br>Houston, Texas | Dr. E.W. Nommensen<br>Mr. B.W. Hutchings |

| Organization | Primary Contact |
|---|---|
| Exxon Research and Development Company<br>Linden, New Jersey | Dr. W. Waddey<br>Dr. Salversen |
| Fabian Oil Refining Company<br>Oakland, California | Mr. B. Fabian |
| Gladieux Refining Company<br>Fort Wayne, Indiana | Mr. R. Marshall |
| Gulf Science and Technology Company<br>Pittsburg, Pennslyvania | Mr. R.T. Kern<br>Dr. W.A. Horn<br>Dr. W. Meyer |
| Keenan Oil Company<br>Cincinnati, Ohio | Mr. S.R. Passell |
| Kinetics Technology International<br>San Marino, California | Dr. R. Minot |
| Lakewood Oil Service, Inc.<br>Santa Fe Springs, California | Mr. D. Bronson |
| Leach Oil Company<br>Compton, California | Mr. R. Leach |
| Liquid Gold Oil Company<br>Alameda, California | Mr. B. Fabian |
| Lubrication Consultant<br>Wellesley, Massachusetts | Mr. J.W. Swain |
| Lubrizol Corporation<br>Whittier, California | Mr. S. Gouta |
| Lubrizol Corporation<br>Wickliffe, Ohio | Mr. L.P. Richardson<br>Dr. P. Asseff |
| MZF Associates<br>Los Angeles, California | Dr. M.Z. Fainman |
| McAuley Oil Company<br>Long Beach, California | Mr. C.S. McAuley |
| Motor Guard Lubricants Company<br>Los Angeles, California | Mr. B. Howe |
| Motor Oils Refining Company<br>McCook, Illinois | Mr. B.R. Williams |
| NORCO<br>Subsidiary of JOC Oil<br>Bayonne, New Jersey | Mr. M. Bernegger<br>Mr. S.H. Ismail |
| Nelco Oil Refining Company<br>National City, California | Mr. R. Humphrey<br>Mr. S. Humphrey |
| Phillips Petroleum Company<br>Bartlesville, Oklahoma | Mr. E.A. Malik |
| Process Consultants, Inc.<br>Denver, Colorado | Dr. J.S. Corlew |

| Organization | Primary Contact |
|---|---|
| Refiners Sales Company<br>Signal Hill, California | Mr. R.G. Hand |
| Research Oil Refining Company<br>Cleveland, Ohio | Mr. C. Carter |
| Richard J. Bigda and Associates<br>Tulsa, Oklahoma | Mr. R.J. Bigda |
| Shell Development, Inc.<br>Houston, Texas | Dr. R.W. Lewis |
| Southwest Research Institute<br>San Antonio, Texas | Mr. N.E. Killion<br>Mr. P.R. Lepisto |
| Stone & Webster Engineering Corporation<br>New York City, New York | Mr. R. Giallela |
| Sun Oil Company<br>Philadelphia, Pennslyvania | Mr. J.L. Helm |
| Talley Brothers, Inc.<br>Huntington Park, California | Mr. R. Wiggins |
| Teknekron, Inc.<br>Berkeley, California | Mr. S. Liroff |
| Torco Oil, Inc.<br>Santa Fe Springs, California | Mr. R. Lancaster |
| Turbo Resources, Ltd.<br>Calgary, Canada | Mr. F. Stuchberry |
| U.S. Refineries of Washington, Inc.<br>Tacoma, Washington | Mr. W. Drexler |
| Vacsol, Inc.<br>(Coral Refining)<br>Kansas City, Kansas | Mr. T. Tierney |
| Warden Oil Company<br>Minneapolis, Minnesota | Mr. A.L. Warden |
| Williams Refining Company<br>Denver, Colorado | Mr. L. Cunningham |

# APPENDIX B

## REVIEWERS COMMENTS

LAND
SEA
AIR
SPACE

SAE COMMITTEE CORRESPONDENCE

Society of Automotive Engineers, Inc.

