Technical Report Documentation Page

1. Report No	2. Government Accession No.	3. Recipient's Catalog No.
1355-1		

4. Title and Subtitle	5. Report Date
Re-Refined Oil Performance and TxDOT Used Oil Collection Procedures	December 1995
	6. Performing Organization Code
7. Author(s) Jesse C. Jones, Timothy T. Maxwell, Raghu Narayan, and Atila Ertas	8. Performaing Organization Report No. Final Report Project No. 0-1355
9. Performing Organization Name and Address Institute for Design and Advanced Technology College of Engineering Texas Tech University Box 41021 Lubbock, Texas 79409-1021	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project No. 0-1355
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P.O. Box 5080 Austin, Texas 78763-5080 Texas Natural Resources and Conservation Commission P.O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Final Report December 1994—September 1995 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The objectives of this study were to: (1) identify chemical and physical differences between re-refined and virgin oil, (2) identify any long-term deterious effects from using re-refined oil in TxDOT equipment, (3) optimize TxDOT lubricating oil and fluid logistic handling procedures, and (4) perform life-cycle cost analysis on viable purchasing and logistic approaches.

Based on oil sample testing performed and other authoritative sources, no significant chemical or physical differences exist between re-refined and virgin oil. Differences noted were related to higher levels of poly-nuclear aromatics (PNA's) in the re-refined oil. PNA's, formed as a result of high temperature and pressure during the combustion process in an engines, are essentially removed during re-refining. The trace amounts detected in new re-refined oil do not affect the physical performance characteristics of the oil. PNA's were detected in used re-refined and virgin oil to the same extent; thus, the process of chemical change during use in an internal combustion engine is the same regardless of the nature of the oil.

An exhaustive literature search relative to deleterious effects of using re-refined oil did not disclose any instances where this had occurred. Significant testing has been performed on engines using re-refined lubricating oil and no cases have been recorded in which the engine operation was affected negatively. The American Petroleun Institute (API) has concluded that the use of re-refined base stock oils are fully acceptable in the blending of end use lubricants.

Recommendations are included concerning TxDOT's lubricating fluid and logistics handling procedures. Many of these recommendations relate to screening suppliers and using the purchasing specifications to insure that only qualified supplier's products are procured. The existing purchasing specifications are acceptable but certain sections need to be enforced to ensure that only quality products are supplied. Several specification interpretations are also suggested.

Several alternative contracting arrangements are suggested that may offer lubricating fluid procurement and disposal cost savings. Suppliers have indicated interest in working with TxDOT to determine the most cost-effective approach for supplying new lubricating fluid products and collecting/disposing of used fluids. It is recommended that TxDOT work with several of these firms to identify the most effective method for handling this problem.

Recommendations and conclusions are made concerning other subjects related to the study. Supplier and refiner visits were made and trip reports are included. A description of the re-refining process, legislative action relative to the use of recycled fluids and information on the experience of other states in regard to the use of re-refined oil are also included.

17. Key Words	18. Distribution Statement
re-refined oil, lubricating oil, lubricating fluids, used oil, used oil collection oil recycling	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	129	

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Re–Refined Oil Performance and TxDOT Used Oil Collection Procedures

Final Report

Project No. 0–1355

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December 1995

Executive Summary

The objectives of this study were to:

1. identify chemical and physical differences between re–refined and virgin oil,
2. identify any long–term deterious effects from using re–refined oil in TxDOT equipment,
3. optimize TxDOT lubricating oil and fluid logistic handling procedures, and
4. perform life–cycle cost analysis on viable purchasing and logistic approaches.

Based on oil sample testing performed during this project as well as many other authoritative sources, no significant chemical or physical differences exist between re–refined and virgin oil. Differences that were noted during this study were related to the higher level of poly–nuclear aromatics (PNA's) in the re–refined oil. PNA's are formed as a result of the high temperatures and pressures experienced during the combustion process in internal combustion engines. These components are essentially removed by the hydrogenation process during re–refining and the trace amounts in new re–refined oil detected during this study do not affect the physical performance characteristics of the oil. PNA's were detected in used re–refined and virgin oil to the same extent, thereby indicating that the process of chemical change during use in an internal combustion engine is the same regardless of the nature of the oil.

An exhaustive search of the literature relative to any deleterious effects of using re–refined oil did not disclose any instances where this had occurred. Significant testing has been performed on engines using re–refined lubricating oil and no cases have been recorded in which the engine operation was affected negatively. The American Petroleun Institute (API) has concluded that the use of re–refined base stock oils are fully acceptable in the blending of end use lubricants.

Recommendations are included concerning TxDOT's lubricating fluid and logistics handling procedures. Many of these recommendations relate to the problem of screening suppliers and using the purchasing specifications to insure that only qualified supplier's products are procured. It was concluded that the existing purchasing specifications are acceptable but that certain sections need to be enforced to ensure that only quality products are supplied. Several specification *interpretations* are also suggested.

Several alternative contracting arrangements are suggested that may offer lubricating fluid procurement and disposal cost savings. Suppliers have indicated interest in working with TxDOT to determine the most cost–effective approach for supplying new lubricating fluid products and collecting/disposing of used fluids. It is recommended that TxDOT work with several of these firms to identify the most effective method for handling this problem.

Recommendations and conclusions are also made concerning several other subjects related to the study. Several supplier and refiner visits were made at TxDOT's request and the reports on these trips are included. A copy of a report from Argonne National Laboratories that provides justification for re–refining used oil for use as a lubricating oil base stock is included in the Appendix. A description of the re–refining process, legislative action relative to the use of recycled fluids and information on the experience of other states in regard to the use of re–refined oil are also included.

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1 Introduction

Supplemental Agreement No. 2 to the *Cooperative Research Agreement Between Texas Tech University and the Texas Department of Transportation* (TxDOT) was signed December 2, 1994. This Agreement includes Project No. 0–1355***, Re–Refined Oil Performance and TxDOT Used Oil Collection Procedures***, the authority under which the study described herein was performed. Work under this agreement was initiated in mid–January 1995 and the first project coordination meeting with the Project Director and other interested TxDOT personnel was held in Austin on January 30, 1995.

The objectives of this study were:

- ❑ to collect information and data on oils and fluids and identify any chemical and physical differences between re–refined and virgin oils and fluids,
- ❑ to collect and test oil samples from TxDOT vehicles and compare virgin and re–refined oils before and after use and identify any long–term deleterious effects related to using re–refined oil in TxDOT equipment,
- ❑ to assess the life cycle cost effectiveness of viable purchasing and logistic approaches for obtaining and distributing re–refined oils,
- ❑ to recommend viable purchasing specifications for re–refined oils and fluids,
- ❑ to conduct a survey of TxDOT used oil and fluid collection and recycling procedures and re–refined oil and fluid usage,
- ❑ to propose viable options for TxDOT lubricating oil and fluid logistic handling procedures and used oil and fluid collection procedures, and
- ❑ to document the results of the study in a detailed report..

These project objectives are addressed in detail by individual sections of this report. In addition, information on the re–refining process, legislative action relative to the use of recycled vehicle fluids, TxDOT demographics pertinent to recycled fluid use, information on the experiences of other states in regard to the use of re–refined oil, and several reports on refinery and supplier visits by the study team are also discussed.

2 Collection and Processing of Used Oil

Used oil is defined by the *US Resource Conservation and Recovery Act* (RCRA) as refined crude oil that is contaminated by physical or chemical impurities through use [20]. Used motor oil is primarily generated from lubricants used in vehicle engines which is collected at commercial and fleet service centers, oil change and lubrication shops, and at used oil collection centers where owners dispose of used oil from their individual vehicles.

The US Environmental Protection Agency (EPA) estimates that Americans buy 2.5 billion gallons of lubricating oil and generate 1.37 billion gallons of used oil each year [36]. The National Oil Recycling Association (NORA) reports that the 1.37 billion gallons of used oil is made up of 856 million gallons from transportation usage and 521 million gallons from industrial generation [39]. The EPA further estimates that 350 million gallons of used oil are improperly disposed of and thus not available for recycling. This leaves a potential quantity of 506 million gallons of oil available for recycling from transportation uses, or 1.02 billion gallons total, assuming no decrease in the amount of oil disposed of improperly. The Texas Department of Transportation (TxDOT) estimates that its usage of motor oil for all vehicles and equipment amounts to about 100,000 gallons per year [36].

A significant amount of oil is also disposed of in used oil filters. A 1992 study indicated that approximately 395 million oil filters are discarded each year in the US. These filters constitute 264,000 tons of metal and contain 20 million gallons of oil [41]. It is obvious that used oil recycling is a big business, important to the US economy as well as to maintaining the quality of the environment.

When used oil is collected for off–site disposal or reuse it enters what is called the Used Oil Management System (UOMS). The UOMS includes independent collectors, minor reprocessors, major reprocessors, and re–refiners [19]. The oil recycling industry consists of reprocessors who remove water and particulate matter from the used oil and sell it for fuel and asphalt extender and re–refiners who filter, dehydrate, strip the fuel, vacuum distill, and hydrotreat the used oil for subsequent use as a petroleum base feed stock. The base feed stock is then sold to refiners and blenders or further processed, by combining with additive packages, into lubricating fluids that are sold under the re–refiners own label. Re–refiners sell that portion of the used oil that is not suitable for full processing as fuel oil and asphalt extender. Refiners purchase processed oil from re–refiners for use as a replacement for virgin crude oil in the production of gasoline, fuel oil, and lubricating oil. Some refiners also blend the re–refined base feed stock with additive packages and sell the end product under their own label.

When re–refined oil is converted into lubricating fluids it can be blended with virgin oil or used *neat*. In either case, oil additives are blended in to bring the end product into conformance with American Petroleum Institute (API) motor oil specifications. In 1991, reprocessors handled 628 million gallons of used oil of which 553 million gallons were converted to industrial fuels. In the same year re–refiners processed 114 million gallons of used oil, of which about one–half was converted to lubricating fluids, with the remainder used for industrial fuel, machine lubricating oil and wood preservative [36].

Reprocessors are reasonably well distributed across the US with collection service in most cities and reprocessing facilities in many of the larger cities and metropolitan areas. However, there are only two re–refining facilities in the US: Safety–Kleen in East Chicago, Indiana and Evergreen in California. The fact that there are only two re–refining facilities in the country creates a barrier to the re–refining of used oil. The problems and cost associated with collecting used oil from the myriad of users scattered over a wide geographical area and transporting it to distant re–refining facilities create a serious impediment to the cost–effectiveness of re–refining used oil. The continuing low cost of virgin crude oil also compounds the difficulties of the re–refining industry. In 1960, there were over 150 companies in the US producing 300 million gallons of re–refined lubricating oil annually. The fact that only two exist at present is due, in part, to the 1965 repeal of a $0.06/gallon sales tax imposed on virgin oil, but not on re–refined oil [36].

Another factor that lead to the demise of the re–refining industry in the 1960's was uncertainty about product quality control, a question that continues to impact reputable re–refiners and blenders in the 1990's. In June 1988, the EPA issued guidelines for the purchase of lubricating oils that contain re–refined oil. These guidelines recommend that procuring agencies establish a minimum content standard of 25% for the amount of re–refined oil contained in lubricating oils, hydraulic fluids, and gear oils purchased by federal, state, and local government agencies and contractors that use federal funds to purchase such products [19]. Several states have also implemented programs to enhance the use of re–refined oil. State–owned vehicles in Texas, New York, Illinois, Wisconsin, Missouri, Michigan, and Indiana, as well as US Postal Service vehicles throughout the country now use re–refined oil products. With present state and Federal government encouragement for the use of recycled lubricating products the situation is again opportune for suppliers, without the necessary facilities and personnel to ensure adequate product quality control, to enter the market with low cost products and underbid reputable suppliers. Further, API certification of suppliers may not afford adequate protection for lubricating fluid product users in these cases. If users cannot be convinced that re–refined lubricating products are equal to the quality of virgin lubricating products, the market for re–refined products will disappear and re–refiners will be forced to sell all of their product as fuel oil, asphalt extender, and base feed stock for refiners to mix with virgin feed stock and subsequently process. Such a development would have the disadvantage of no longer allowing users to easily validate compliance with state and Federal guidelines for using products with a specified minimum content of re–refined oil, but would greatly simplify the procurement process and user lubricating fluid handling operations. Refiners could be required to provide certification that required levels of re–refined base stock was used in the refining process.

Regulations and incentives related to the recycling and re–refining of waste oil are listed in Appendix I.

3 The Re–Refining Process

The oil re–refining process commonly used today includes three distillation stages, followed by a hydrotreating process. The distillation stages (dehydration, fuel stripping, and vacuum distillation) produce distilled oil, fuel, and asphalt extender products. The distilled oil is then hydrotreated to yield finished base oils and light distillates. Figure 1 depicts the re–refining process and shows the various stages which are described below. The entire oil recycling process is shown in Figure 2.

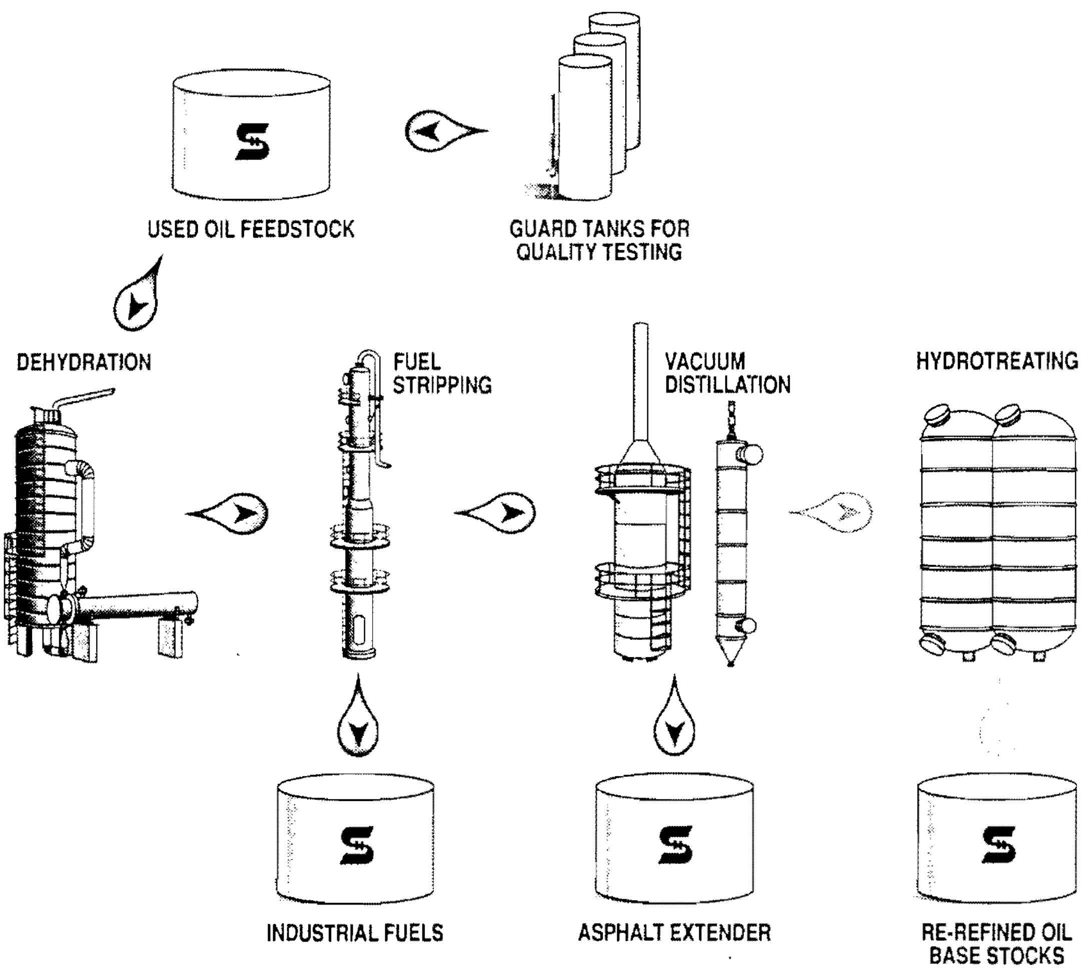


Figure 1 Schematic Diagram of Oil Re–Refining Process
(Taken from *The next step in oil evolution...Renewing our non–renewable resources*, Safety–Kleen Brochure, 1991 [50])

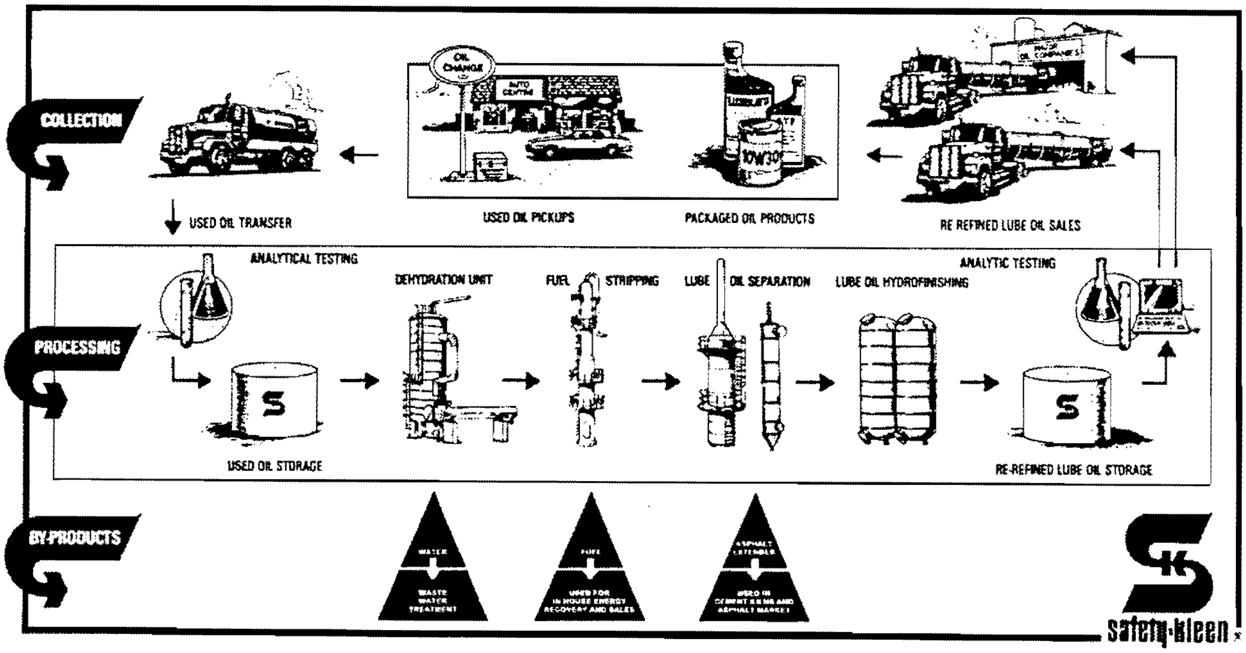


Figure 2 Oil Recycling Process
(Provided by Safety–Kleen)

In the dehydration process pretested feedstocks enter the dehydration stage where water and light end fuels are separated from the oil at 275°F and atmospheric pressure. Fuels are routed to storage facilities and waste–waters are removed from the process and subsequently treated and disposed of.

To strip the fuel the dehydrated oil is fed into a fuel stripping unit maintained at 450°F and a slight vacuum, which causes the fuel to vaporize. The fuel vapor is then condensed and routed to storage facilities for use in the re–refining process or to be sold as an industrial fuel.

In the vacuum distillation unit, defueled oil is vaporized in a thin film evaporator operating at 750°F under extreme vacuum. The oil vapor is then condensed into three oil fractions and pumped to intermediate storage prior to hydrotreating. This stage also yields industrial fuel and asphalt extender.

The final stage in the re–refining process is hydrotreating in which sulfur, nitrogen, chlorine, and oxygenated compounds are removed from the product stream. Any remaining traces of heavy metals and other inorganic species are also eliminated during this high temperature, high pressure, catalytic hydrogenation process. The high concentration of inorganic species in used oil (see Table 1) can present problems with catalysts at this stage in the refining process [24]. The hydrotreated oil is then separated from the hydrogen in high pressure separators and light distillates are stripped from the oil with steam in a low pressure separator. The hydrogen used in this stage is recycled through a purification system which scrubs and recompresses it for reuse.

In 1976 the National Bureau of Standards (now the National Institute of Science and Technology, NIST) initiated the Recycled Oil Program which was created under the

Table 1 Compositions of Used Oils and Other Fuels
(Taken from *Assessment of Opportunities to Increase the Recovery and Recycling Rates of Waste Oils*, USDOE Report No. ANL/ESD–29 [24])

Component	Used Gasoline Engine Oil[a]	Used Diesel Engine Oil[a]	Virgin Lube[a]	#4 Fuel Oil[a]	Residenti-al Fuel Oil[b]	Crude Oil[c]	North American Coals[d]
Ash, wt%	0.54	0.46	0.14	0.55	0–0.5	0.01–0.12	5–14
Sulfur, wt%	0.36	0.25	0.36	0.19	0.3–0.4	0.1–3.8	1.5–6.0
Nitrogen, wt%	0.04	0.02	0.02	0.03	NAe	0.05–0.3	1–2
Barium, ppm	2.7	3.4	<1.0	<1.0	0.7–95.0	NA	NA
Beryllium, ppm	<0.02	<0.02	<0.02	<0.02	NA	NA	NA
Cadmium, ppm	1.5	2.4	<0.25	<0.25	0	NA	NA
Chromium, ppm	3.2	3.9	<2	<2	13–14	NA	9–330
Lead, ppm	47.2	57	<20	<20	1.7–4.1	NA	7–40
Nickel, ppm	1	1.8	<1.2	8.4	3–118	1–55	3–200
Zinc, ppm	1,162	1,114	1,210	9	0	NA	20–240
Halogens, ppm	350	234	<200	<200	NA	NA	40–3,000

[a] Source of data: Elliot, 1993
[b] Source of data: Mueller and Associates, Inc., 1989
[c] Source of data: HPI Consultants, 1987
[d] Source of data: Prather et. al., 1979
[e] NA — Not available

Energy Policy and Conservation Act (1975) to assess substantial equivalency between re–refined and virgin oils. The acid/clay treatment process was the dominant method used throughout the world, to re–refine used oil at this time [27]. A detailed study conducted over a six year period by the National Bureau of Standards, showed that the hydrocarbon constituents in base oils derived from re–refining used automotive oils through the acid/clay treatment process had no difference in molecular structure when compared to the base oils derived from virgin crude oils. Measurable differences in chlorine content, poly–nuclear aromatic compounds, oxyacids, and trace additive/wear metals were detected. However, it was concluded that the presence of these compounds did not affect the overall performance of the lubricating oils [27].

Since the early eighties, a number of new processes such as high pressure hydro–treating, vacuum distillation, short path distillation, and solvent extraction have been developed for re–refining used oil. These processes have been developed due to the environmental problems associated with the disposal of acid sludge produced in the acid/clay treatment process.

High pressure hydro–treatment was perfected in the mid–seventies to reduce sulfur, nitrogen, and other inorganic matter in highly contaminated and sour heavy crude oils. This same technology, when applied to used oil, results in a base oil that is

Table 2 Energy Impacts of Waste Oil Reuse Options
(Taken from *Assessment of Opportunities to Increase the Recovery and Recycling Rates of Waste Oils*, USDOE Report No. ANL/ESD–29 [24])

Energy Balance (btu/bbl waste oil)	Reuse Option				
	Burning without Treatment in Space Heaters	Reprocessing to Fuel and Burning	Reprocessing in Refinery Coker[a]	Re–refining in Dedicated Unit	Re–refining in Primary Refinery
Transportation energy	0	–144,000	–198,000	–198,000	–198,000
Processing energy consumed	0	–294,000	–207,000	–742,000	–742,000
Processing energy saved[b]	745,000	745,000	474,000	1,722,000	1,722,000
Energy recovered	5,564,000	5,564,000	5,564,000	5,564,000	5,564,000
Net energy recovered	6,309,000	5,871,000	5,633,000	6,346,000	6,346,000

[a] Energy consumed and energy saved are estimated for upstream of coker only; downstream process energies consumed and saved cancel one another.
[b] Processing energy saved is the energy required to manufacture subsitute desulfurized oil (for burning) or lubricating oil (for re–refining).

indistinguishable from base oil from virgin crude feedstock, especially when chlorine content, poly–nuclear aromatic compounds, oxyacids, and trace additive/wear metals are compared. Extensive testing of base oils produced by this process (as well as lubricants formulated from it) have been undertaken by Safety–Kleen and Lyondell Corporation to assess their performance. No difference in their performance was detected when compared to base oils and lubricants formulated from virgin crude oil.

The most thorough performance evaluation of automotive lubricants formulated from re–refined oil was conducted over a two year period in 1979—80 by the Royal Canadian Mounted Police [4] (Armstrong et.al.). Eight new police patrol cars, four on virgin oil and four on re–refined oil, were run under normal fleet operation and maintenance practices for 65,000 miles. The fleet oil change interval was 3,100 miles. All the engines were disassembled and rated at the end of their fleet service. There were no oil related problems, and engine parts showed normal wear and deposits.

The importance of having adequate analytical chemistry laboratory and quality control support of the re–refining process cannot be overstated. The re–refinery must have a used oil collection system that will provide an adequate supply of *re–refinable quality* used oil. All incoming used oil must be tested for hazardous materials such as polychlorinated biphenyls (PCB's), total halogens, and heavy metals before processing. Federal government regulatory standards must be met as well. Statistical process quality control testing must also be performed at each step in the process. If quality control is properly implemented the resulting end product will be paraffinic

Table 3 Assessment of Re–Refining Energy with Multiple Use Cycles Assumed (Taken from *Assessment of Opportunities to Increase the Recovery and Recycling Rates of Waste Oils*, USDOE Report No. ANL/ESD–29 [24])

Assessment Category	Energy Balance (BTU/bbl waste oil)					
	1st Cycle	2nd Cycle	3rd Cycle	4th Cycle	5th Cycle	Total
Transportation energy	–198,000	–118,000	–70,000	–41,000	–25,000	–452,000
Processing energy consumed	–742,000	–441,000	–262,000	–155,000	–92,000	–1,692,000
Processing energy saved	1,722,000	1,023,000	608,000	361,000	214,000	3,928,000
Energy recovered	5,564,000	3,305,000	1,963,000	1,166,000	693,000	12,691,000
Net energy recovered	6,346,000	3,769,000	2,239,000	1,331,000	790,000	14,475,000

Assumptions: 66% yield for lubricating oil, 20% additives in formulated product oil, and 75% recovery of used oil.

base oils that meet or exceed customer, industry, and government standards of consistency and quality.

Justification for re–refining used oil for subsequent use in various lubricating fluids has been made in a report from Argonne National Laboratories [24]. This report makes the case that greater energy savings result from re–refining used oil rather than burning it as a fuel for industrial process heat. The differences in energy savings among the various reuse options are small and reportedly outside the accuracy of the energy savings estimates. The energy savings of various used oil reclamation techniques are compared in Table 2. However, recycling the used oil many times reportedly strengthens the conclusion that re–refining is the most energy conservative solution for this environmental/resource conservation problem (see Table 3). This report further makes the case that no serious environmental consequences arise from any of the options for recycling used oil.

4 Re–Refined Oil Legislation and Regulations

Several areas related to lubricating oils and fluids are addressed by federal legislation. Topics of concern can be loosely grouped into the following general categories.

- ❑ Prevention of environmental pollution: This category includes the production and processing of crude oil, the transportation and storage of lubricating oils and fluids (including used oil and fluids), the disposal of used oils and fluids, and the record keeping required to document the disposition of oils and other hazardous materials.
- ❑ Liability related to environmental pollution: This category is related primarily to the punishment for conviction associated with pollution of the environment.
- ❑ Waste prevention and natural resource conservation: This category relates primarily to conservation efforts such as reduction in the amount of product being used and the associated reduction in the amount of natural resources consumed. In addition, the increased recycling of used oils and fluids also reduces the rate at which natural resources are consumed.
- ❑ Energy conservation: This category is related to the reduction of energy consumed in the production, distribution, and recycling or disposal of lubricating oils and fluids.
- ❑ Protection of the economy: This category is related to a reduction in the amount of imported petroleum and the associated detrimental effect on the balance of payments.

The Clean Air Act (CAA) of 1970 and its amendments (Clean Air Act Amendments of 1990) set levels for vehicle emissions and provided for the establishment of the Environmental Protection Agency or EPA. Lubricating oil production and recycling is not greatly affected by the CAA except through the creation of the EPA. The Alternative Motor Fuels Act of 1988 and the National Energy Security Act of 1992 both address the increased use of domestic fuels and reduction of imported crude oil.

The Supporting Statement For Information Collection Request 1286, entitled *Used Oil Management Standards Recordkeeping and Reporting Requirements* [49], states

> *Section 3014 of the Resource Conservation Act (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA), directs EPA to "promulgate regulations ... as may be necessary to protect public*

health and the environment from hazards associated with recycled oil" and at the same time, not to discourage used oil recycling. This mandate was amended to RCRA as Section 3012 by the Used Oil Recycling ACT (UORA) of 1980, and later redesignated as Section 3014 by HSWA.

Thus, several bills and EPA procedures address the transportation of used or waste oil. Strict requirements are set forth regarding the spillage of waste oil and related cleanup, and the records keeping and resulting paper trail to be generated and maintained for waste oil. The record keeping required of generators, transporters, processors/re–refiners or burners of used oil significantly affects any used oil recycling program. The generator (TxDOT in the current context) must be able to document the end disposition of used oil that it generates. Responsibility for used oil (and other hazardous materials) does not end when the material is collected by a transporter, processor or re–refiner. Thus, clearly a long term, stable, and mutually beneficial relationship must exist between TxDOT and the party or parties that dispose of TxDOT's used oil.

Section 6002 of the RCRA requires entities that receive federal tax money and spend more than $10,000 per year on an item identified under EPA guidelines to purchase that item with recycled content. Re–refined oil was designated by EPA as a guideline item in 1988 (40 CFR Part 252).

Executive Order 12873, October 20, 1993, addresses the use of re–refined oil by federal agencies. This order requires that agencies establish and maintain an affirmative procurement program to ensure that 100% of agency purchases of designated EPA guideline items meet or exceed EPA Specifications. Re–refined oil, as indicated above, is on the EPA guideline list. In addition, the federal plan must create an awareness and outreach program for the private sector to facilitate markets for environmentally preferable and recycled products and establish incentives, provide guidance, and coordinate appropriate educational programs for agency employees.

Texas Senate Bill SB No. 1340, 72nd Regular Session [45], states that all state agencies should give preference to motor oils and lubricants that contain at least 25% recycled oil as long as the cost and quality are comparable to new oil and lubricants. It is possibly significant that the bill refers to recycled oils rather than re–refined oils. SB 1340 also establishes a Used Oil Recycling Program which involves public education and the provision of used oil collection facilities. A Used Oil Recycling Fund is established by SB 1340. The fund is supported by a fee on the first sale of motor oil (a 2¢ per quart fee on all motor oil sold for use in Texas) and registration fees related to the transportation, marketing, and recycling of used oil. The fund is used to support public education; grants; registration of used oil collection centers, used oil transporters, marketers, and recyclers; administrative costs; and to restore sites identified within the state that have been contaminated by improper oil management.

Thus, both federal and state legislation address the use of re–refined oil and lubricants. The federal rules and legislation are a bit more strict in requiring federal agencies to purchase re–refined oil, whereas, the state legislation only directs state agencies to give preference to the purchase of re–refined oil and lubricants. In addition, there is a significant body of federal law and EPA regulations related to the transportation and storage of used oil.

5 Refinery and Supplier Visits

During the course of this project, several visits were made to oil refineries, used oil re–refineries, and to re–refined oil suppliers. These visits provided significant background information on the re–refining process and problems associated with collecting, re–refining, and distributing re–refined oil and fluids. A description of these visits is provided below.

5.1 Safety–Kleen Corp. Refinery, East Chicago, Indiana

Dr. Raghu Narayan and Mr. Jesse Jones visited the Safety–Kleen refinery in East Chicago on June 5, 1995. The purpose of this visit was to familiarize the study team with the re–refining process used at this plant and to assess the adequacy of process and quality control.

Safety–Kleen is the largest recycler of automotive and industrial hazardous and non–hazardous waste fluids in the world. The East Chicago facility is the ultimate destination for used oil collected from a network of over 100,000 service stations, car dealerships, and industrial oil generators in the US. This facility is currently processing over 80,000,000 gallons of used oil per year. Safety–Kleen collects, processes, and recovers contaminated fluids for reuse through a worldwide network of 262 branches, 13 solvent recycling centers, 3 fuel blending facilities and 2 used oil re–refining plants, located in East Chicago, Indiana, and Breslau, Ontario, Canada. In addition to the fuel and asphalt extender by–products of the re–refining process, Safety–Kleen produces automotive, diesel, and locomotive engine oils; gear lubricants; power transmission fluids; hydraulic oils; and industrial oils.

The study team was favorably impressed with the Safety–Kleen refinery operation and the supporting analytical laboratory facilities. The process and quality control capabilities were considered comparable to that in a modern, well–run oil refinery. Both the API and Lubricants Review Committee have reviewed the operations at this plant and have concluded that the base oils produced meet industry specifications and that the refinery process is properly controlled. When the physical characteristics of viscosity, flash point, sulfur level, viscosity index, specific gravity, boiling range, low temperature viscosity, and additive solubility were considered, no differences existed between Safety–Kleen base oils and base oils made from virgin crude oil. The equivalence of re–refined and virgin oil base stocks is addressed in Chapter 3. Specifically, a study by the Hsu, Ku, and Becker of the National Bureau of Standards [27] describes a long term comparison of re–refined and virgin oil base stocks.

Based on the observations made during this one day review of operations at the Safety–Kleen refinery located in East Chicago, Indiana, the study team found no reason to question the statement that base oils produced at this plant are equivalent to those produced from virgin crude oil. TxDOT should have no concern about the use of base feedstock oils produced at this facility. Operations associated with subsequent blending of the base stock oil and packaging as lubricating fluids under the Safety–Kleen labels *America's Choice, America's Pride and Performance Plus* were not inspected.

5.2 Texas Petroleum Resources and Services Inc., Houston, Texas

At the request of TxDOT personnel, Dr. Timothy Maxwell and Mr. Jesse Jones visited the Texas Petroleum Resources and Services (TPRS) facility in Houston, Texas, on April 3, 1995. The purpose of this visit was to evaluate the capability of this company to supply lubricating products of satisfactory quality to TxDOT. A detailed description of this visit and related comments has been provided to TxDOT in a separate report.

5.3 Lyondell Petrochemical Company, Houston, Texas

On April 3, 1995, Drs. Raghu Nayaran and Timothy Maxwell, and Mr. Jesse Jones visited the Lyondell refinery in Houston, Texas. The purpose of the visit was to assess Lyondell's interest in producing re–refined lubricating oil products and to evaluate the facilities and personnel.

Lyondell Petrochemical Company was formed out of Atlantic Refining Company (ARCO) in 1985. Lyondell basically consists of the ARCO refinery and petrochemical assets that were located in Houston, Texas. Lyondell presently operates from 15 terminals serving the US domestic market. The Houston refinery, the nation's 9th largest, is a full–conversion facility that has the capability to refine a wide range of crude oil feedstocks into high–value fuel products without producing lower–value residual oil. Lyondell has joined with the national oil company of Venezuela in a joint venture to make the refinery a world–class heavy crude oil processing facility. Lyondell produces automotive fuel and lubricating products, industrial lubricants, heating oil, jet fuel, white mineral oils and metalworking products. Lyondell uses some used oil in its refining process. It feeds the used oil to a coker that separates the inorganic species from the hydrocarbons which are then used to make gasoline, heating oil, and jet fuel. They also blend lubricants from re–refined base feedstock which is purchased from Safety–Kleen. Lyondell's re–refined products are sold under the *Enviroil* label.

The study team was favorably impressed with the facilities and personnel at Lyondell. Discussions with Lyondell personnel provided considerable insight into the re–refining industry and the particular point–of–view of the major refiners. Lyondell certainly has the capability to deliver a quality re–refined product and use of Safety–Kleen re–refined base oil feedstock should ensure that products supplied by Lyondell continue to meet TxDOT requirements for lubricating products.

6 Literature Related to Re–Refined Oil and Fluids

A vast amount of literature was accumulated during the course of this study. The more significant publications are summarized below in order as listed in the reference section.

The Texas Natural Resources Conservation Commission (TNRCC) provides a brochure entitled *A Practical Guide to Establishing A Community Used Oil Collection Program* [1]. This brochure explains in nontechnical language the importance of collecting and recycling used oil and it provides potential collectors (cities, communities, etc.) valuable information on organizing a collection program, registering the collection center, purchasing required equipment, disposing of the collected oil, and publicizing the program.

TNRCC prepared *A Report to the 74th Legislature: Pollution Prevention and Waste Reduction in Texas* [2]. This document provides an overview of all recycling and waste reduction programs within the state; in particular, the Texas Used Oil Recycling Program summarized. The number of registered public or private used oil collection centers in Texas has grown form 589 in 1992 to 1,348 in 1995. Over 1.3 million gallons of used oil were collected in 1994 (about twice the amount collected in 1993). It is interesting to compare this 1.3 million gallons of used oil per year to the approximate 100,000 gallons of used oil generated by TxDOT each year.