Committee:

Reply To: D. M. Stehouwer
Fuels and Lubricants Dept.
GM Research Laboratories
Warren, Michigan 48090

May 17, 1978

Mr. R. Tom Northrup
Staff Engineer
Society of Automotive Engineers, Inc.
2100 West Big Beaver
Troy, MI 48084

Dear Mr. Northrup:

Your letter of May 2, 1978 requesting comments on Volume II* of "Utilization of Used Oil" has been forwarded to me for reply. By copy of this letter, we are submitting our comments directly to Mr. Jerome F. Collins of the Department of Energy.

With the exception of the authors' comments on the need for pretreatment of used oil before burning as a fuel, we are in general agreement with the overall conclusions reached. Our analysis agrees with the authors' conclusion that the energy savings which can be realized by burning untreated oil exceed the savings realized by the most widely used, Acid-Clay re-refining process. We also agree that requirements for a medium or high level of pretreatment of used oil prior to burning, or advanced re-refining processes can alter the relative energy savings of the available options.

However, the authors' choice of burning used oil with a medium level of pretreatment as the baseline for comparison of the energy savings possible with the various used oil utilization methods, does not depict the energy situation clearly. Current practice is to recover the heating value of used oil without any pretreatment. Selection of this case as the baseline for comparison would more accurately present the energy costs of the used oil utilization options available.

For example, Table 8 on page 38 and Table 12 on page 45 of the Executive Summary could be revised as attached. Viewed in this way, burning with pretreatment, the Acid-Clay, Clay, Propane Extraction and BERC Solvent processes all show a net energy loss when compared to the current practice of burning without pretreatment.

The need for pretreatment of used oil to meet air quality standards has not been shown. An EPA study (EPA-600/5-74-032 Conclusions attached) concluded that "large energy users could blend small percentages of low treated or untreated waste oil with their existing energy source

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*Authors' note: Volume II of the review copy has been incorporated into this final copy as Part II.

without necessarily adding emission control equipment." Further, the EPA report stated that electrostatic precipitation systems removed 98+ percent of the lead generated from firing of a 3 mass percent waste oil/97 mass percent coal fuel blend. These findings together with the expected decline in lead content of used oil as the usage of lead in gasoline decreases make it clear that burning of mixtures of untreated used oil is a viable option for future utilization of used oil.

The following are offered as minor editorial comments: The Glossary lists Alkane Sulfonates as sodium salts whereas calcium or magnesium salts are more frequently used. On page 31 of the Executive Summary, the text indicates Figure 13 shows energy "savings" with pretreatment. In fact Figure 13 shows energy "losses" with pretreatment. On Table 8 page 38 the Energy Savings for the Clay process should read - 2,330 BTU/Gal.

General Motors encourages the recycling of used oils as an important means of conserving our vital resources and protecting our environment. This report provides valuable data for comparing the energy conservation and economics of used oil recycling. In any recycling program, of course, the consumer must be protected by standards which measure the ability of the recycled product to perform its intended function.

Sincerely,

David M. Stehouwer
Fuels and Lubricants Dept.

DMS/see

Enclosures

cc: N. A. Hunstad
R. H. Kabel
J. F. Collins

REVISED

Table 8. Comparison of Energy Savings for Various Re-Refining Processes Relative to Utilization by Burning(a)

| Re-Refining Process | Process Parameters |  | Energy Savings, Btu/Gal Used Oil | (c) Energy Savings, BTU/Gal Used Oil |
|---|---|---|---|---|
|  | Yield, % Used Oil | Energy, Btu/Gal Used Oil |  |  |
| Acid-Clay | 65 | 7,660 | 6,780 | -8,250 |
| Clay | 60 | 7,160 | ⊖ 2,330 | -17,360 |
| Caustic-Clay | 62(b) | 10,640 | 19,720 | +4,690 |
| Propane Extraction | 70 | 22,570 | 720 | -14,310 |
|  | 82 | 23,550 | 22,810 | +7,770 |
| Distillation Hydrotreating | 76 | 9,820 | 25,690 | +10,660 |
| BERC Solvent | 71 | 23,150 | 2,040 | -13,000 |
| MZF Solvent | 76 | 18,700 | 16,350 | +1,310 |