M. Alves dos Reis [3] developed a solution of potassium hydroxide in 2–propanol and a hydrocarbon, which segregates organic sludge from waste oils. The operation of re–refining waste lubricating oils by treatment with an organic solvent which dissolves base oil and flocculates the major part of additives and particulate matter is intended to substitute the classical reaction with sulfuric acid, which generates an acid sludge and creates difficult disposal problems. Upon separation with this technique, the sludge may be used as a component of asphalts, or better, as a component of offset inks, consequently increasing the value of waste oils. A description of the fundamental extraction–flocculation operation and integration in a re–refining plant is presented. Pilot plant results show that the proposed technology produces a re–refined oil with properties quite similar to virgin oils.

Armstrong and Strigner [4] conducted a field test and laboratory analysis program to evaluate the comparative performance characteristics of a virgin and an acid/clay re–

refined API–SE/SAE 20W–40 automotive engine lubricating oil. Eight new police patrol cars (four on virgin and 4 on re–refined oil) were run in normal operation for 100,000 km (about 62,500 miles) with an oil change interval of 5,000 km (3,125 miles). Inspection of the engine components showed that there were no oil related problems with any of the vehicles. In general, both oils operated satisfactorily and were considered substantially equivalent.

Brinkman and Dickson [5] suggested that used oils are an excellent example of a high–volume recyclable commodity that can be turned from waste into valuable products. The degree of hazard posed by improper management of used oils as related to the contaminants typically found in waste oil is debated. Samples for this study were taken at every step in a used oil management system, including the re–refining process. Concentrations of chlorinated solvents, metals (Cd, Cr, and Pb), and polynuclear aromatics were compared for each step in the used oil management program and with past studies.

Brinkman, Dickson, and Wilkinson [6] processed approximately 225,000 gallons of used oil contaminated with polychlorinated biphenyls (PCB's) through a full–scale re–refinery using vacuum distillation/hydrotreatment technology. The catalytic reaction with hydrogen not only destroyed the PCB's but also generated useful petroleum products, including lubricating oil. Testing of the used oil feed as well as all intermediates, by-products, and products allowed for the monitoring of the fate of the PCB's and demonstrated their destruction. The important advantage of the hydrogenation reaction chemistry is pointed out and the fact that the chemistry involved in the catalytic destruction of PCB's is well documented.

Brinkman and San Julian [7] site several options for the recycling of wastes from off–highway operations. Parts can be cleaned with solvents that are recycled over and over, on a regular schedule and possibly not be considered as hazardous waste. Recycling used oil might involve ensuring that the waste oil goes to a re–refiner and using re–refined lubricants. Reclamation and reuse are good options for antifreeze and segregated industrial solvents. Brinkman and San Julian suggest that even for more complex wastes, including oil filters and mixed liquid wastes, there are opportunities to reclaim the recyclable solvent and metallic portions of the waste, while blending the remainder for cement kiln fuel. Thus, in the end, almost nothing is left for land disposal. This technique not only satisfies waste minimization requirements, but also eliminates long–term liability for future environmental releases from the disposal site.

Brinkman [8] indicates that recent technology enhancements and Safety–Kleen's marketing decisions to significantly increase volume throughput have combined to produce the next generation of used oil refineries. With a feedstock capacity of 75 million gallons per year, the first of these units, which is in full production in East Chicago, Ind., is believed to be the largest used oil refinery in the world. The primary factor which allowed Safety–Kleen to construct this large facility is the potential use of an existing collection system within its industrial solvent servicing business. Brinkman emphasizes the importance of properly handling the used oil resource.

Brinkman [9] reviews several re–refining process configuration options and notes the recent resurgence of used lubricating oil re–refining due largely to the availability and active promotion of the many new and varied technologies. Even though a recent annotated bibliography provides abstracts for 266 publications on new processes and over 1,200 abstracts on used oil recycling in general that were released since 1970, Brinkman reviews a selected few process schemes that have advanced to commercialization. Several of these schemes have been implemented and the selection process to determine which general approaches seem most commercially viable has begun to converge. Brinkman indicates that due to the maturing of the technology, only a few variations of one generic process, thin film evaporators, have accounted for most plants built in the late 1970's and early 1980's.

The recycling of the two largest categories of waste hydrocarbons, used lubricating oil and contaminated fuels, is discussed by Brinkman [10]. The reasons for a decline in recycling, what would seem to be a natural business, are as diverse as the participants in the industry and include undercapitalized small businesses, an increasing complexity of products/additives, specifications forbidding the use of recycled materials, and the high cost of environmental compliance. Many other reasons for the decline in recycling apply to individual facilities, but it is apparent that not all forces are favorable to the expansion of the waste hydrocarbons industry.

In 1985, Brinkman [11] noted that more than 1 billion gallons of used lubricants are generated in the United States annually. Of that 1 billion gallons, only about 100 million gallons reached recyclers to be re–refined into lubricants. The balance of the used oil is burned as a fuel or disposed of as a waste, more importantly, too often waste oil is disposed of improperly. The used lubricants could be recovered for reuse at a relatively low additional investment in time, money, and energy.

The Fourth International Symposium on the Performance Evaluation of Automobile Fuels and Lubricants, sponsored by the Co–ordinating European Council for the Development of Performance Tests for Transportation Fuels, Lubricants and Other Fluids, was held in Birmingham, United Kingdom from May 5 to May 7, 1993. There are many papers in the proceedings of this symposium that are relevant to the testing, licensing, certification, and performance of motor oils [12, 14, 15, 25, 30, 35, and 63].

The ***SAE Fuel and Lubricants Primer for Automotive Engineers***, Second Edition, published in 1986, includes several papers related to lubricating oils, oil additives, oil properties. Schmidt and Foster [44] present an overview of the operations and processes used in modern refineries and discuss product blending. Clark, et.al.

[13] describe engine oil classification systems, API service classification, the API service classification symbol, engine testing, and fuel economy testing. Watson and McDonnell [62] review the technology of oil additives.

Engine Oils and Automotive Lubrication, edited by Bartz and distributed by SAE contains several articles on lubricating oils [16, 29, 42, and 54]. The articles in this book cover, base oils for automotive lubricants, engine oils and their evaluation, oil additives, and several specific topics related to lubrication problems.

An integrated systematic approach to link the needs of an organization to its suppliers is presented by Fernandez [21]. Basically, the overall quality objectives of an organization must be understood and linked to the objectives of the purchasing department and to the suppliers. The approach to Total Quality Management emphasizes the concepts of policy deployment as applied to strategic planning and integration of the purchasing and supplier management functions. Supplier process improvement is identified as an integral part of supplier management.

A report prepared for the State of Florida [22] presents information on the current status of used oil recycling, the generation and recovery of used oil in Florida, conclusions regarding the need for minimum content standards, and price preferences and purchasing goals for lubricating oil made from used oil.

The Department of Defense's Joint Oil Analysis Program – Technical Support Center in Pensacola, Florida is evaluating Fourier transform infrared spectroscopy (FT–IR), which can determine oil condition and contamination. FT–IR spectroscopy can, in reduced time, determine synthetic oil condition and contamination. The FT–IR spectroscopy can quantitatively measure water, fuel, and glycol and can qualitatively measure soot and by–products formed by reaction with nitrogen, oxygen, and sulfur [23].

Graziano and Daniels [24] identify research needs and approaches to increase recovery and recycling of used oils. This research should address three waste oil challenges: 1) recover and recycle waste oil that is currently disposed of or misused; 2) identify and implement lubricating oil source and loss reduction opportunities; and 3) develop and foster an effective waste oil recycling infrastructure based on energy savings, reduced environmental impacts, and competitive economics. The potential for a significant energy savings related to re–refining waste oil into lubricating products is shown.

A comparison of re–refined and virgin base oils is presented by Hsu, Ku, and Becker [27]. Ten re–refined and seven virgin base oils that represented a cross–section of the processing technologies in use in 1982 were compared. Detail differences between the base oils included higher contents of chlorine, polars, oxyacids, and trace additives; however, the authors concluded that the differences were insignificant or could be compensated for with proper additive packages. It should be noted that the re–refining processes and technologies have improved significantly during the past ten years.

This reference also provides a good resource of both virgin and re–refined base oil properties.

McKeagan [32] offers an in–depth look at the market and operating factors which affect the profitability of re–refining used oil. He presents results on comparative analysis of three technologies currently used in North America. These technologies avoid the environmental problems created by disposal of acid/clay residues produced in older, less sophisticated re–refining processes. McKeagan predicts that re–refined lubricants can be produced for about $0.54 per gallon and virgin lubricants for about $0.85 per gallon when accounting for feed stock costs, processing and by–product credits.

The SAE Labeling Assessment Program is described by McMillian and Stewart [33]. The history and scope of the program are described and the results of analyses of 1,813 engine oil samples purchased from the retail market during a six year period are presented. A total of 81 oil samples were found to be questionably labeled.

Lubricants and Their Applications by Miller [34] is an excellent basic reference for anyone responsible for maintaining vehicles or machines. Miller discusses the various types of oils and lubricants available and describes methods for selecting the proper lubricants for each application and the best suppliers.

Waste Oil: Reclaiming Technology, Utilization and Disposal from Mueller Associates, Inc. [37] describes and assesses the current, as of 1989, status of the waste oil industry including the generation, collection, disposal, reclaiming and utilization of waste oil.

Neale's ***Lubrication: A Tribology Handbook*** [38] provides a discussion of selecting lubricants, lubrication components, lubrication systems, the operation of lubricating systems and machines, and environmental concerns related to lubricants.

Pyziak and Brinkman [40] point out the advantages and disadvantages of current oil and oily water disposal techniques. They discuss each disposal technique, from improper disposal to the highest forms of recycling, emphasizing the environmental (long– and short–term) ramifications. Techniques covered include indiscriminate dumping, landfilling, road oiling and foliage control, burning for energy recovery, reclaiming, re–refining.

Stitzel [48] designed and implemented the Washington Citizens for Recycling (WCFR) program. In this article he discusses the efforts initiated by WCFR to increase the use of re–refined motor oil by public and private sector vehicle fleets. In order for WCFR to get started, they had to estimate the volumes of new, used, processed and re–refined oil and the potential economic advantage of re–refineries over virgin lubricating oil plants. Funding for WCFR comes from the *Clean Washington Center*, the state's market development agency, which is organizationally under the wing of the state Department of Trade and Economic Development. This funding has allowed WCFR to establish a great deal of information that addresses such topics as: What fleets are currently using re–refined oil? What quality standards does re–refined oil meet? What are the potential environmental, economic and public image implications of switching to re–refined oil?

Texas Recycles: Marketing Our Neglected Resources [52] published by the Texas General Land Office provides recommendations for developing a recycling infrastructure for Texas. One section of the report addresses recycling used oil specifically.

Used Oil to Diesel [53] summarizes a program in Washington state based on the Shurtleff technology which offers the possibility to process used oil into #2 diesel and a non–leachable ash cake.

Villena–Denton [54, 55, 56, 57, 58, 59, and 60] reports on the *evolution* of the oil recycling industry. Key events that brought about the recycling industries emergence includes the oil crisis precipitated by the Israeli–Arab war which caused world crude oil prices to quadruple, and two Congressional mandates that included requests "to develop test procedures for the determination of substantial equivalency of re–refined or otherwise processed used oil with new oil for a particular end use" and "to revise specifications to allow the use of recycled materials to the maximum extent possible with jeopardizing the intended use of the item". The re–refining industry needs *standard* tests to evaluate used oil feedstocks, base stocks and finished re–refined lubricants. The public perception that finished lubricants made from re–refined basestocks can not be of the same quality as those made from virgin oils is not consistent with reality. Villena–Denton discusses citations by Ted Selby, president of Savant, Inc., an independent testing laboratory in Midland, Mich., in which comparative data showed that in several tests engine oils from re–refined basestocks were at least on par with those from virgin basestocks. It was also noted that in a number of areas the re–refined oils tested were better than most oils of the same SAE grade on the market.

A summary of oil properties obtained from the internet is included in Appendix II.

7 Results of Oil and Fluids Sampling and Testing

7.1 Oil Sampling Procedure

A simple oil collection procedure was developed for obtaining used oil samples. New 100 ml size polyethylene containers were used to collect used and virgin oil samples. Used oil was collected directly from the crankcase of various TxDOT vehicles as the oil was being drained. This prevented any contact of the oil with any other surface other than the polyethylene sample container.

Each TxDOT sampling location, as shown in Table 4, was shipped an appropriate number of sample bottles along with sampling and labeling instructions as shown in Figures 3 and 4. Each TxDOT location returned the sample bottles to the Chemical Engineering Department at Texas Tech University for comparative qualitative analysis. The samples received from the districts are listed in Table 5. New oil was used as the bench–mark for comparison.

Table 4 TxDOT Districts Selected to Provide Oil Samples

District #	District Location	Type of Vehicle Used for Samples
5	Lubbock	Light trucks Heavy duty truck (diesel powered DPS pursuit vehicles
15	San Antonio	Courtesy vehicles Heavy duty truck (diesel powered)
16	Corpus Christi	Light trucks or sedans Heavy duty truck (diesel powered)
20	Beaumont	Courtesy vehicles Light trucks or sedans Heavy duty truck (diesel powered)
24	El Paso	Courtesy vehicles Heavy duty truck (diesel powered
	DPS Austin	Pursuit vehicles

Gas chromatography/mass spectrophotometry (GC/MS) was used as the primary screening technique for this project. While other techniques such as Fourier Transform Infra–red spectroscopy (FT–IR) are much more effective for quantitative analysis, screening runs using GC/MS technique gave sufficient confidence of the sensitivity of the technique to detect differences in the chemical composition of the oil samples.

TxDOT Used Oil Sample Data Sheet

Please send oil sample with this data sheet attached to

Dr. Raghu S. Narayan
Department of Chemical Engineering
Texas Tech University
Lubbock, Texas 79423

(806) 742–3553

INSTRUCTIONS: Assign a number to each oil sample taken. (Use your District #, a vehicle ID #, and a sequence number separated by hyphens.) Be sure that this number is clearly indicated on both the sample bottle and this form. The sample bottles provided will hold 250 mL; at least 200 mL of sample is required. Part of the sample will be processed by a standard oil sample analysis procedure. Additional gas chromatograph and mass spectrometer tests will be carried out with the remaining sample. These tests are extremely sensitive and can detect organic compounds to the parts per billion level. Thus, it is important that the samples not be contaminated and that they truly represent the oil drained from the vehicle. Please follow the steps listed below when collecting samples.

1. Be sure that engine is warm (not hot) before draining oil.
2. After removing the oil plug allow oil to drain for a few seconds to avoid collecting sediment in the pan.
3. Fill the sample bottle directly from the oil stream draining from the engine oil pan.
4. Close the bottle securely and clean any excess oil from the bottle
5. Clearly label the bottle with the assigned sample number.

Used Oil Sample No.______________________________
District Office # ________ District Office location ______________________
Date sample taken ______________ Vehicle VIN number ______________
Type of vehicle ______________________________
Engine type ____________________ Fuel type ____________________
Vehicle mileage (or hours of use) since last oil change ______________
Type and brand of oil used in vehicle (if known) (e.g. America's Choice 10W30) ________
____
Brief history of vehicle ______________________________
____
____
____

Figure 3 Used Oil Sample Data Sheet

MEMORANDUM

Mechanical Engineering Department
Phone (806) 742-3563 Texas Tech University FAX (806) 742-3540

Date: December 29, 1995

To: TxDOT Re-Refined Oil Sample Collection Locations

From: Timothy T. Maxwell
Associate Professor
Mechanical Engineering Department

Subject: Collection of used oil samples

Texas Tech is conducting a program for TxDOT to study the effect of using re–refined lubricating oils on vehicle and equipment performance. A part of this program involves collecting samples of lubricating oil when scheduled vehicle oil changes are performed. Oil samples will be collected at six locations as indicated below. Ideally, samples should be collected from pairs of similar vehicles where one vehicle is using re–refined oil and the other vehicle is using virgin oil; however, this arrangement may not be possible in all cases. When not possible, please collect samples from two similar vehicles using re–refined oil.

The table below indicates sample collection locations and the vehicle types at each location. If the vehicle types identified are not available please make a reasonable substitution and note the substitution on the oil sample data sheets.

1. Buddy Ussery Lubbock District Office PO Box 771 Lubbock , TX (806) 748–4456	Light trucks Heavy duty trucks (diesel powered) DPS pursuit vehicles
2. John Martinez Corpus Christi District Office 1701 South Padre Island Rd Corpus Christi, TX 78416 (512) 808-2323	Light trucks or sedans Heavy duty trucks (diesel powered)
3. Larry Strey San Antonio District Office 4615 NW Loop 410 San Antonio, TX 78284 (210) 615–5976	Courtesy patrol vehicles Heavy duty truck s(diesel powered)
4. Marvin Littlepage Beaumont District Office 8350 US 69 North Beaumont, TX 77708 (409) 898–5738	Courtesy patrol vehicles, light trucks, or sedans Heavy duty trucks (diesel powered)
5. Joe Rivera El Paso District Office 212 North Clark Dr. El Paso, TX 79905–3106 (915) 774–4293	Courtesy patrol vehicles Heavy duty trucks (diesel powered)
6. DPS Austin	DPS Pursuit vehicles

Sample bottles are being shipped to you on Thursday, April 20, 1995. Please let me know if you do not receive them in a few days. A copy of the sample data sheet is attached. Please make as many copies of this sheet as you need.

If you have any questions please call me or Jesse Jones at the number above.

Figure 4 Memo sent to Districts with Oil Sample Data Sheets

7.2 GC/MS Analysis

The as–received oil samples were checked for integrity (no leaks or broken seals) and logged in the master sample analysis log book. In order to ensure that a complete and thorough analysis of the hydrocarbon content of the oil sample be obtained, standard EPA approved methods were adopted to prepare the oil samples for analysis. A brief description of the methodology follows.

Exactly 10 ml of the oil sample received from the various TxDOT locations was placed in a separatory funnel with 50 ml of solvent. The funnel was capped and shaken vigorously to thoroughly mix the oil sample and solvent. The mixture was allowed to settle into two layers; a lighter solvent layer on top and a higher oily–sludge layer on the bottom. The stop–cock at the bottom of the separatory funnel was opened to completely drain the oily sludge. The remaining solution in the separatory funnel was again shaken vigorously and the liquid allowed to settle again. If no further separation was observed, the liquid mixture was transferred to a 100 ml flask. Exactly 100 microliters of the extract was transferred to a 5 ml vial. Exactly 1 ml of the solvent was added to this extract to obtain a 10/1 dilution of the original extract. Two other similar vials were prepared in exactly the same manner. Each oil sample run was thus prepared in triplicate for GC/MS analysis. The vials were sealed and stored in a refrigerator for analysis later. Initially methylene chloride and hexane were evaluated as the solvent candidates using virgin unused lube–oil to assure that the above procedure resulted in a reproducible technique. Hexane was used as the solvent for all samples. The extracted samples were then analyzed using a state–of–the–art Hewlett–Packard Model 5980 GC/MS system.

Table 5 Oil Samples Received

District #	District Location	Number of Samples	Vehicle Type	Fuel Type
5	Lubbock	11	Pickup truck DPS pursuit vehicle	Gasoline/LPG Gasoline
15	San Antonio	11	Pickup trucks	Gasoline/LPG
16	Corpus Christi			
20	Beaumont	1	Aerial truck	Diesel
24	El Paso			
	DPS Austin	3	DPS pursuit vehicles	Gasoline

The GC/MS analysis basically consists of two steps. A known volume (typically 10 microliters) of the sample is automatically drawn from the vials (which are placed on a tray) and injected into a carefully controlled flowing stream of pure helium. The injected sample vaporizes in the flowing helium and enters a long thin capillary tubing which is commonly termed as the chromatographic column. The capillary tubing is filled with an adsorbent. As the mixture of helium containing the extracted oil sample contacts the adsorbent in the column, the chemical compounds contained in the extracted oil sample adsorb on the surface of the adsorbent. As the helium continues to flow over the adsorbent, some of the lighter and less polar compounds, desorb from the adsorbent and begin to flow with the helium and exit the column. The rate at which the compounds are eluted from the column is a function of helium flow rate as well as the operating temperature of the column. Careful adjustment of both the variables is necessary to provide reproducible and meaningful results. The capillary column, therefore, performs the function of a molecular filter, and essentially separates the various chemical species present in the oil samples commonly by its volatility (boiling point) and polarity. For complex mixtures such as those represented by these oil samples carefully, programming the temperature of the column is very crucial; unfortunately there is no a priori way to determine this except by trial and error.

The helium mixture upon exiting the column enters the mass spectrometer where the flowing sample is subjected to high–energy electron bombardment. This bombardment results in the fragmentation of the chemical species that has been eluted from the capillary column. Each chemical species fragments into a standard set of radicals of a particular molecular weight. A thermal conductivity detector detects these fragments and produces an electric fingerprint with the molecular weight of each fragment clearly identified. By identifying the fragments, a precise determination of the identity of the original chemical species can be made.

Each Hewlett–Packard GC/MS system is supplied with a sophisticated software package called Chemstation®. Using the thermal conductivity detectors electric finger print, using the principles of artificial intelligence, the software ranks the probable identity of the chemical species present in decreasing order of probability. Each sample run took approximately 40 minutes. From the above descriptions, it can be seen, that a considerable amount of time was invested in preparing and analyzing the oil samples.

Figures 5 and 6 illustrate the chromatograms obtained from the GC/MS runs for a pair of unused virgin and re–refined oil samples as well as a pair of used virgin and re-refined oil samples. The x–axis indicates the time of each GC/MS run and the y–axis indicates the relative abundance of the chemical species present in the extracted oil sample. The sharp spikes on the chromatogram are individual chemical species eluted from the capillary column. As can be seen from Figures 5 and 6, lube oil is a blend of a considerable number of compounds; some of these compounds are listed in Tables 6, 7 and 8. Examination of the chromatograms of the virgin and unused re–refined oil

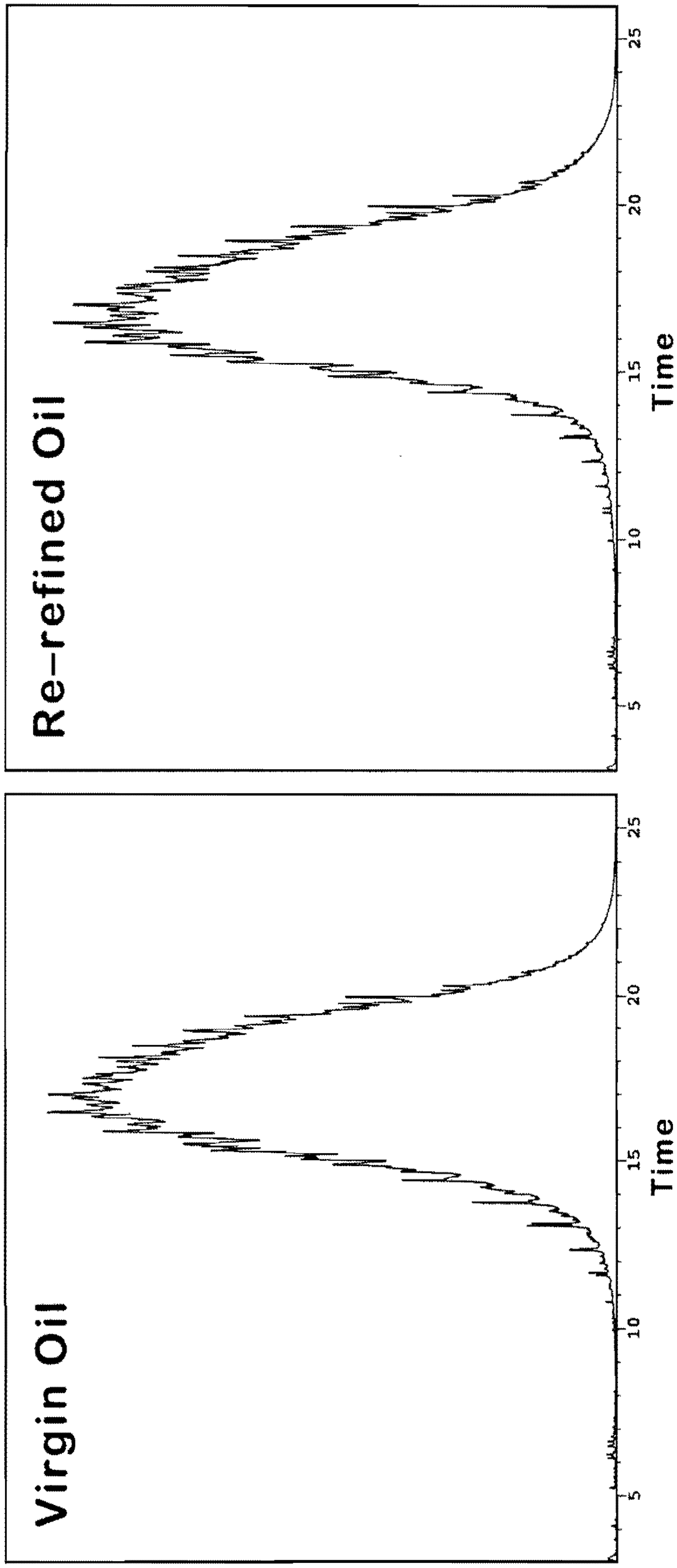


Figure 5 Comparison of Virgin and Re–Refined Oil Sample Test Results for Unused Oils

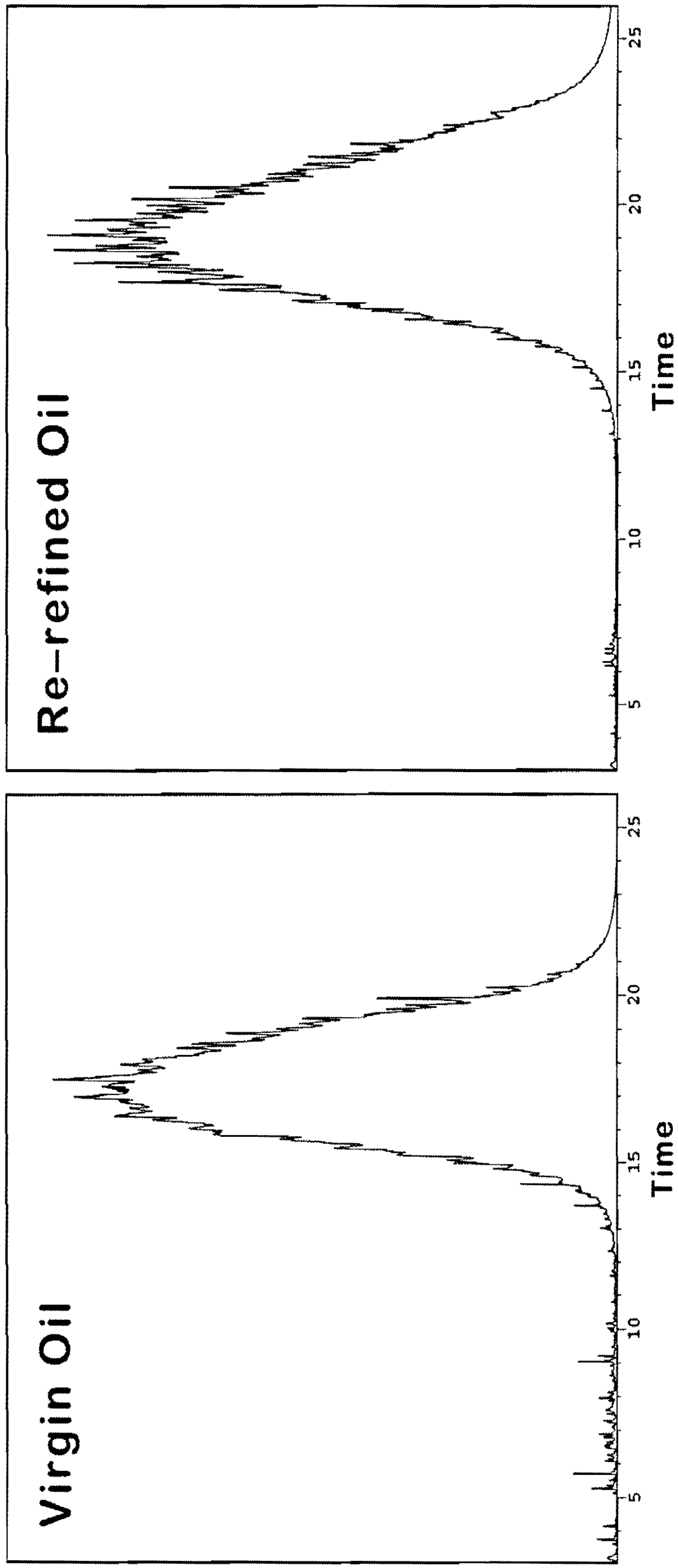


Figure 6 Comparison of Virgin and Re–Refined Oil Sample Test Results for Used Oils

indicates that there is essentially no difference between the two. This is an extremely important outcome of the analytical effort undertaken for this investigation in that it unequivocally demonstrates almost a one–for–one equivalence between the two oil samples.

Examination of the chromatograms of the used virgin and re–refined oils indicate differences towards the end of the analytical run (between 20–25 minutes). This difference indicates the presence of heavy hydrocarbon species that are formed in minor quantities during normal use. These chemical species are formed by molecular rearrangement of some of branched paraffinic and naphthenic species that are typically present in the base oil from which lubricating oils are formulated.

7.3 Conclusions and Recommendations

The comparative used oil analysis indicated that the relative differences in the chemical composition between the references (new virgin oil/new re–refined oil) was only in the level of poly–nuclear aromatics (PNA). A list of the observed PNA's is shown below:

- ❑ naphthalene
- ❑ acenaphthene
- ❑ acenaphthalene
- ❑ chrysene
- ❑ pyrene
- ❑ fluorene
- ❑ phenanthrene
- ❑ benzofluoranthene
- ❑ benzopyrene
- ❑ anthracene
- ❑ fluoranthene

PNA's were observed to the same extent in the used re–refined oil as in the used virgin oil, thereby indicating the process of compositional changes are similar regardless of the nature of the oil. PNA's are formed due to the extreme conditions of temperature and pressure during the operation of an internal combustion engine.

Tables 6, 7 and 8 and Figures 7 and 8 illustrate the influence of molecular structure on viscosity and pour point, two extremely important properties of lubricating oils. Table 6 shows that straight chain paraffins have the highest viscosity of all hydrocarbon species. For example, $nC_{26}H_{54}$ (normal eicosane) has a viscosity index of 188, whereas a branched form of this compound with the same molecular formula (*n*–butyl 9–docosane) has a viscosity index of 124. An aromatic ring compound, such as *n*–dodecyl 2–phenanthrene ($C_{26}H_{34}$), containing the same number of carbon atoms, 26 in this instance, but with a much lower number of hydrogen atoms has a viscosity index of 61. Figures 7 and 8 illustrate the above clearly. It is quite obvious from the above that as more PNA's are formed, the overall viscosity of the lubricating oil is reduced.

Used oil when decontaminated, distilled, and re–refined by catalytically treating the distilled oil with high pressure hydrogen to convert the poly–nuclear aromatic compounds to either *naphthenic* or *parafinnic* types produces a base oil that is almost indistinguishable from virgin base oil. Thus there is no technical basis to conclude that re–refined oils will perform differently than virgin oils.

Table 6 Monocyclic Hydrocarbons [6]

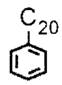
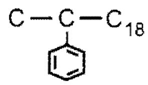
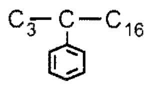
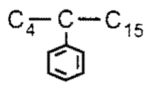
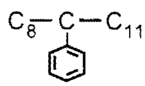
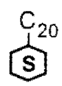
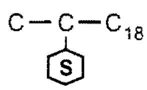
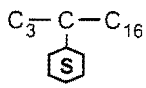
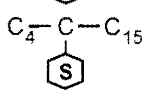
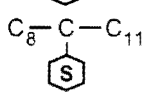
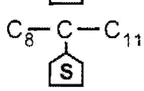
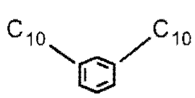
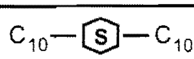
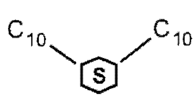
Serial No.	Molecular Formula	Structural Formula	Designation	Viscosity (mm^2/s) 40°C	Viscosity (mm^2/s) 100°C	VI	Pour Point (°C)
4	$C_{26}H_{54}$	nC_{26}	*n*-hexacosane	(10.7)	3.24	188	+56.2
25	$C_{26}H_{46}$		Phenyl 1-eicosane	(12.15)	3.26	143	+42.3
26	$C_{26}H_{46}$		Phenyl 2-eicosane	12.0	3.32	156	+29.0
27	$C_{26}H_{46}$		Phenyl 4-eicosane	13.2	3.30	120	+31.4
28	$C_{26}H_{46}$		Phenyl 5-eicosane	13.7	3.30	109	+30.2
29	$C_{26}H_{46}$		Phenyl 9-eicosane	12.9	3.12	102	+17.9
30	$C_{26}H_{52}$		Cyclohexyl 1-eicosane	(15.15)	4.05	180	+47.9
31	$C_{26}H_{52}$		Cyclohexyl 2-eicosane	16.03	4.07	162	+13.1
32	$C_{26}H_{52}$		Cyclohexyl 4-eicosane	15.7	3.71	126	+16.0
33	$C_{26}H_{52}$		Cyclohexyl 5-eicosane	16.1	3.68	115	−2.2
34	$C_{26}H_{52}$		Cyclohexyl 9-eicosane	14.9	3.44	106	nd
35	$C_{26}H_{52}$		Cyclopentyl 1-eicosane	(13.1)	3.72	187	+45.0
36	$C_{26}H_{52}$		Cyclopentyl 11-eicosane	11.65	3.04	122	−12.7
37	$C_{26}H_{46}$		Di-*n*-decyl 1,4-benzene	11.4	3.28	172	+29.0
38	$C_{26}H_{46}$		Di-*n*-decyl 1,3-benzene	10.7	3.06	152	nd
39	$C_{26}H_{52}$		Di-*n*-decyl 1,4-cyclohexane	15.4	4.00	168	nd
40	$C_{26}H_{52}$		Di-*n*-decyl 1,3-cyclohexane	13.9	3.59	148	nd

Table 7 Hydrocarbons with Two or More Fused Rings [6]

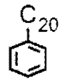
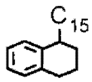
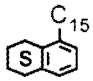
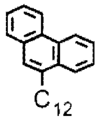
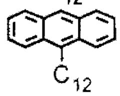
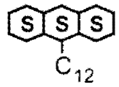
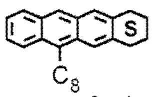
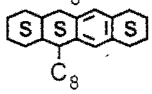
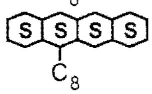
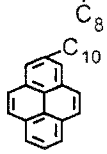
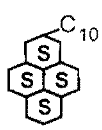
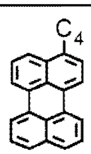
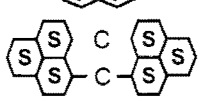
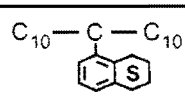
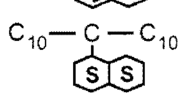
Serial No.	Molecular Formula	Structural Formula	Designation	Viscosity (mm^2/s) 40°C	100°C	VI	Pour Point (°C)
4	$C_{26}H_{54}$	nC_{26}	*n*-hexacosane	(10.7)	3.24	188	+56.2
25	$C_{26}H_{46}$		Phenyl 1-eicosane	(12.15)	3.26	143	+42.3
56	$C_{26}H_{42}$		*n*-dhexadecyl 1-indane	14.1	3.55	138	+33
57	$C_{26}H_{42}$		(ar-1-tetralyl) 1-pentadecane	17.8	4.02	125	+33
58	$C_{26}H_{34}$		*n*-dodeyl 2-phenanthrene	30.9	5.20	97	nd
59	$C_{26}H_{34}$		*n*-dodeyl 9-phenanthrene	(49.1)	6.25	61	+76
60	$C_{26}H_{34}$		*n*-dodeyl 9-anthracene	(82.4)	6.89	–25	+49
61	$C_{26}H_{48}$		*n*-dodeyl 9-perhydroanthracene	41.4	5.87	76	>34
62	$C_{26}H_{32}$		*n*-octyl 9-(tetrahydro 1,2,3,4)-naphthacene	669	18.0	–124	nd
63	$C_{26}H_{40}$		*n*-octyl 9-(dodecahydro 1,2,3,4,5,6,7,8,9,10,17, 18)-naphthacene	298	12.6	–76	nd
64	$C_{26}H_{46}$		*n*-octyl 9-perhydronaphthacene	261	11.87	–70	nd
65	$C_{26}H_{30}$		*n*-decyl 3-pyrene	80.3	7.28	12	nd
66	$C_{26}H_{46}$		*n*-decyl 4-perhydropyrene	41.5	6.10	89	nd
67	$C_{26}H_{24}$		*n*-hexyl 3-perylene	(500)	20.2	1	+141.5
68	$C_{26}H_{42}$		di (perhydroacenaphthyl-5 1,1-ethane		108		nd
69	$C_{31}H_{54}$		ar α-tetralyl 11-heneicosane	40.6	6.07	92	+8
70	$C_{31}H_{60}$		α-decalyl 11-heneicosane	41.1	6.19	95	–40

Table 8 Influence of Side Chains on Hydrocarbons Properties [6]