(a) Used oil pretreated for contaminant removal prior to burning

(b) Process also produces 16% fuel oil

(c) Savings relative to utilization by burning with no pretreatment

REVISED

Table 12. Comparison of Energy Savings for Various Used Oil Utilization Methods Relative to Burning with Pretreatment

| Method and Process | Energy Savings, Btu/ gal used oil | Potential Petroleum Savings, Millions Barrels per Year |
|---|---|---|
| **Burning** | | |
| Without any Pretreatment for Contaminant Removal | Baseline | Baseline |
| With Medium Level of Pretreatment for Contaminant Removal | -15,000 | -3.6 |
| **Re-Refining** | | |
| Acid-Clay | -8,200 | -2.0 |
| Clay | -17,300 | -4.1 |
| Caustic-Clay | 4,700 | 1.1 |
| Propane Extraction | -14,300/7,800 | -3.4/1.8 |
| Distillation-Hydrotreating | 10,700 | 2.5 |
| BERC Solvent | -13,000 | -3.1 |
| MZF Solvent | 1,400 | 0.3 |

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 19 1978

OFFICE OF WATER AND
HAZARDOUS MATERIALS

Mr. Jerry Collins
Division of Industrial Energy Conservation
U.S. Department of Energy
Washington, D.C. 20545

Dear Mr. Collins:

The Aerospace Corporation study of the Utilization of Used Oil-Volume II, which you sent to me for review has many significant points. To my knowledge, the study is very accurate. However, the energy savings that have been calculated for re-refining used oil versus refining virgin oil are dependent on the energy number assigned to refining virgin oil. Information has come to me that the number used in this study for energy in refining virgin oil is well below the industry average and in fact is well below what could be expected in the future when the new oil, with a smaller lube cut, is used for production of lubricating oils. Therefore, a stronger case should be made for recycling used oil based on energy conservation.

I believe that the issue of resource conservation is much more important than the energy issue, since the country will be facing a resource (oil) shortage rather than an energy shortage in the coming years. Therefore, I feel that the significant resource conservation benefits of re-refining used oil versus burning used oil must be stressed, and the resource ramifications of our policies should be stated as the major conclusions rather than the energy issue.

Thank you for providing me with the opportunity to review this study. I believe that both Volumes I and II of the study will go a long way in providing the necessary background information to help the country in recycling this valuable resource.

Yours truly,

Hugh B. Kaufman

Hugh B. Kaufman, Chairman
Used Oil Subcommittee
Interagency Committee on
Resource Recovery

**American Petroleum Institute**
2101 L Street Northwest
Washington, D.C. 20037
202-457-7000

June 7, 1978

Dr. Jerome F. Collins, Chief
Alternative Materials Utilization Branch
Department of Energy
Washington, DC 20545

Dear Dr. Collins:

Pursuant to your request, I have reviewed the Aerospace Report No. ATR - 77(7384) - 1, Vol. I & II with emphasis on Volume II (Utilization of Used Oil - Energy Conservation and Economics).

The report represents the gathering of much data along with considerable thought in organizing the information. I feel the report is quite well done and represents considerable work. However, as you have requested, I will comment on those areas which I feel could cause some misunderstanding. My comments are not as detailed as I would like to have had them. This is due to my time limit.

I would like to state that I support appropriate recycling of used lubricating oils and the conservation of such a valuable resource. I do not believe so much emphasis should be placed on crankcase engine oils to be re-refined back into crankcase engine oils. I believe the crankcase engine oils should be collected for recycling into the most suitable re-use consistent with conservation, and economically and environmentally sound practices.

First, I think it is important to note that this report does not present anything really new. Rather it is an assembly of well-known data and facts from which little in the way of conclusions are or can be made.

Specifically, I offer the following observations and comments:

- The Glossary of Terms needs some clarification; otherwise, it could result in misunderstanding that could lead to a wrong decision.

- The estimate of lube oil used and used oil generated starting with 1975 and carrying through to the projections for the year 2000 are not good numbers. Therefore, there could most likely be some alterations in other parts of the report to be more factual. For example, all the best numbers show that in 1975 the total lube oil used was 2.104 billion gallons not 2.8 billion gallons as given in the report. Likewise, breakdown volumes for automotive and industrial are wrong.

- Oils are usually changed because of contamination; today it would be unusual for oil to be changed because of oil deterioration.

- Decline of the Re-refining industry started as a result of the 1965 Tax Revision law which placed a tax on virgin oil used to blend with re-refined oil for non-highway purposes.

- Under proposed processes, the NORCO plant is not under construction. In fact, the company is out of business and did not represent a valid development. Likewise, the MZF process has not been developed to a point where it warrants the consideration given in this report. Although the BERC process has produced Pilot Plant material and has a high energy demand, it would seem logical to extend investigation before considering less sure or proven proposed processes.

- Comparative economics require certain baselines and assumptions, However, the assumption of a universal $0.15 per gallon cost to get used to a re-refining location does not relate to many "real-world" situations.

- Due to the complexity of petroleum refining, past efforts to compare the economics of refining with re-refining, has produced as many answers as attempts; it is an almost impossible task. Therefore, anything that would restrain economic checks and balances in our "free enterprise" system would be counterproductive to energy and resource conservation.

- The reference to type of engine oil as SE 20W, etc., is a wrong designation. The author is confusing service classifications with viscosity classifications. This is not significant to the report value; but it, along with other references and comments, indicate possible confusion which could transfer to people having to read this report and make decisions.

Thanks for this opportunity to comment on this report. After you had an opportunity to consider my comments, I would be happy to discuss them in more detail with you.

Sincerely,

H. E. Tiffany

H. E. Tiffany

APR
Association of
Petroleum Re-refiners

1730 Pennsylvania Avenue, N.W.
Washington, D.C. 20006 202 / 785-0500

June 2, 1978

Dr. Jerome Collins
Chief, Alternative Materials
Utilization Branch
Office of the Assistant Secretary
Conservation & Solar Applications
U. S. Department of Energy
Washington, D.C. 20545

Dear Dr. Collins:

I appreciate your affording the Association of Petroleum Re-refiners the opportunity to comment on the report "Utilization of Used Oil, Volume II, Energy Conservation and Economics."

We are pleased that the conclusions of the study confirm earlier works and show that a definite, favorable energy balance exists for re-refining. Also, we are happy with the recommendation that although the magnitude of the total potential energy savings may not be great, re-refining should be part of the nation's overall conservation programs, and the Department of Energy is therefore encouraged to take an active role to maximize this effort.

We are concerned, however, that this balance may be understated because of the failure of the research to verify data from the producers of virgin lube oils as to the energy consumption in their processes. As this is a cornerstone to the energy balance calculations, it represents a flaw and one must question why the major oil companies refused to provide this information.

We would like to specifically endorse Recommendation part 5.2.2 covering sludge utilization. Sludge disposal is a critical problem for re-refiners and an effort directed toward utilization of these materials would clearly be in the interest of the orderly growth of re-refining.

We are unable to provide the staff to evaluate at this time the technical basis for the assessments presented and the assumptions relating to the process comparisons of lubricating oils versus re-refined oils. We are particularly uncertain as to recommendations for further evaluation of selected processes, based on the energy efficiency, when such efficiencies are based on the developers' claims as to process yields and the like. To scale up process evaluation and testing to pilot plant levels on the basis of such claims is questionable. More accurate data are becoming available for processes that have been demonstrated to be commercially feasible and, therefore, may indeed be a better bet for energy conservation.

We greatly appreciate the Department's interest in re-refining and its willingness to take an active role in the development of this industry as a means to help conserve petroleum and to maximize energy savings. We look forward to working with you in the future in every way that we can.

Very truly yours,

Duane H. Ekedahl
Executive Director

# APPENDIX C

## ABBREVIATIONS

| | |
|---|---|
| API | American Petroleum Institute |
| APR | Association of Petroleum Re-Refiners |
| ARA | Automotive Research Associates |
| ARB | Army Review Board |
| ARCO | Atlantic Richfield Company |
| ARL | Automotive Research Laboratories |
| ASLE | American Society of Lubrication Engineers |
| ASTM | American Society for Testing and Materials |
| ATF | Automatic Transmission Fluid |
| BERC | Bartlesville Energy Research Center |
| BOC | Bureau of the Census |
| BOM | Bureau of Mines |
| BPSD or b/sd | barrels per stream day |
| BS&W | bottom solids and water |
| Btu | British thermal unit |
| CRC | Coordinating Research Council of the SAE |
| DOD | Department of Defense |
| DOI | Department of the Interior |
| DOT | Department of Transportation |
| EP | extreme pressure |
| EPA | Environmental Protection Agency |
| ERDA | Energy Research and Development Administration |
| FTC | Federal Trade Commission |
| GM | General Motors |
| HVI | high viscosity index |
| IFP | Institute Francais du Petrole |
| IRS | Internal Revenue Service |
| KTI | Kinetics Technology International |
| LVI | low viscosity index |
| MEK | methyl ethyl ketone |
| MIL | military |