Serial No.	Molecular Formula	Structural Formula	Designation	Viscosity (mm^2/s)		VI	Pour Point (°C)
				40°C	100°C		
1	$C_{20}H_{42}$	nC_{20}	*n*-eicosane	5.25	1.90	nd	+36.6
10	$C_{20}H_{42}$	$C-C(C)-C_3-C(C)-C_4-C(C)-C_3-C(C)-C$	tetramethyl 2,6,11, 15-hexadecane	5.33	1.77	nd	nd
11	$C_{20}H_{42}$	$C_4-C(C_4)-C_{11}$	*n*-butyl 5-hexadecane	4.86	1.66	nd	−11.6
12	$C_{30}H_{62}$	$C-C(C)-C_3-C(C)-C_3-C(C)-C_4-C(C)-C_3-C(C)-C_3-C(C)-C$	hexamethyl 1,6,10,15,19, 23-tetracosane	19.3	4.14	117	−38
13	$C_{30}H_{62}$	$C_8-C(C_8)-C_{13}$	*n*-octyl 9-docosane	13.4	3.49	144	+8.6
4	$C_{26}H_{54}$	nC_{26}	*n*-hexacosane	(10.7)	3.24	188	+56.2
14	$C_{26}H_{54}$	$C_2-C(C_2)-C_{21}$	ethyl 3-tetracosane	10.8	3.23	182	+30.1
15	$C_{26}H_{54}$	$C_4-C(C_4)-C_{17}$	*n*-butyl 5-docosane	10.6	2.97	141	+20.8
16	$C_{26}H_{54}$	$C_5-C(C_4)-C_{15}$	*n*-butyl 7-docosane	10.4	2.87	128	+3.2
17	$C_{26}H_{54}$	$C_8-C(C_4)-C_{13}$	*n*-butyl 9-docosane	9.92	2.76	124	+1.3
18	$C_{26}H_{54}$	$C_{10}-C(C_8)-C_{13}$	*n*-butyl 11-docosane	9.65	2.73	128	0
19	$C_{26}H_{54}$	$C_4-C(C_4)-C_8-C(C_4)-C_4$	di *n*-butyl 5, 14-octadecane	11.24	2.78	83	+5.7
20	$C_{26}H_{54}$	$C_{10}-C(C_5)-C_{10}$	*n*-amyl 11-heneicosane	9.37	2.68	126	−9.1
21	$C_{26}H_{54}$	$C_5-C(C_5)-C_4-C(C_5)-C_5$	di-*n* amyl 6, 11-hexadecanehexyl	10.9	2.68	70	−16.2
22	$C_{26}H_{54}$	$C_{10}-C(C(C_2)(C_2))-C_{10}$	pentyl 3 11-heneicosane	9.64	2.69	120	−40
23	$C_{26}H_{54}$	$C_{10}-C(C-C(C)(C)-C)-C_{10}$	neoopentyl 11-heneicosane	10.9	2.83	104	−21
24	$C_{26}H_{53}$	$(C_2-C(C_2)-C)_4$ $C-C_{13}$	ethlyl 3 (ethyl 2-butyl) 5-octadecane	10.99	2.83	102	nd

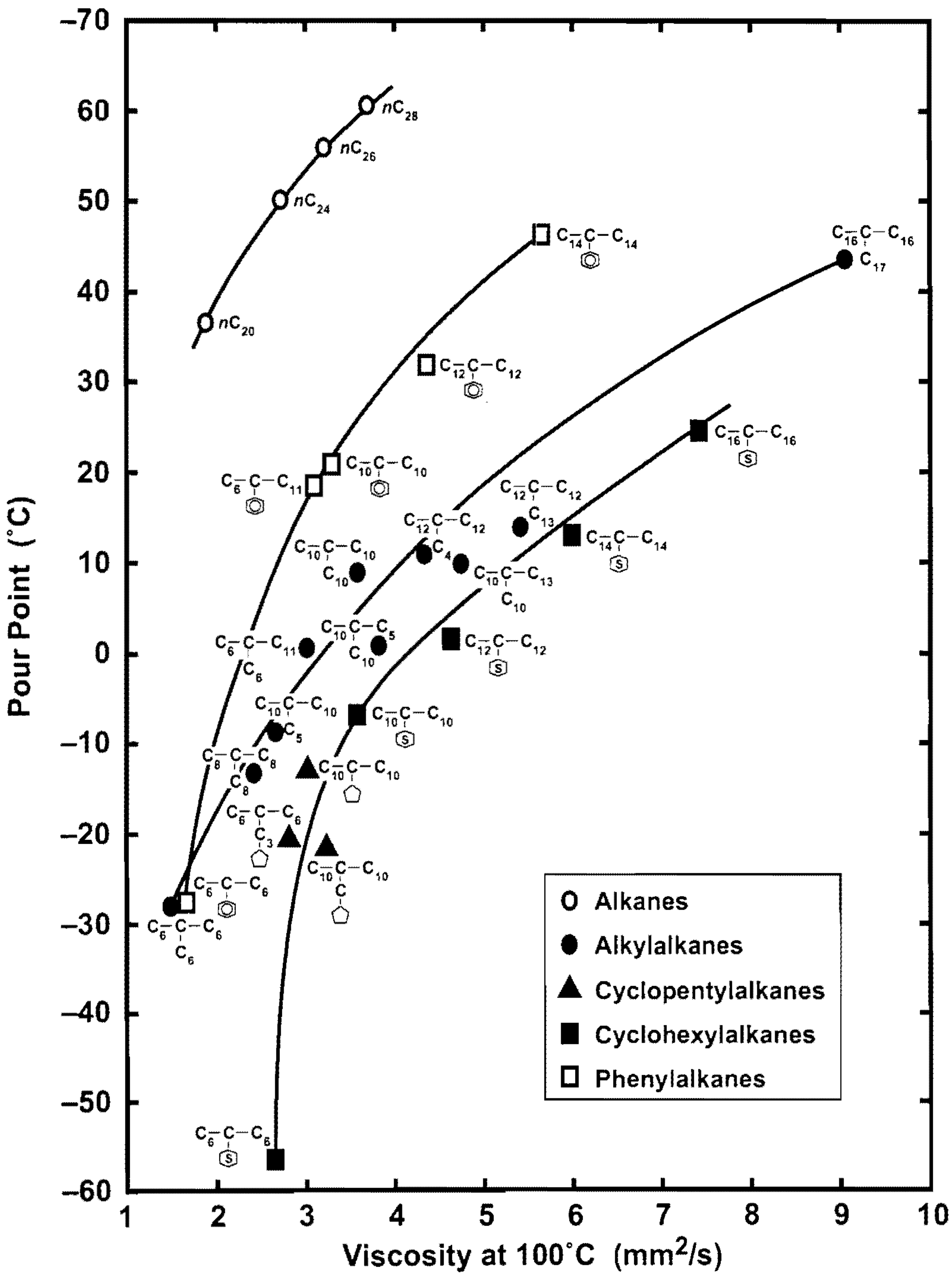


Figure 7 Pour Point of a Number of Hydrocarbons [6]

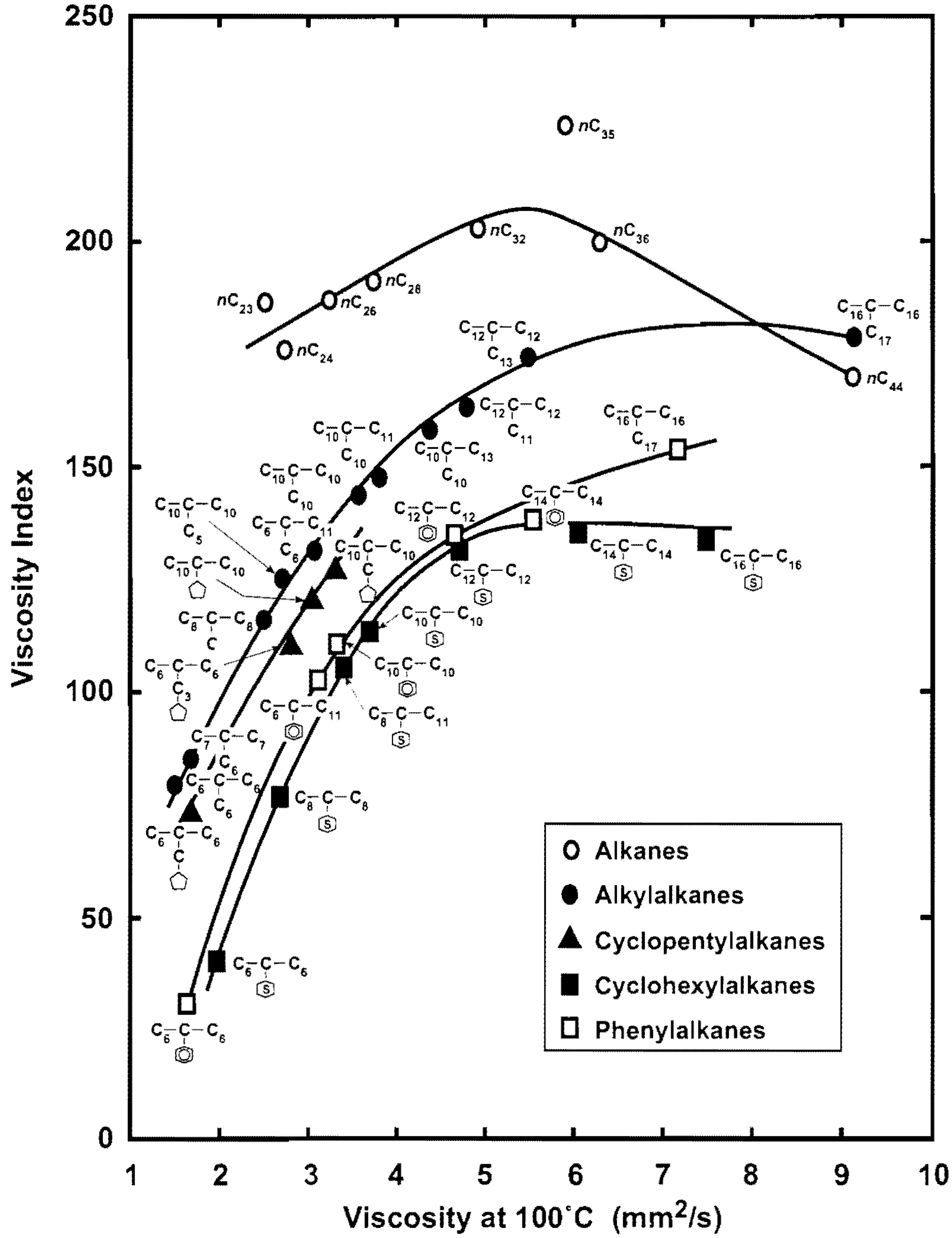


Figure 8 Viscosity Index of a Number of Hydrocarbons branched at Mid-chain [6]

8 Life–Cycle Cost of Using Re–Refined Oil

It has been thoroughly substantiated by many authoritative sources, as well as this study, that there is essentially no difference in virgin base stock oils and re–refined base stock oils. Further, additive packages purchased from reputable refiners are processed to meet API specification requirements. Thus, if the blending process is performed properly and no contamination is introduced in the packaging process, the re–refined lubricant end–product will be equivalent to the virgin lubricant end–product in every way. From a quality and performance standpoint, the substantial equivalence of re–refined oil with virgin oil is undisputed by knowledgeable authorities. Extensive laboratory testing and field studies conducted by the National Bureau of Standards, the US Army, the Department of Energy, the Environmental Protection Agency, and various lubricant suppliers have concluded that re–refined oil is substantially equivalent to virgin oil. API licensed re–refined oils must pass the same cold start and pumpability tests, rust and corrosion tests, engine wear tests, high temperature oil thickening tests, deposit tests, and phosphorous tests that virgin oils are required to pass. Thus, wear experienced by the engine (or vehicle) due to the use of re–refined oil and fluids will be no different than that experienced using virgin lubrication fluids. Maintenance procedure frequencies such as oil and filter changes, etc., are not affected by the use of re–refined lubricating products; therefore, the life cycle cost increase (if any) resulting from the use of re–refined fluids will be that related to the increased cost of the oil, plus any additional logistics costs incurred.

It is somewhat more costly for TxDOT to stock both virgin and re–refined lubricating fluids of the same classification. It is therefore recommended that TxDOT procure these products based on the lowest qualified bid and use them without concern as to whether they are re–refined or virgin in origin. Product specification and supplier quality control requirements established by TxDOT must be structured and enforced to ensure delivery of acceptable product. This approach appears to satisfy the requirements of Senate Bill SB 1340 72^{nd} Legislature, which states “employees that purchase motor oil and other automotive lubricants for state–owned vehicles shall give preference to motor oils and lubricants that contain at least 25% recycled oil, the cost to the state and the quality being comparable to new oil and lubricants.”

Considerable savings can be made in the procurement of lubricating products in bulk (large) quantities. Differences in bulk and drum prices average between $0.14 and $0.36 per gallon, depending on the contractual arrangement with the drum vendor. Reconditioned drums vary in cost between $12.00 to $14.00, and new drums between $22.00 and $28.00, depending on paint decor as well as the location of the drum vendor. The price differential for bulk versus quart container procurement varies from $0.80 to $1.00/gallon and for bulk versus 5–gallon containers is approximately $0.60/gallon. The optimum bulk delivery quantity is 6,000 gallons, thus TxDOT could save $2160.00 on a single delivery, or almost $29,000.00/year, in motor oil procurement cost by purchasing in bulk quantities versus 55–gallon drums. The annual savings from purchasing in bulk quantities versus quart containers could amount to as much as $80,000. If other fluids were purchased in bulk quantities the savings would be even greater. Unfortunately, this is not the total cost to TxDOT since some arrangement would have to be made to package and deliver the product from the bulk storage location to the use point within the district. The cost of establishing these bulk storage facilities and the attendant cost and problems of packaging and delivering the product to the use points would be significant and may make this approach impracticable for TxDOT. However, this approach should be evaluated by TxDOT through an in–house study before abandoning it entirely.

Another possibility would be for TxDOT to contract with a wholesale distributor to provide this service. Typically, wholesale distributors have these bulk storage facilities available for a wide variety of products. They supply the retailer (in this case TxDOT) from these facilities in the container sizes requested. Fortunately, these distributors are located in many cities within the state which should allow the needs of the various TxDOT districts to be met with prompt and efficient service. TxDOT could contract with these distributors for the total fluids supply and distribution effort or could contract for the fluids with the refiners/blenders and with the distributors for the bulk storage and delivery service.

TxDOT can obtain a significant amount of valuable information about lubricating fluids supply by contacting the various suppliers and/or wholesale distributors and requesting proposals as to how they would solve this problem and at what cost. Discussions with Lyondell and Safety–Kleen indicated that both of these potential suppliers would be interested in working with TxDOT in solving this problem.

The cost associated with disposing of used re–refined lubricating fluids is no different than that associated with virgin lubricating fluids. Reprocessors and re–refiners in the used oil collection business are able to reclaim valuable fuel oil, asphalt extender, and base stock oil from used re–refined fluids just as they are from used virgin lubricating fluids. At present 7 districts are receiving a small fee (5.5 cents to 15 cents per gallon) from used oil collection vendors. The remaining 19 districts have their oil collected at no cost. If properly located collection facilities were available adjacent to rail spurs so that used fluids could be transported by rail to centralized collection points, it might be possible to increase the value of the used product. This would require additional handling of the used product by the districts and increase their costs; however, the increased costs might be more than offset by the increased value of the used product and the reduced liability associated with used lubricating fluid collection. The greatest cost associated with used oil collection is in transporting the used oil to the reprocessing or re–refining facility.

If TxDOT should opt to contract for lubricating fluids using a *closed–loop* arrangement (lubricating fluids supply and used fluids collection services provided under one contract), the districts that are receiving payment for used fluids collection will lose this source of income and may incur a cost for the collection service. However, if used oil can be collected in quantities approximating the bulk lubricating fluid delivery volumes, no charge is usually assessed for the collection service. Both Safety–Kleen and Lyondell have indicated an interest in providing *closed–loop* service to TxDOT. As indicated above, increased protection against liability claims resulting from improper handling of used lubricating fluids may more than compensate for any increased collection cost, depending on the state's vulnerability in this regard.

9 Purchasing Specifications for Re–Refined Oil and Fluids

There is no basic difference in the ability of re–refined oils and virgin oils to properly lubricate, cool, and protect engines and machinery. Once the used oil has been properly re–refined it is quite difficult to distinguish it from virgin oil. In fact, retailers are not required to mark oil containers as to the content of re–refined base stock; hence, oil purchased on the spot market could be blended partially from re–refined base stock. However, due to the market price of re–refined oil versus virgin oil and the minimal availability of the re–refined base stock, it is not likely that unmarked re–refined oil is currently on the market.

The technical specifications for re–refined oil should be the same as those for virgin oil. API certification for a given service is based on performance tests and physical properties and not on the original source of the feedstock. Thus, to ensure that TxDOT receives re–refined oil of the same grade and certification as virgin oil, it is only necessary to specify the appropriate API rating. The API Service Symbol (*doughnut*) for labeling engine oils with regard to service and energy serving categories is shown in Figure 9. The symbol consists of upper and lower annular segments, as well as a circular area in the center. The upper segment is used to show the API service category (such as SH/CD). The center area is reserved to show only the appropriate SAE

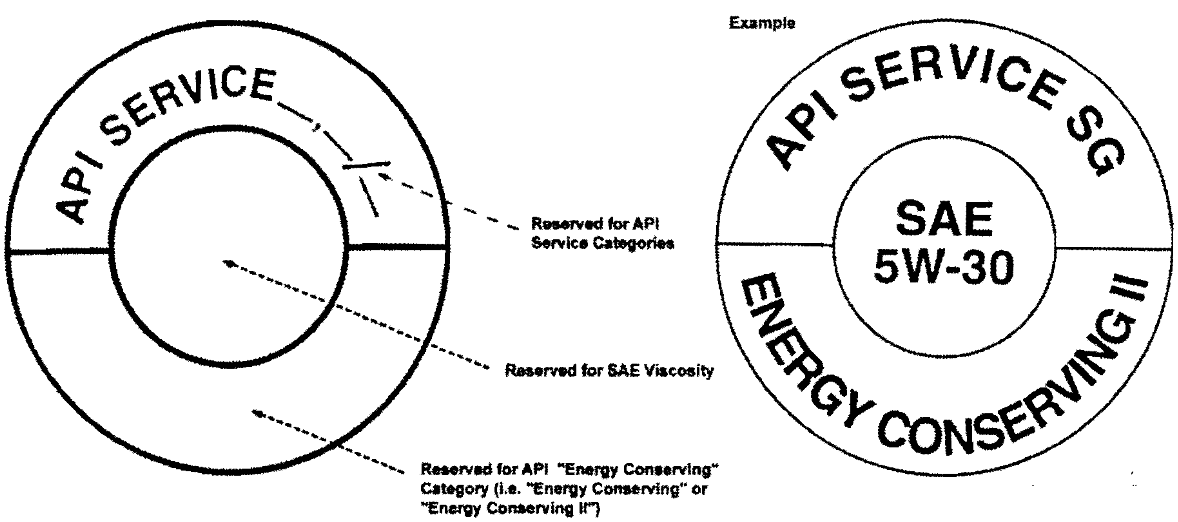


Figure 9 American Petroleum Institute Service Symbol or *Doughnut* [43]

viscosity grade(s) as defined in the latest version of SAE J300. The lower segment is reserved to show the categories *Energy Conserving* or *Energy Conserving II*, provided the oil meets the ASTM requirements of SAE J1423. API will license oil packagers and/or marketers to use the symbol in which *Energy Conserving* or *Energy Conserving II* should be displayed. It is the responsibility of the packager and/or marketer to verify that the oil being labeled meets the requirements for the designations used in the service symbol, including the API service category or categories, the SAE viscosity grade or grades, and *Energy Conserving* or *Energy Conserving II* categories (if included). The test procedure used for evaluating energy–conserving characteristics of oils is intended to measure the effects of engine oils on the fuel consumption of passenger cars, vans, and light–duty trucks. This test procedure is described in ASTM Research Report No. RR:DO2:1204. TxDOT has the right to request documentation from suppliers verifying that motor oil provided meets the requirements of the designations used in the service symbol. This appears to be an excellent way for TxDOT to insure that it deals only with reputable blenders and packagers. A request for this documentation, which requires engine testing to determine the effects of the supplier's motor oil on fuel consumption, should ensure that only qualified blenders and packagers, that have had such testing performed on their motor oil, are qualified to bid.