| | |
|---|---|
| MVI | medium viscosity index |
| NBS | National Bureau of Standards |
| NORCO | National Oil Recovery Corporation |
| OPEC | Organization of Petroleum Exporting Countries |
| P&E | plant and equipment |
| PNA | polynuclear aromatics |
| PROP | Phillips Re-Refined Oil Process |
| QA | quality assurance |
| QPL | Qualified Products List |
| RDC | rotating disc contactor |
| SAE | Society of Automotive Engineers |
| SRI | Southwest Research Institute |
| SUS | Saybolt universal seconds |
| TBP | true boiling point |
| VI | viscosity index |

# APPENDIX D
# GLOSSARY

| | |
|---|---|
| Acid Sludge | The residue left after treating petroleum oil with sulfuric acid for the removal of impurities. The sludge is a black, viscous substance containing the spent acid and the impurities which the acid has removed from the oil. |
| Additive | A chemical added to oil to enhance certain characteristics or to give it other desirable properties. |
| Aliphatics | One of the two classes of organic petrochemicals; the other is the aromatics. The most important aliphatics are the gases ethylene, butylene, acetylene, and propylene. |
| Alkane | A saturated paraffinic hydrocarbon. |
| Alkane Sulfonate | A substituted hydrocarbon in which one group is a sulfonic acid group or its salt (usually sodium salt); used frequently as detergent stock. |
| Alkylation Process | The process of making gasoline-range liquids from refinery gases; e.g., isobutane, butylenes, and others. The resulting alkylates are highly desirable components for blending in premium grade gasolines. |
| Aniline Number (or Point) | Temperature, in °C at which mixtures of petroleum and aniline become miscible. The value is a measure of sludge solvent power. A lower aniline point usually is associated with high solvent power. |
| °API | Degrees API. An American Petroleum Institute density scale used frequently for hydrocarbons:<br>$^{\circ}\text{API} = \frac{141.5}{\text{SG } 60^{\circ}\text{ F}/60^{\circ}\text{ F}} - 131.5$<br>where SG is specific gravity. |
| Aromatics | A group of hydrocarbon fractions that form the basis of most organic chemicals so far synthesized. The name aromatics derives from their rather pleasant odor. The unique ring structure of their carbon atoms makes it possible to transform aromatics into an almost endless number of chemicals. Benzene, toluene, and xylene are the principal aromatics and are commonly referred to as the BTX group. |

| | |
|---|---|
| Ash, Sulfate | A measure of metallic residue in petroleum products. ASTM test D-874 describes the method. The ash remaining after reaction with $H_2SO_4$ is calculated as weight percent sulfates. |
| Asphaltenes | High molecular weight hydrocarbons of asphaltic nature. Insoluble in petroleum naphtha but soluble in benzene; believed to be responsible for sludge and varnish deposits. |
| Asphalt | A solid hydrocarbon found as a natural deposit. Crude oil of high asphaltic content when subjected to distillation to remove the lighter fractions such as naphtha and kerosine, leaves asphalt as a residue. Asphalt is dark brown or black in color and at normal temperatures is a solid. |
| Asphalt-Base Crude | Crude oil containing very little paraffin wax and a primarily asphaltic residue. Sulfur, oxygen, and nitrogen are often relatively high. This type crude is particularly suitable for making high-quality gasoline, lubricating oil, and asphalt. |
| Atmospheric Still | A refining vessel in which crude oil is heated and product is distilled off at the pressure of one atmosphere. |
| Azeotrope | Liquid mixture that maintains a constant boiling point and produces a vapor of the same composition as the mixture. |
| Barrel | A unit of petroleum capacity equal to 42 gallons. |
| Base Stock | Refined lubricating oil fractions usually produced from crude petroleum. One or more of these fractions are used in manufacturing finished lubricating oils. |
| °Baumé | A density scale, expressed in degrees Baumé (°Bé). For liquids heavier than water, specific gravity SG is related by the equation:<br>$SG = \frac{145}{145 - {}^{\circ}Bé}$ |
| Benzene Insoluble | A measure of the tendency of a motor oil to break down during high-temperature oxidative attack; ASTM Test No. D-893 describes the procedure. High values of benzene insolubles are undesirable. |
| Blending | The process of mixing two or more oils having different properties to obtain a lubricating oil of intermediate or desired properties. |
| Bright Stocks | High viscosity, fully refined, and dewaxed lubricating oils; used for blending with lower viscosity oils. The name originated from the clear, bright appearance of the dewaxed lubes. |