Motor oil containing re–refined base stock from the Safety–Kleen facility in Chicago is sold with an API Engine Service Designation of SH/CD. Category SH was adopted in 1992 to describe engine oil first mandated in 1993. It is for use in service typical of gasoline engines in present and earlier passenger cars, vans and light trucks operating under vehicle manufacters' recommended maintenence procedures. Engine oils developed for this category provide performance exceeding the minimum requirements of API Service Category SG, which it is intended to replace, in the areas of deposit control, oil oxidation, wear, rust, and corrosion. Oils meeting API SH requirements have been tested according to the Chemical Manufacturers Association (CMA) Product Approval Code of Practice and may utilize the API Base Oil Interchange and Viscosity Grade Engine Testing Guidelines. They may be used where API Service Category SG and earlier categories are recommended. Category CD covers service typical of certain naturally asperated, turbocharged or supercharged diesel engines where highly effective control of wear and deposits is vital, or when using fuels with a wide quality range (including high–sulfur fuels). Oils designed for this service were introduced in 1955 and provide protection from high–temperature deposits and bearing corrosion in these diesel engines. Most major vehicle and engine manufacturers state in writing that equipment operators may use re–refined oil in their vehicles without affecting warranties (see Appendix III). Usually there is also a caution to ensure that the oil is re–refined and not reclaimed or reprocessed.

The Magnusson–Moss Warranty Act stipulates that manufacturers cannot void warranties if the re–refined oil meets the manufacturer's recommendations, as specified in the warranty book. If the re–refined oil meets that standard through testing and licensing, the manufacturer must honor the warranty. This requirement also appears to offer some protection for TxDOT in ensuring that only qualified products are procured. TxDOT should be able to request documentation from packagers and blenders to verify that motor oil supplied has been tested to show that it meets manufacturer's standards through engine testing; otherwise, the engine manufacturer can legally void the warranty.

The quality control exersized during the processing, blending, and packaging of oil is of utmost importance. Dirty or improperly blended oil is not acceptable whether it is made from re–refined or virgin base stock. There is a significant problem related to poor quality control by companies that do not understand the need for quality and do not have the expertise to enforce adequate quality control. This problem is exacerbated by the relatively small volume of re–refined oil produced, the current market where re–refined oil is sold at a premium, and the potential for many companies desiring to *get in on the band wagon*. To alleviate this problem the present TxDOT procurement specification could be strengthened by possibly including a requirement for compliance with ISO 9000 or Total Quality Management (TQM) practices. ISO 9000 is a series of international standards, or modules, relating to quality control in the manufacturing, process and service industries. Most of the 20 ISO 9000 modules are considered to be directly applicable to supplier quality management. In the US the approach that industry has taken to achieve high quality has been to apply quality assurance techniques. During the past ten years this has evolved into TQM approaches, which involve a systematic approach to identifying market needs and honing work practices to meet those needs. Organizations can run their own TQM programs but many prefer to adopt a recognized standard and to seek external approval for their system. In the United Kingdom, BS 5750 is the standard for quality assurance and TQM systems. Internationally, BS 5750 is known as ISO 9000. These two standards are identical. ISO 9000, although developed in Europe for European industry, has been largely accepted by US industry, including many major refiners and re–refiners. Inspection for certification in accordance with ISO 9000 requires payment of a fee which is determined by the size of the supplier's organization and the complexity of its quality control system. The certification body reviews the supplier's quality manual and procedures, visits the premises to interview quality staff and to ensure that the quality system is in place. Finally, a report is generated that confirms that the standard has been met or indicates the changes needed in the system to meet the standard. A list of certification bodies can be obtained from the National Accreditation Council for Certification Bodies (NACCB). In choosing a certification body, it is best to identify one with experience in working with the type of business in which the supplier is involved.

Another possibility for insuring the quality of lubricating fluids purchased by TxDOT would be to require certification of suppliers in accordance with the TQM procedures presently in use by major US industries. These procedures involve visits to the supplier's facilities, assessment of the company's capability for providing a quality product on time and within cost projections, insuring that a statistical quality control program is in place, and evaluating the commitment and dedication of the management and work force. This process is referred to as a supplier audit or verification. Some of the areas of concentration for supplier audit teams are listed below:

Management: Commitment to quality, style, empowerment, educational background, previous experience, etc.

Process: What is the process? Is it systematic? Does it involve appropriate affected areas?

Procurement: Is the procurement process fast? Are levels of authority clearly defined? Are customer requirements considered in the bidding process? Is price considered before quality? Does the supplier have up–to–date procurement systems? Does the supplier use electronic data interchange?

Quality Assurance: How does the supplier assure the quality of the process output? Is it inspection driven or does the supplier methodology include prevention–based methods?

Receipt Inspection: Does the organization simply accept all products as supplied? Does it have different policies for different levels of supplier certification? Is the supplier's goal to reduce the amount of incoming inspection by certifying its own suppliers? Are there clearly documented specifications that can be used to inspect at receipt? Is there a clear way of separating rejected materials from acceptable materials? What are the return policies?

Materials management: Does the supplier have up–to–date material management systems? Are there policies for the optimization of stocking levels? Are just–in–time practices followed?

Materials storage, handling, and shipping: Are there controls for shelf life of time–dependent raw materials? Are volatile or toxic materials properly secured, labeled, handled, and protected to safe–guard against environmental accidents? Are modern, up–to–date material handling equipment used and proper maintenence procedures followed? Are products properly protected during shipping through adequate packaging?

Process management: Are process controls in place? Are employees trained to recognize out of control conditions and know what actions to follow to bring the process back into control? Are analysis techniques used to prevent special causes and to manage or reduce common causes and the variability of the processes? Is there a good tie from the process management area to improvement processes?

Inspection, testing, and examination: Are first item samples sent for testing and inspection before approval of initial shipments from a new supplier? Are follow–up inspections made until the supplier attains the appropriate certification level according to the acceptable risk of a defect?

Specification and change control: Is there a set methodology to keep track of and assure that specification and process changes are recorded and approved by all involved before implementation of the change, that all employees affected are properly trained in the new procedures, and that lots are properly tracked to reflect the process in effect when the lot was manufactured?

Calibration and lab controls: Does the supplier have a periodic maintenence and testing schedule to calibrate all measurement devices? Is the schedule in place in the lab area as well as on the operations floor or anywhere else that measurements are made?

Quality information: Has a quality information system been put in place, whereby information can be tracked by lot, suppler, timing, process status, customer, rejects, costs, or any other data field that the supplier or the buying organization may feel is an important quality characteristic?

Nonconforming material control: Is there a method in place to identify and tag nonconforming materials, whether incoming or work in process? This material must be excluded from the regular flow of work in order to avoid the possibility of it being combined with acceptable material.

Corrective action process: Does a method exist to follow–up on corrective actions identified by all levels of employees? This could range from a suggestion system to a more sophisticated team improvement project tracking system.

The preceding list of areas of concentration were taken from Total Quality in Purchasing and Supplier Management by R. R. Fernandez, published by St. Lucie Press, Delray Beach, Florida. This list is not meant to be exhaustive and TxDOT should determine the areas that are most important to them for the particular supplier being audited. This reference also includes information on different levels of certification in use by US industry.

Careful attention to quality control by both the supplier and TxDOT can alleviate the problem of out–of–spec conditions and provide TxDOT with quality re–refined lubricating oils and fluids.

Another way to increase the likelihood of maintaining quality control would be to contract with companies to both provide lubricating oils and fluids and collect the used oil and fluid (known as closed–loop). Requiring the supplier to not only provide, but to also collect and process the used oil, would tend to eliminate suppliers that do not have the capability or the desire to provide quality products, protect the environment, and conserve energy.

TxDOT's specification requirement for qualification of the bidder could also be used to ensure that only capable bidders are approved to supply re–refined lubricating products. Under this paragraph the bidder can be required to provide evidence that validates his ability to furnish products in accordance with the terms and conditions of the contract specifications. The state has the right to make the final determination as to the bidder's ability to satisfactorily comply with the purchase order. This may be especially helpful in regard to the API designation *Energy Conserving* or *Energy Conserving II* since the use of these designations must be supported by engine testing, as indicated above. TxDOT's specification also includes a statement that *only refiner's labels will be accepted in this procurement.* The meaning of this statement was not clear to the study team but if the procurement can be limited to *refiners* only, the quality problem discussed above can be essentially eliminated.

Including a requirement for compliance with Green Seal Standard GS–3, which applies primarily to ensuring the integrity of the environment, could also strengthen the quality control aspects of the TxDOT procurement specification. For re–refined oil products Green Seal Standard GS–3 includes requirements for re–refined oil content, toxic constituent limits, and packaging and labeling. Green Seal offers certification for all products covered by its Standards. Organizations authorized to use the Green Seal Certification Mark on their product are subject to an ongoing program of testing, inspection, and enforcement. Underwriters Laboratories Inc. serves as Green Seal's primary testing and factory inspection contractor. For additional information on Green Seal or any of its programs, contact:

Green Seal
Suite 275
1250 23rd Street, NW
Washington, DC 20037–1101
(202) 331–7337

In summary, the study team concluded that TxDOT's specification No. TxDOT–405–39–01 for the purchase of oils and lubricants can be satisfactorally used for the procurement of re–refined lubricating fluids. The problem of insuring that only reputable suppliers are certified to supply these products is addressed above. It is noteworthy that there are several hundred suppliers of these products in the US and that over 98% of the lubricating fluids sold are provided by the top ten or so, most of whom are refiners.

10 Survey of Used Oil and Fluid Collection Procedures

A questionnaire, shown in Appendix IV, was prepared and sent to each of the 26 TxDOT districts to solicit information on 1) the use of re–refined oils and lubricants and 2) the current procedure used by each district to dispose of used oil. The questionnaires as returned are presented in Appendix V. Table 9 presents a summary of the survey results and the compiled responses are provided in Table 10.

The districts reported that TxDOT consumes approximately 113,000 gallons of oil and hydraulic fluid per year of which approximately 33,000 gallons or 29% is re–refined. Approximately 60% of the districts regularly use some re–refined oil in their vehicles; however, in some cases the amount of re–refined oil used is very small. The remaining districts feel that they should not use re–refined oil in their vehicles either because they do not have confidence in re–refined oils or because of the typically higher cost of re–refined oil with respect to virgin oil. Several districts indicate that a stronger endorsement by the vehicle and engine manufacturers would help their confidence in re–refined oil. These districts should be explicitly made aware of the statements available from the manufacturers (see Appendix III).

Only 7 districts (Districts 11, 12, 13, 17, 20, 21, and 29) reported problems related to the use of re–refined oil. Six of the seven reports involved dirt, debris, water, or other contamination found during tests or inspection of new containers of oil. At least one of the districts indicated that they had also seen similar debris or discoloration in virgin oil containers. Only 3 districts reported engine problems related to excessive oil consumption and abrasive wear; both of which could be caused by dirty oil. District 11 described a problem of increased oil consumption in 6 Ford Tauruses; however, they could not be certain that the re–refined oil caused the problem. They were not sure which brand of re–refined oil was involved but they are no longer using re–refined oil. District 13 reported the failure of a Cummings diesel engine. The turbocharger went out first followed by the main and rod bearings and ending in total engine failure. This mishap, the only significant engine problem reported, was apparently oil related; however, some of the personnel think that it is definitely related to the use of re–refined oil and others are not sure. Safety–Kleen oil delivered in 55 gallon drums (there was also a comment that the oil looked darker in the drum than virgin oil) was used in the engine. In addition, 7 districts indicated a problem with the cleanliness of oil delivered in drums. These results indicate that there may be a significant problem associated with the contamination of re–refined oil during the blending and/or packaging processes.

The questionnaire results showed that approximately 7,719 TxDOT vehicles are using re–refined oil: 3,672 gasoline fueled vehicles, 2,328 diesel fueled vehicles, and 1719 alternatively fueled vehicles. Most of the districts perform oil changes both in–house and by contract.

A little over 90,000 gallons of used oil and fluid is disposed of each year. Most of the districts, 19 to be exact, reported that their used oil was picked up at no cost by local contractors. The other 7 districts receive from $0.055 to $0.15 per gallon of used oil. Districts may need to pay for the disposal of used oil filters. None of the districts has

Table 9 Summary of Questionnaire Responses

Topic	Result
Virgin engine oil used	4,668.5 gal/month
Re–refined engine oil used	2,025 gal/month
Virgin hydraulic fluid used	2,034 gal/month
Re–refined hydraulic fluid used	725 gal/month
Total used engine oil generated	5,849 gal/month
Total used hydraulic fluid generated	1,410 gal/month
Total other used fluids generated (anti–freeze and gear lube)	507 gal/month
Number of Districts reporting testing of used oil before pickup by service	2
Number of vehicle using re–refined oil	
Gasoline fueled	3,672
Diesel fueled	2,328
Natural gas fueled	213
LPG fueled	790
Other	716
Number of Districts using re–refined oil	15
Number of Districts reporting problems with re–refined oil	7
Number of Districts that perform in–house oil changes	24
Use service for oil changes	20
Both in–house and service	19
Number of Districts reporting problems with cleanliness of oil delivered in drums	7

Table 10 Compiled Responses from Questionnaires

Dist No	Total used engine oil generated per month (gal)	Total used hydraulic fluid generated per month (gal)	Total used other fluids generated per month (gal)	Company that picks up used fluids	Pick–up service contract or as necessary	Used fluids sold for (¢/gal)	Used fluids are picked up every	Are used fluids tested before pick up	Problem with used fluid disposal (pick up refused)
1	74	–	–	EPPCO	Contract	7	4 – 6 months	NO	NO
2	187	68	–	Procycle Oil Inc	Contract	8.5	month	NO	NO
3	250	100	25	IMC Oil Service	As Necessary	0	2 months	NO	NO
4	300	150	0	Unknown	–	0	–	–	NO
5	1,000	200	150	Specialty Oil	As Necessary	0	2 months	YES	NO
6	150	50	25	Recon Systems	As Necessary	0	2 months	NO	NO
7	42	15	-	Procycle Oil Inc	Contract	0	year	NO	NO
8	400	200	0	Industrial Service Company	As Necessary	0	2 months	NO	NO
9	500	100	–	Enviro Save Oil Recovery	Contract	0	3 months	NO	NO
10	17	–	–	Enviromental Petroleum Prods	As Necessary	0	6 months	NO	NO
11	48	12	–	Industrial Service Company	As Necessary	0	6 months	NO	NO
12	350	65	–	Holcomb Waste Oil	Contract	15	month	NO	NO
13	277	42	33	Frank's Waste Oil	Contract	5.5	6 months	NO	NO
14	193	10	16	Frank's Waste Oil	Contract	11	4 months	NO	NO
15	451	96	–	Alamo Petroleum Exchange	–	0	month	NO	NO
16	10	10	–	Procycle Oil Inc	Contract	3	3 months	NO	NO
17	285	117	43	Leabert Lacour	Contract	0	month	NO	NO
18	90	50	–	Dallas Oil Service	As Necessary	3	2 months	NO	NO
19	20	50	10	Industrial Service Company	As Necessary	0	as needed	NO	NO
20	400	50	–	Frank's Waste Oil	As Necessary	0	3 – 4 months	NO	YES
21	–	–	–	Various vendors	As Necessary	0	6 months	NO	NO
22	245	0	185	EPPCO	Contract	0	6 – 12 months	NO	NO
23	50	–	20	Industrial Service Company	As Necessary	0	6 months	NO	NO
24	250	20	–	Nunn Waste Mgt	As Necessary	0	6 months	YES	YES
25	110	–	–	Industrial Service Company	As Necessary	0	–	NO	NO
29	150	5	5	H & H Waste Oil	As Necessary	0	month	NO	NO
Total	5,849	1,410	512			2.04 avg	3 months avg		

Table 10 Compiled Responses from Questionnaires (continued)

Dist No	Oil recovered from crushed and drained used filters	Used oil filters disposed of by	Used oil goes to re–refined oil or fuel and asphalt	Disctrict regularly uses re–refined oil in its vehicles	District does not use re–refined oil because	Oil changes performed in–house or by service	Oil change service (if used) uses re–refined oil	Oil change service used
1	YES	Contract	Re–refined oil	YES		Both	YES	-
2	YES	Vendor recycles	Don't know	YES		In–house	–	-
3	YES	Environmental Insight, Inc.	Don't know	For testing		Both	NO	KWIK Change Oil
4	NO	Contract	Don't know	NO	Cost of re–refined oil	Both	NO	Pete's Auto
5	YES	Picked up by oil company	Don't know	NO	Poor	In–house	–	-
6	YES	Incinerated	Re–refined oil	YES		Both	YES	Several vendors
7	YES	GBF Filter services	Neither	YES	No access in outlying areas	Both	YES	Concho Car Wash & Lube
8	YES	Contract	Neither	NO	More expensive	Both	NO	Several contractors
9	YES	Contract	Both	YES		Both	NO	Several contractors
10	YES	Recycled	Fuel & asphalt	NO	No access	Service	NO	Fast Oil & Lube
11	YES	Contract	Don't know	YES		Both	YES	-
12	YES	Contract	Don't know	NO	More expensive	Both	NO	-
13	YES	Contract	Fuel & asphalt	YES		Both	NO	-
14	YES	Disposal service	Don't know	YES		Both	NO	Texaco Express Lube
15	YES	Contract	Don't know	YES		Both	NO	-
16	NO	Contract disposal	Fuel & asphalt	NO	Not convinced that re–refined oil is OK	Both	YES	Wal Mart
17	YES	-	Don't know	NO	Problems with ests of new re–refined oil	Both	NO	Townshire Chevron
18	–	-	Re–refined oil	NO		Both	NO	-
19	YES	Recycled	Fuel & asphalt	YES		Service	YES	Several contractors
20	YES	Contract disposal	Don't know	YES		In–house	–	-
21	YES	Safety–Kleen picks up filters	Don't know	YES		Both	YES	Several contractors
22	YES	Contract Dosposal	Don't know	YES		Both	NO	Several contractors
23	YES	Contract	Don't know	Approx 20%	Poor availability	Both	NO	-
24	YES	Contract	Don't know	YES		In–house	–	-
25	YES	Contract	Don't know	NO		Both	NO	Dugas's Service Station
29	YES	Picked up	Re–refined oil	NO	Bad reports	In–house	–	-