| | |
|---|---|
| BS&W | Abbreviation for bottom solids and water. Ordinarily found in petroleum crudes, undistilled fuels, and used oils. |
| Butane | A hydrocarbon compound. At ordinary atmospheric conditions, butane is a gas but it is easily liquefied; one of the most useful LP-gases, widely used as a household fuel. |
| Casinghead Gasoline | A very volatile fuel obtained from condensation of the low boiling constituents of natural gas derived from oil wells. |
| Chromatography | A technique for separating fluid mixtures by virtue of differences in rates of migration of the fluid components in a packed column. Column packings of alumina, silica gel, activated carbon, and other materials are used. |
| Clay | The filtering medium, especially Fuller's earth, used in refining; a substance which tends to adsorb and neutralize materials present in the oil. |
| Clay Treatment | Adsorptive purification of oils by contacting the oil to be purified with finely divided natural or synthetic mineral adsorbents ("clays"). |
| Cleveland Open Cup (C.O.C.) | A type of flash point test in which liquid is heated in an open cup to measure temperature at which vapor ignites. |
| Color, ASTM | A color comparison test using colored glass standards. Refer to ASTM Tests D156 and D1500. |
| Conradson Carbon Residue (C.C.R.) | A measure of the tendency of a lube oil to produce varnish and sludge; measured in weight percent. |
| Centistoke (Cs) | A unit of kinematic viscosity. |
| Cracking | Process by which petroleum fractions are decomposed to produce fuels, oils, and other products; normally carried out at elevated temperature with and without the aid of a catalyst. |
| Cutting Oils | Special oils used to lubricate and cool metal-cutting tools. |
| Cyclization | A thermocatalytic process for producing ring-type compounds from straight or branch chain paraffin. |
| Detergent Additive | A material added to lubricating oils to hold in suspension oil-breakdown products and dirt accumulated in service. A more exact description of this additive function is "dispersant". |

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| Distillate | Liquid hydrocarbons, usually water-white or pale straw color and of high API gravity (above 60°), recovered from wet gas by a separator that condenses the liquid out of the gas stream. |
| Distillation | The refining process of separating crude oil components by heating, vaporizing, and subsequent condensing of the fractions by cooling. |
| Drum | A 55-gallon metal container; a standard container used for shipping lubricating oil and other petroleum products. |
| Engler Viscosity | A kinematic viscosity scale expressed in degrees; e.g., 2.3° Engler. |
| EP | Extreme pressure. Refers to additives put into oils for protection of surfaces with very high bearing loads. |
| Feed or Feedstock | Crude oil or other hydrocarbons that are the basic materials for a refining or manufacturing process. |
| Finishing | The final step in a lube oil production process intended to remove traces of resinous materials and chemically active compounds, so as to improve and stabilize color. |
| Flash Point | The temperature at which a given substance ignites. |
| Flushing Oils | Oils or compounds formulated for the purpose of removing used oil, decomposed matter, metal cuttings, and sludge from lubricating passages and engine parts. |
| Fractionation | Separation of a mixture of liquids into lower-boiling and higher-boiling products. The process may be batch or continuous and may yield pure products or other mixtures with narrower boiling ranges than the original feed. |
| Fractionator | A tall, cylindrical refining vessel where liquid feedstocks are separated into various components or fractions. |
| Fuller's Earth | A naturally occurring adsorptive clay, which is treated, ground, and purified before use; used for removal of color and odor bodies and acidic contaminants in oils. |
| Furfural | An extractive solvent of extremely pungent odor, used extensively for refining a wide range of lubricating oils and diesel fuels; a liquid aldehyde. |
| Gas Oil | A refined fraction of crude oil, somewhat heavier than kerosine; often used as diesel fuel. |

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| Grease | A lubricating substance (solid or semisolid) made from lubricating oil and a thickening agent. The lube oils may be light or heavy cylinder oils; the thickening agent (usually soaps) may be any material that when mixed with oil produces a grease structure. |
| Heavy Ends | In refinery parlance, heavy ends are the heavier fractions of refined oil -- fuel oil, lubes, paraffin, and asphalt -- remaining after the lighter fractions have been distilled off. See also Light Ends. |
| Hydraulic Oil | Lubricating oil ranging in viscosity from about 150 to about 2200 SUS at 100°F; usually compounded with anti-foam and anti-corrosion additives; used for hydraulic power and control systems, enclosed gears, circulating lubrication systems, and similar systems. |
| Hydrocarbons | Organic chemical compounds of hydrogen and carbon atoms. These compounds are vast in number and form the basis of all petroleum products. They may exist as gases, liquids, or solids. An example of each is methane, hexane, and asphalt, respectively. |
| Hydrogenation | Addition of hydrogen to an unsaturated hydrocarbon; usually carried out in presence of catalyst and at elevated temperature and pressure. |
| Hydrotreating | A severe hydrogenation process for base oil stock production. |
| IBP | Initial boiling point; usually expressed as °F at one atmosphere. |
| Industrial Lube Oils | As classified by the U. S. Department of Commerce, these comprise marine, industrial, and railroad oils intended primarily for lubrication purposes including oils for cutting operations. |
| Interfacial Tension | The force required to transfer a surface from one fluid phase to another; expressed in dynes per centimeter and measured with a tensiometer. For oils, distilled water usually is used as the second fluid phase. |
| Isomerization | Restructuring of a molecule to produce a branched chain compound without any change in the number of atoms; usually requires the input of some form of energy to cause the change. |
| Light Ends | The more volatile products of petroleum refining, e. g., butane, propane, gasoline. |

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| Mercaptans | Chemical compounds containing sulfur; present in certain refined products that impart an objectionable odor to the product. |
| Methanol | Methyl alcohol; a colorless, flammable liquid derived from methane (natural gas). |
| Mid-Continent Crude | Oil produced principally in Kansas, Oklahoma, and North Texas. |
| Mineral Oil | A "pure" base oil of petroleum origin without any additives. |
| Molecular Sieve | Adsorbents of either natural but mostly synthetic mineral origin having well-defined properties and capable of adsorbing molecules of a specific size. May be used for separation of gas mixtures and as a catalyst. |
| Naphtha | A volatile, colorless liquid obtained from petroleum distillation; used as a solvent in the manufacture of paint, as a dry-cleaning fluid, and for blending with casinghead gasoline in producing motor gasoline. |
| Naphthene | Any of a series of saturated cyclic hydrocarbons; yields useful aromatic hydrocarbons on dehydrogenation. |
| Neutral Stock | Lubricating oil stock with impurities, particularly acids, removed that has been dewaxed and can be blended with bright stock to make good lube oil; one of the many fractions of crude oil that, owing to special properties, is ideal as a blending stock for making high-quality lube oil. |
| Neutralization Number | The number of milligrams of potassium hydroxide needed to neutralize 1.0 gram of oil sample. Refer to ASTM Test D974. |
| Oleum | A heavy, oily, strongly corrosive solution of sulfur trioxide in anhydrous sulfuric acid. |
| Other Industrial Oils | A U. S. Department of Commerce designation; products derived primarily from petroleum and having a viscosity of more than 45 SSU at 100°F and intended for nonlubricating use. Excludes solvents, asphalts, petrochemicals, etc. |
| Paraffinic | Having the nature of a paraffin. Paraffins are saturated hydrocarbons having no double or triple bonds. They may be straight chain or branched chain. Paraffins are relatively inert but can be oxidized or burned when temperatures are high enough. |
| Pentane Insolubles | Asphaltic bodies in new or used motor oils insoluble in pentane, expressed in weight percent. Refer to ASTM Test No. D893. |