Table 10 Compiled Responses from Questionnaires (continued)

Dist No	Number of vehicles using re–refined oil by fuel type					Total number of vehicles using re–refined oil	Number of vehicles using re–refined oil by vehicle use	
	Gasoline	Diesel fuel	Natural gas & gasoline	LPG & Gasoline	Other fuel		On–road use (licensed)	Off–road use
1	298	226	–	98	–	622	319	205
2	357	274	99	121	–	851	619	232
3	1	–	–	2	–	3	3	–
4	4	–	–	–	–	4	–	–
5	1	1	–	–	–	2	2	–
6	165	210	9	105	–	489	235	140
7	19	27	–	36	–	82	–	–
8	–	–	–	–	–	0	–	–
9	221	128	22	114	146	631	349	146
10	–	–	–	–	–	0	–	–
11	123	145	–	55	–	323	–	–
12	1	–	–	–	–	1	1	–
13	211	389	–	–	–	600	Can't tell from response	
14	121	135	12	37	185	490	260	163
15	2000	500	50	125	385	3060	4	205
16	6	6	–	3	–	15	10	3
17	–	–	–	–	–	0	–	–
18	–	–	–	–	–	0	–	–
19	5	–	–	1	–	6	6	–
20	–	–	–	–	–	0	–	–
21	93	225	18	71	–	407	308	99
22	25	22	–	11	–	58	48	10
23	20	40	–	11	–	71	33	38
24	–	–	–	–	–	0	–	–
25	1	–	–	–	–	1	1	–
29	0	–	3	–	–	3	3	–
Total	3,672	2,328	213	790	716	7,719	2,201	1,241

Table 10 Compiled Responses from Questionnaires (continued)

Dist No	Oil or fluid used per month (gal)				Problems with the use of re-refined oil	Re-refined oil purchased by quart ot drum	Quart oil containers are disposed of by	Cleanliness problems with oil purchased in drums
	Total engine oil	Total hyd fluid	Re-refined engine oil	Re-refined hyd fluid				
1	210	136	210	136	NO	Both	Recycle	YES
2	220	90	220	42	NO	Quart	Regular trash service	YES
3	250	300	As needed for 3 vehicles	–	NO	Quart	Leave them with oil change contractor	NO
4	300	150	–	–	NO	None	Dump	YES
5	1000	200	4	200	NO	Quart	Dumpster	YES
6	40.5	20	15.5	15	NO	Both	Garbage collection	NO
7	30	12	98	–	NO	Quart	Trash	YES
8	400	200	–	–	NO	Mostly Drum	–	–
9	500	106	350	106	NO	Both	Usually trash	YES
10	16	49	–	25	NO	–	–	NO
11	–	–	–	–	YES	Quart	Trash can	–
12	116	36	2.5	–	YES	Quart	Contract	NO
13	260	61	260	–	YES	Drum	–	NO
14	200	30	200	–	NO	Both	Discarded	NO
15	60	26	391	70	NO	Both	–	NO
16	10	10	10	–	NO	Drum	–	NO
17	285	117	–	–	YES	–	–	–
18	90	50	–	–	NO	Drum	–	–
19	–	–	–	–	NO	Quart	Recycling	–
20	–	–	–	–	YES	Drum	–	YES
21	221	131	221	131	YES	Quart	Trash dumpster	–
22	–	15	–	–	NO	Quart	Trash can	–
23	30	20	12	–	NO	Both	Trash dumpster	NO
24	30	20	30	–	NO	Quart	Trash after draining	–
25	250	200	–	–	NO	Quart	Trash after draining	YES
29	150	55	–	–	YES	Quart	Trash can	–
Total	4,668.5	2,034	2,025	725	7 YES			

had problems disposing of their used fluids and only 2 report that the used oil is tested before being picked up.

All new dump trucks purchased by TxDOT during the past two to three years have been delivered with re–refined hydraulic fluid in the hydraulic systems.

Some selected comments from the questionnaires are included below by general topic.

General use of re–refined oil and fluids:

Most of our outlying areas do not have easy access to re–refined motor oils.

Drums of oil used at district shop, quarts are used at remote sights.

We have oil change contract and take re–refined oil by the quarts to contractor and he disposes of empty containers.

TxDOT should require all state vehicles to use re–refined motor oil if available in their area.

Re–refined oil under contract is more expensive than new oil is being purchased on local bids.

I feel that tremendous dollar value of our equipment fleet makes me very uncomfortable to move away from assurance we have from major oil companies integrity in assuring us the new oil and fluids we purchased meets all of the requirements of equipment manufacturers recommendations.

Our district purchased 2 barrels and realized they were more expensive than new oil we were purchasing and did not purchase any additional because we are not out any expense to dispense of our oil at this time.

Oil service contract company cannot get re–refined oil.

More expensive, using in one vehicle, monitoring by oil analysis.

Question wisdom of servicing $15,000 diesel engines with re–refined oils prior to extensive testing.

Decision was left to the users based on ease of tracking.

Convincing people that it meets specifications and is fine as good.

We use oil recommended by equipment manufacturer.

Until equipment manufacturers recommend re–refined engine oil and hydraulic fluids in their equipment there will remain a lack of confidence in the product.

Problems with re–refined oil and fluids:

No–oil sample results show no problems for the approximately 200 samples this past year of both re–refined oil and new refined oil.

Yes, reports of oil consumption on approximately 6 units.

High silicone on many of the oil analysis sampler.

Basic sediment & water, metals, halogens, up.

Problems with engine failure–difficult to prove oil cause. Problems: Flattened camshafts, blown turbo–chargers, galled pistons, crankcase and overhead sludge.

The Bryan District used re–refined oil from October 94 until December 1994. We had samples taken from new bottles of oil and sent off for analysis. The samples returned bad several different times and we discontinued the use of re–refined oils.

Found impurities in new bottles of oil during sample tests.

It was found that some drums of re–refined hydraulic fluid which was received at the warehouse were out of manufacturer's specifications because of high water, solids, and metal contents.

We have found debris & sediment in the bottom of the containers

Webb and Duval counties report they have experienced no difference in the performance of engines, whether use is in new or old equipment.

Yes, oil contaminated.

Engine began leaking, high abrasive content, low TBN.

Repeated bad reports: High silicon and low total base number.

Drums versus quart containers:

For servicing purposes we purchase drums because of our oil guns, and it is cheaper by the drum.

All of our location is set up with dispensers to accommodate drums — oil is piped to service areas from drums and uses power pumps to transfer oil.

Disposal of used oil and fluids:

Used oil is being picked up at each location in our district for no charge to Dept.

District 13 has successfully maintained annual contracts for vendors to purchase used oil district–wide for 20 plus years.

Burner fuel market, marine market (is a blending process)

Oil drums contained too much free water. Liquids were later picked up and a nominal fee was charged for handling the water.

It would be greatly beneficial if regulating authorities would afford municipal generators the same flexibility as it does commercial generators concerning hazardous waste which exhibits only D001 characteristic in reference to used oil.

It is still unclear to some of us what we are to do to cover TxDOT.

Disposal of used oil filters:

They are put into a drain barrel then transferred to another barrel which is picked up by our contract vendor.

Leabert Lacour pick up used oil filters. There is a $80.00 fee for disposing of used oil filters.

After filters are drained, they are picked up by Pro–Cycle Oil of Boyd, Texas at a cost of $1.20 per gallon.

Used oil filters are drained then placed in 55 gallon drums until contractor is called to pick up filters.

Crushed/drained filters sold as scrap metal–uncrushed drained filters contracted with filter recycler.

Picked up by H&H @ $75.00/55 gall drum.

It is understandable that personnel responsible for maintaining expensive equipment would have serious and sincere questions about the quality of oil and lubricants that they are required to use. The most significant observation made from the results of the questionnaire is that most if not all problems resulting from the use of re–refined oil and fluids is associated with contamination and is not related to the basic characteristics of the fluids. Further, it is suggested by several of the comments received that trust in the quality of products obtained from the larger and more well known suppliers is a major reason for preferring virgin oil. Indeed, the cases of contaminated re–refined oil may well be related to the much smaller amounts of production and the associated problems. Smaller suppliers who do not have the capability to ensure adequate quality control of the blending and packaging operations may create problems for the entire re–refined oil program.

11 Used Oil and Fluids Collection and Recycling

The results from the survey indicated that the districts were not having difficulties disposing of used oil and filters at present. In fact some of them are getting paid for their used oil. However, only about 10 of the districts are currently disposing of used oil via a contractor. The remainder of the districts dispose of their used oil on an as needed basis through various venders. Hence, TxDOT may be exposing itself to a potential lawsuit related to the improper disposal of used oil or used oil filters. The originator of used oil is responsible of the proper disposal even after the oil has been picked up by a disposal company. The best policy is to contract with a reputable company and create an obvious paper trail that leads to the disposal of the oil.

An essential element of an effective used oil collection and recycling program is to have in place a comprehensive set of procedures that can be strictly adhered to. For example, it is imperative that any oil collection system diligently segregate and store waste fluids in an appropriate manner. A second key step is a used–oil pre-qualification which ensures that the used–oil is not contaminated. Samples of used oil should analyzed to ensure this is indeed the case prior to shipment to the re–refiner's facility. These efforts would ensure that downstream re-refining of the used oil have the highest level of recovery of base-oil stock.

Further, it is necessary to minimize the cost of collecting and transporting the used fluids to a central site. Visits were made to several used oil collection companies to discuss the problems related to collecting and transporting used fluids.

Mr. Scott L. Hesseltine, Resources Recovery Branch Manager at the Lubbock Safety–Kleen office, indicated that Safety-Kleen collects used oil including gear oils, hydraulic oils etc. from an approved list of generators. The used oil is collected every 12 weeks and transported by regional Safety–Kleen trucks and stored in regional tanks. The oil is then transported to the Denton Safety–Kleen facility for cleaning before transport to the Safety–Kleen refinery in East Chicago. Figure 10 depicts the Safety–Kleen collection system. Figure 11 shows the location of Safety–Kleen branch offices in Texas.

Industrial oil is also collected; however, there is a fee of $0.20 per gallon. Solid wastes are collected in 55 gallon drums for varying fees $225 to $825 per drum). Used oil filters are picked up in 30 gallon containers for $79 per container. Oil filters are

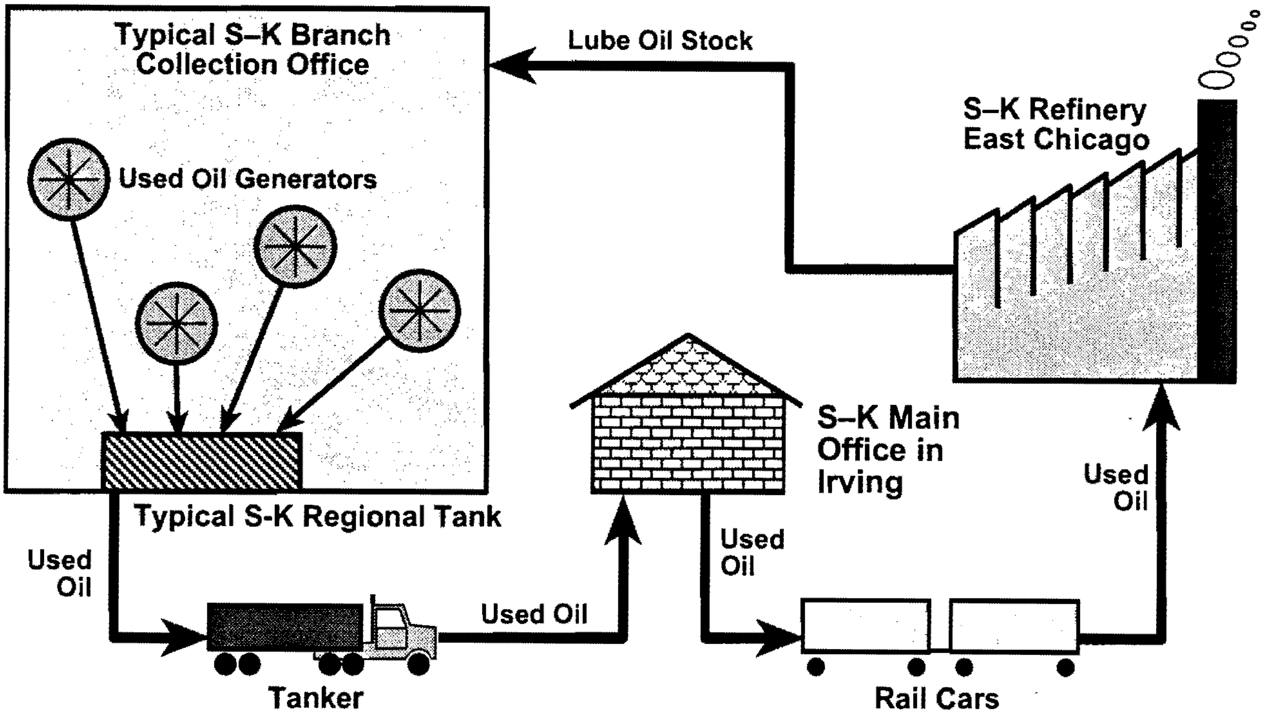


Figure 10 Safety–Kleen Used Oil Recovery System

crushed and washed to recover any oil left in them. The recovered oil is re–refined into lubricating oil. The paper from the oil filter is burned for energy and the metal is made into concrete reinforcement bars. Figure 12 depicts this process.

Discussion were also held with Mr. Carroll Porter, Mr. Buster Estill, and Mr. Curtis Estill of E & E Environmental, P.O. Box 683, Brownfield, Texas 779316; E & E Enterprises, PO Box 683, Brownfield, Texas 779316; and C & C Operating, Inc., Odessa, Texas 79763. They recycle used oil, oil filters, and antifreeze. Used oil is picked up from generators monthly at no charge unless special timing or routing is required or if oil is contaminated. All used oil collected by E&E is recycled into industrial fuel.

Transportation of used oil from individual generators scattered across the state to the recycling or re–refining point is a major expense. Thus, it desirable to perform as much transportation by rail as possible. Figure 12 shows the location of Safety–Kleen branch offices relative to rail roads across Texas. If used oil is to be re–refined into lubricating oil, the transportation costs must be minimized. Most of the oil recycling that produces industrial fuels can be completed with a much less sophisticated and less expensive facility than a refinery; hence, transportation costs for recycled oil is typically less than for re–refined oil.

An attractive alternative that TxDOT should consider is a *closed loop* oil supply. In other words, the vender that supplies oil (virgin or re–refined) will also collect and dispose of the used oil and filters. By taking this approach, TxDOT can ensure that it not only used re–refined oils but that its used oil is re–refined into lubricating oil

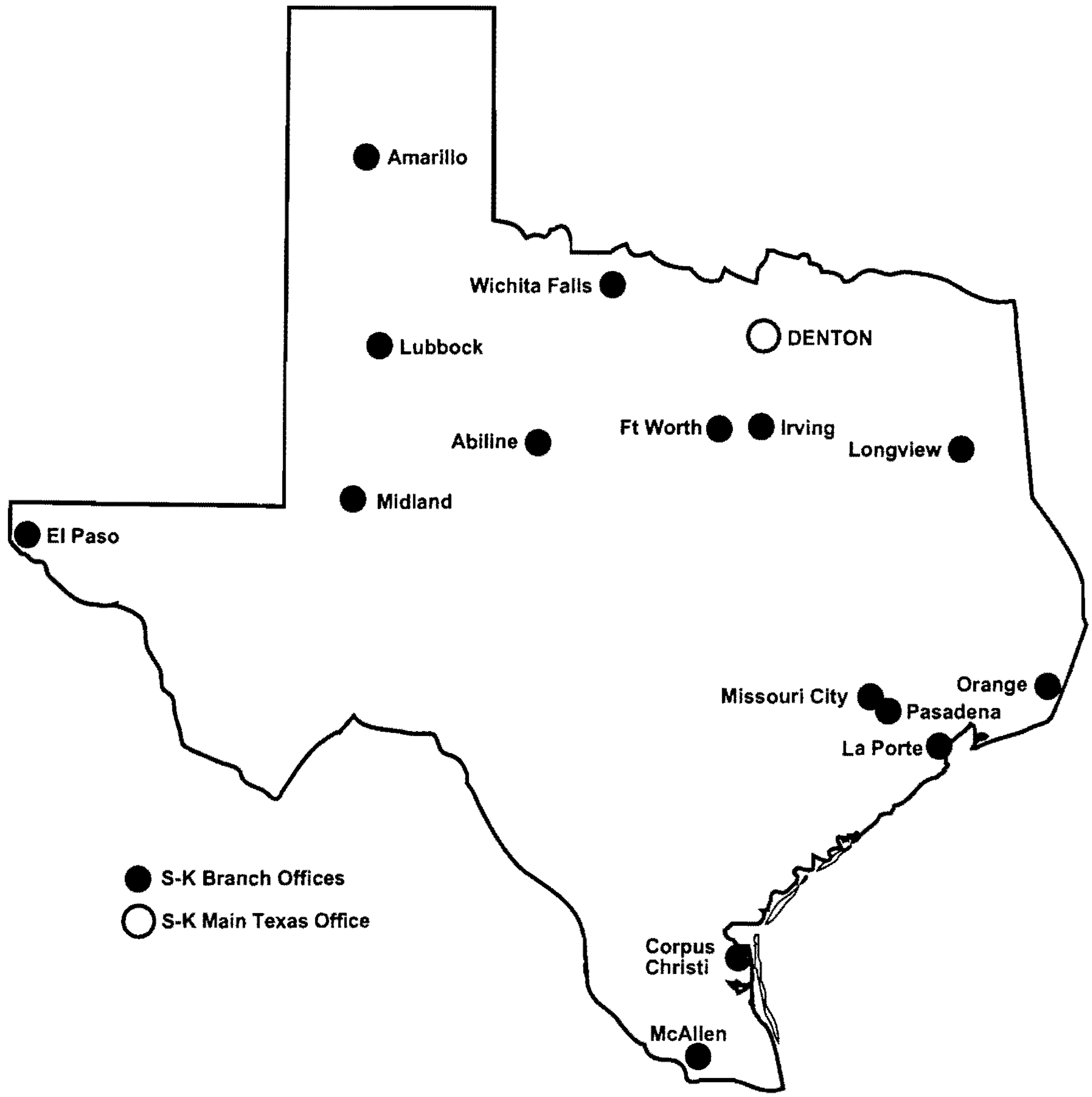


Figure 11 Safety–Kleen Branch Offices in Texas

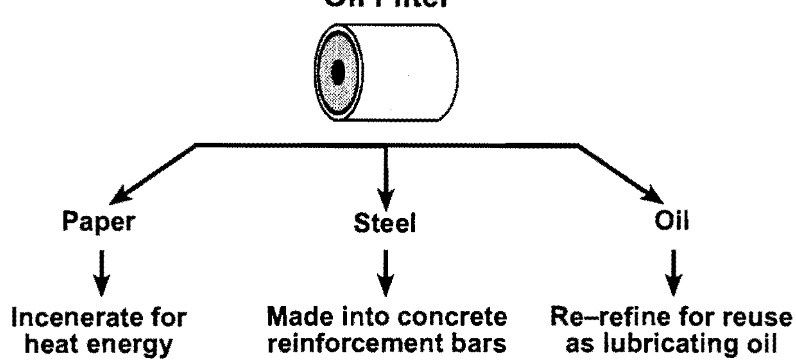


Figure 12 Used Oil Filter Disposal Process

rather than recycled into fuel. Both Safety–Kleen and Lyondell have indicated a strong interest in providing closed loop service. The only disadvantage to closed loop service is that at least initially it may increase the cost of oil products. However, once the system is in place and more re–refined oil is available, the costs should not exceed other alternatives.