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| Process Oil | Oils that are formulated into the final product, such as rubber plasticizers. |
| Pour Point | Lowest temperature at which useful flow properties of a lube oil exist. Refer to ASTM Test No. D97. |
| Quench Oil | A specially refined oil with a high flashpoint used in steel mills to cool hot metal. |
| Raffinate | The purified stream from a liquid-liquid solvent extraction system. The raffinate is nearly solvent free. The second liquid phase is termed the extract and possesses most of the solvent. |
| Reduced Crude Oil | Crude oil that has undergone at least one distillation process to separate some of the lighter hydrocarbons. Reducing crude lowers its API gravity. |
| Residuals | A term used to describe oils that are "leftovers" in various refining processes; heavy black oils used in ships' boilers and in heating plants. |
| Saponification Number | A measure of the amount of acidic and saponifiable materials in oils; expressed as milligrams KOH per gram sample. Refer to ASTM Test No. D94. |
| Saybolt Furol Seconds (SFS) | A measurement of the viscosity of a heavy oil. Sixty cubic centimeters of an oil are put in an instrument known as a Saybolt viscosimeter and permitted to flow through a standardized orifice in the bottom at a specified temperature. The seconds for flow-through is the oil's viscosity, its SFS number. See also Saybolt Universal Seconds. |
| Saybolt Universal Seconds (SUS) | A measurement of the viscosity of a light oil. A measured quantity of oil, usually 60 cubic centimeters, is put in an instrument known as a Saybolt viscosimeter and permitted to flow through an orifice in the bottom at a specified temperature. The number of seconds required for the flow-through is the oil's SUS number, its viscosity. |
| Slop Oils or Slops | Waste oils frequently heavily contaminated with water, fuels, dirt, and debris. |
| Sludge Flocculant | A compound which causes aggregation of small suspended particles and thereby hastens settling. |
| Sludge Rating | The tendency of an oil to deposit insoluble materials in critical engine parts. A value of 10 indicates a clean engine. Refer to ASTM STP 315E sequence V-C tests. |
| Solvent Bright Stock | See Bright Stock. |

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| Solvent Neutral Oil | Base stocks of essentially paraffinic nature and having viscosities generally of less than $\approx 600$ SSU. |
| Space Velocity | A measure of the interaction of a catalyst bed with the incoming reactants, usually expressed as a reciprocal time, e.g., $hr^{-1}$, $sec^{-1}$; may be expressed as cubic feet reactants per unit time per cubic feet of catalyst. |
| Spindle Oil | A naphthenic base stock. |
| Steam Stripping | Use of steam to entrain lower boiling compounds from a mixture. The vapor mixture may be condensed and the condensate separated into an aqueous phase and an oil phase. |
| Sweetening | Removal of sulfur from hydrocarbon stocks. |
| Tank Bottoms | Heavy sludges accumulating in the bottoms of storage tanks after repeated use. |
| Used Oil | Oil that has deteriorated in service and is considered to have reached the end of its useful life, unless purified for re-use. |
| Vacuum Distillation | Distillation under reduced pressure (less than atmospheric) which lowers the boiling temperature of the liquid being distilled. This technique with its relatively low temperatures prevents cracking or decomposition of the charge stock. |
| Varnish Rating | Varnish is an oil-insoluble lustrous deposit not removable by wiping with a soft cloth. Oils are rated (10 = clean) by ASTM STP 315E for such deposits on critical engine parts. |
| Virgin Oil | Oil products manufactured from previously unused petroleum materials. |
| Viscosity | One of the physical properties of a liquid, viz., ability to flow; the more viscous the oil, for example, the less readily it will 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. Refer to ASTM D567. |
| Viscosity Index Improver | An additive which generally increases the oil viscosity at high temperature, but less so at lower temperatures. |
| White Oil | High purity clear mineral oils of different viscosities and densities. Some used as industrial lubricants and some in pharmaceutical applications. |