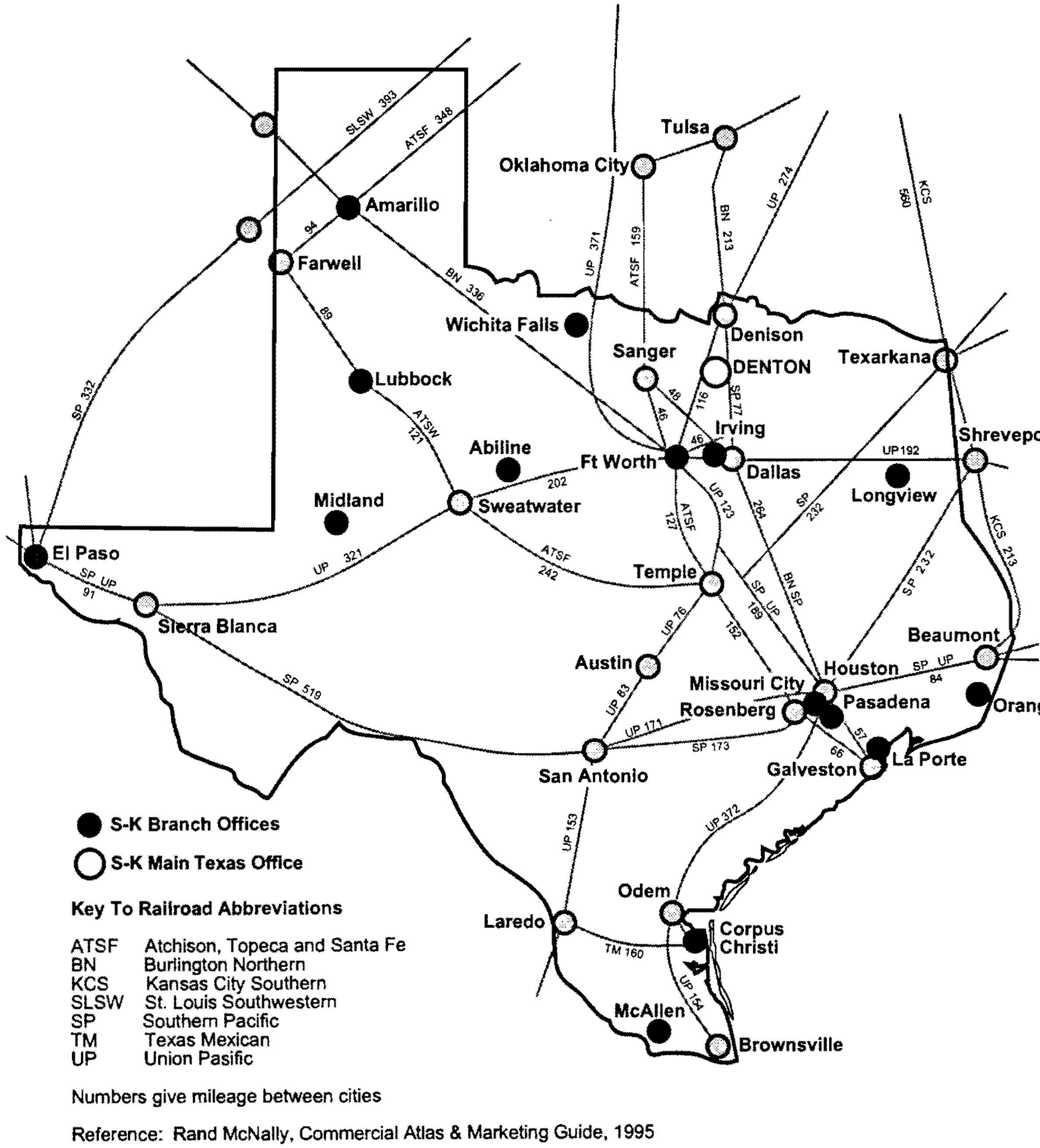


Figure 13 Major Railroads as Related to Safety–Kleen Branch Offices in Texas

12 Recommendations and Conclusions

1. Although the study team was not able to schedule an inspection of the Evergreen re–refinery in California, a review of facilities and operations at the Safety–Kleen re–refinery in Indiana supported the contention that re–refined oil base stock is essentially equivalent to virgin crude oil base stock. Base stock oils recovered in the re–refining process meet all API standards for base oils. API has modified their definition of *base stock* to include the use of re–refined oils.
2. If properly performed in appropriate facilities with the necessary quality control, the use of re–refined base oils in the blending of lubricating fluids will provide fully acceptable end–products. Reports by several TxDOT Districts regarding contaminants in purchased re–refined lubricating oil products are thought to be related to quality control problems associated with container processing rather than with the re–refined base oil or additive. These problems, although possibly statistically insignificant, need to be addressed by the reputable suppliers. It is apparent, however, that some lubricating fluid suppliers, qualified by TxDOT procurement regulations, do not have appropriate facilities and personnel necessary to ensure delivery of quality products. This is a potentially serious problem that needs to be addressed in one of the following ways:
    a. TxDOT could qualify their suppliers by requiring compliance with ISO 9000 or by using Total Quality Management techniques similar to those used by major industries such as Chrysler, Ford and General Motors. This process involves such things as visits to supplier's plants, evaluation of management systems and human resources, insuring that statistical quality control procedures are being used, verifying that a cost monitoring system is in place, and determining that suppliers have adequate facilities and personnel. Suppliers are certified as part of this procedure in a process referred to as a supplier *audit* or *verification.*
    b. Requiring suppliers to furnish documentation that demonstrates that oil furnished with the API service symbol label meets the requirements for the designations thereon, including the API service category, the SAE viscosity grade, and *Energy Conserving* or *Energy Conserving II*. This is a requirement of SAE Standard J1423 dated February 1992.
    c. Requiring suppliers to furnish documentation that demonstrates that oil furnished meets manufacturer's recommendations, as stated in the equip-

ment warranty. The Magnusson–Moss Warranty Act stipulates that manufacturers cannot void warranties if the re–refined oil meets these recommendations through *testing* and licensing.

d. Reverting to the approach of purchasing lubricating products with major refiner labels only, and demanding proof periodically from the refiners that not less than 25% of the feedstock used in producing the end–product was re–refined base oil. This will entail some difficulty in relating the *proof statement* to the actual product purchased, but the benefits for the refiners should encourage their wholehearted participation in solving this problem. One significant disadvantage to this approach is that it may relegate the re–refiners to being suppliers of base oils only. However, the increased sales of base oil might outweigh the losses associated with not selling the higher value added lubricating fluid end–product.

e. Contracting with lubricating fluid suppliers for *closed loop* (used oil collection and re–refined fluid supply) services only. This would undoubtedly entail contracting problems for TxDOT, but would afford additional insurance against violations of environmental protection regulations, etc. Lyondell and Safety–Kleen have both expressed interest in this approach. It is likely that other major suppliers would be interested as well.

f. Including a requirement for compliance with Green Seal Standard GS–3 in lubricating fluid procurement specifications. Although this Standard applies primarily to ensuring the integrity of the environment, it also includes certain quality requirements related to product performance, packaging, and labeling. Organizations authorized to use the Green Seal Certification Mark on their product are subject to an ongoing program of testing, inspection, and enforcement.

3. Based on a report published by Argonne National Laboratories [24], there appears to be justification, from an energy conservation point–of–view, for the re–refining of used oil for reuse in lubricating fluids, in addition to reprocessing for use as a fuel or asphalt extender. This conclusion is based on the fact that used oil can be recycled several times if not consumed as when it is used as a fuel or asphalt extender.

4. There appears to be considerable interest on the part of at least some major refiners in participating in the re–refined lubricating fluid supply process. Lyondell is trying to identify their role in this area and, based on an inspection of their facilities at the Houston refinery, is positioned to be an active player in this process.

5. No change is required in TxDOT's specification covering the purchase of oils and lubricants. There is no basic difference in the ability of re–refined oils and virgin oils to properly lubricate, cool and protect engines and machinery. Technical specifications for re–refined oil and virgin oil should be the same. API does not distinguish between re–refined and virgin base stock oils used in the blending of lubricating fluids; thus, it is only necessary to specify the API rat-

ing to ensure that TxDOT receives re–refined oil of the same grade and certification as virgin oil.

The problem in procurement is not with the quality of the re–refined oil but with the quality control of the blending and packaging operation. Suggestions relating to specification and/or procurement practice changes that may afford protection against low–quality suppliers are outlined above in recommendation (2).

6. Considerable savings can be made in the procurement of lubricating fluids in bulk quantities. The savings realized from purchasing in bulk quantities versus quart containers can be as much as $1.00/gallon. However, TxDOT would have to establish the bulk storage facilities and arrange for packaging and delivering the fluids to the users, the cost of which may be prohibitive.

   Another possibility which may warrant study is to contract with wholesale distributors for the total fluids supply and distribution effort or contract with refiners/blenders for the fluids and with the distributors for the bulk storage and delivery service. Wholesale distributors are widely dispersed across the state and many of these have significant bulk storage and packaging facilities. Most cities of any size have such distributors which should allow prompt and efficient service.

7. The cost of disposing of used re–refined fluids is no different than that associated with virgin lubricating fluids. If properly located collection facilities are available so that transportation costs to the re–refinery can be minimized, the value of the used fluids can be increased. Important considerations in this regard are the volume of used product collected per trip and the mode of transportation. Bulk collections (6,000 gallons is desirable) are the most cost effective and rail shipment is less expensive than transport truck. If bulk lubricating fluid purchases are made under a *closed–loop* contracting arrangement and used fluid collections are of the same approximate volume as the deliveries, no charge is usually made for collection.

8. The re–refined oil use and used oil disposal questionnaire responses from the districts lead to several interesting observations.

   a TxDOT consumes approximately 113,000 gallons of oil per year and produces over 90,000 gallons of waste oil per year.

   b Almost 1/3 of the oil used by TxDOT (33,000 gallons per year) is re–refined oil and over 6,000 TxDOT vehicles are using re–refined oil.

   c Problems encountered by TxDOT with respect to re–refined oils appear to be almost entirely related to poor quality control during blending and/or packaging of the oil.

   d Districts do not appear to be encountering any difficulty in disposing of used oil and used oil filters. Most of the waste oil is not introduced into the re–refining feedstock stream.

9. If TxDOT wishes to have its used oil re–refined into lubricating oil, it will be necessary to modify the current used oil disposal process. Most of TxDOT's used oil is disposed of through local comapies that convert the used oil inot other products suchas fuel. Transportaion of the used oil to the re–refinery for re–refining is the major problem. The used oil must be collected at a few centralized locations and transported, probably by rail, to the refinery. Such a program will require direct interaction with Safety–Kleen or another company that can re–refine the used oil.

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APPENDIX I

State Regulations and Incentives for Recycled and Re–Refined Waste Oil

Table AI.1 State Waste Oil Regulations [24]

State	General Comments	Disposal Bans	Other Stringent Requirements	Fees or Taxes	Used Oil Filters
Alabama	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal reguated as hazardous waste.	No liquids allowed in landfills. Use as road oil, dust suppressant, or weed killer prohibited.	Stricter storage requirements (e.g. stipulated minimum capacity and precipitation control for secondary containment, and removal and decontamination procedures at closure.)		
Alaska	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	No liquids allowed in landfills.	Mandate that commercial water vessels be equipped with a place to deposit used oils.	Proposed for future discussion.	
Arizona	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Disposal in sewers or waters, on land, or by incineration allowed only if permitted/authorized.	Recycle does not include burning of used oil as fuel.	6¢/gal tax on burning of on–spec oil; 20¢/gal tax on burning of off–spec oil.	
Arkansas	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Provision adopted to permit application as dust suppressant under stringent restrictions.	Processors and re–refiners required to submit annual used oil activity reports.		Procedures for disposal recommended.
California	Used oil regulated as hazardous waste until it meets state established purity standards. Certified sites that collect DIY oil are exempt from most hazardous waste requirements	Disposal in sewers or waters, on land, or by incineration allowed only if permitted/authorized. Dust suppressant, herbicide, and road oil applications restricted.	Stricter "purity standards," including: lead less than 50 ppm, halogens less than 1,000 ppm. Certification, recordkeeping and reporting requirements.	16¢/gal tax on oils sold in state.	
Colorado	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Land disposal or use as dust suppressant or weed killer prohibited.			
Connecticut	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfilling and incineration prohibited.	Burning of used oil in residential boilers prohibited. Permit requirements for transporters and marketers. Marketers must have written analysis plan.	Waste oil treaters pay $14,000 fee for five year permit. $500 annual permit fee for transporters.	Procedures for disposal recommended.
Delaware	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal or use as road oil, dust suppressant, or weed killer prohibited.		$300/yr permit fee for used oil transporters.	
D.C.	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Use for dust suppression or road oil, and discharge into sewers prohibited.			

Table AI.1 State Waste Oil Regulations (continued) [24]

State	General Comments	Disposal Bans	Other Stringent Requirements	Fees or Taxes	Used Oil Filters
Florida	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Solid waste landfill disposal; discharge into sewers or waters; and use as road oil, dust suppressant, or weed killer prohibited.	Transporters, collectors, and recyclers required to register with state. Recordkeeping and reporting requirements associated with registration.	$100 registration fee for recyclers, transporters, marketers, and burners of off–spec fuel.	Excluding households, oil filters cannot be disposed of in landfill. Filter generators, transporters, and processors must register with state.
Georgia	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Use for road oil, dust suppressant, or weed killer prohibited. Landfill disposal allowed under limited circumstances.			
Hawaii	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Discharge into sewers, waters, or on ground prohibited.	State permits and recordkeeping required for transporters, recyclers, burners, and marketers.		
Idaho	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	No landfill disposal unless it is the "only reasonable alternative." Road oil and dust suppressant applications restricted.			
Illinois	Used oil regulated as "special waste" includes hazardous waste that could pose threats to human health or to environment. Used oil destined for disposal is regulated as hazardous waste.	Land disposal or use as road oil, dust suppressant, or weed killer prohibited.	State "special waste" permits required for transporters, burners, and recyclers.		
Indiana	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Solid waste landfill disposal, and use as road oil or dust suppressant prohibited.			
Iowa	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Sanitary landfill disposal; discharge into state waterways; and use as road oil, dust suppressant, or weed killer prohibited.	Motor oil retailers must list location of nearest collection site. State sets standards for collection sites, including supervision requirements.		
Kansas	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal and use as road oil or dust suppressant prohibited.	Registration for transporters. Recyclers must be permitted. Generators (greater than 500 gal/yr) required to accept DIY oil. Retailers must post locations of nearest collection site.		

Table AI.1 State Waste Oil Regulations (continued) [24]

State	General Comments	Disposal Bans	Other Stringent Requirements	Fees or Taxes	Used Oil Filters
Kentucky	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Discharge into sewers or waters and incineration other than for energy recovery prohibited. Use for dust suppression or road oiling allowed only if oil does not have hazardous characteristics.	Registration, recordkeeping, and reporting requirements for used oil transporters, storage facilities, and recyclers. Oil retailers required to post locations of collection sites.	Annual $300 registration fee for marketers and burners.	
Louisiana	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Solid waste landfill disposal; discharge into sewers or waters; and use as road oil, dust suppressant, or weed killer prohibited.			
Maine	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal and use as road oil, dust suppressant, or weed killer prohibited.	License requirements include liability insurance, recordkeeping, inspection, and training. Waste oil storage facilities subject to rebuttable presumption, restricting locations in certain high--risk areas.	$1,500 application and $500/yr renewal lees for waste oil storage facility license: $100/yr fee for transporter license; $.02/gal fee to transport waste into state; 1¢/gal fee to collect oil in state.	
Maryland	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Discharge into sewers, waters, or land and incineration prohibited.	Motor oil retailers required to post locations of collection sites. All persons prohibited from knowingly adding any liquid or solid substance to used oil. Closure and secondary containment requirements apply for used oil handlers.		
Massachusetts	Used oil regulated as hazardous waste.	Use for road oil, dust suppressant, or weed killer prohibited.	Motor oil retailers required to accept used oil from customers free of charge. Used oil regulated as hazardous waste.	18.2¢/gal tax for hazardous waste. DIY collectors exempted.	
Michigan	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal, discharge into sewers or waters, and municipal solid waste incineration prohibited.	Bonding and licensing required for transporters, burners, and recyclers of "liquid industrial wastes."		
Minnesota	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Used oil prohibited from mixed municipal solid waste. Use for road oil or dust suppressant prohibited.	Motor oil retailers required to post locations of collection sites. Industrial generators required to report activities.		Disposal of used oil filters with municipal solid waste prohibited.

Table AI.1 State Waste Oil Regulations (continued) [24]

State	General Comments	Disposal Bans	Other Stringent Requirements	Fees or Taxes	Used Oil Filters
Mississippi	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Use as dust suppressant or weed killer prohibited.			
Missouri	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Solid waste landfill disposal, discharge to environment, or use as road oil or dust suppressant prohibited.	Secondary containment required at transfer facilities, recyclers, and off-spec oil burners with capacities greater than 10% of waste volume. Waste oil containing 2–50 ppm PCBs assigned special state waste code.		
Montana	Used oil defined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Disposal of free liquids in landfills prohibited. Dust suppression prohibited except for household DIY oil changers and farmers.	Motor oil retailers required to post locations of collection sites.		
Nebraska	Used At destined for receding or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Use for dust suppression or road oil prohibited. Complete ban on land application under consideration.			
Nevada	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Disposal in sanitary landfill or other unpermitted disposal site, and use as dust suppressant or weed killer prohibited.	Only conditionally exempt small-quantity generators permitted, with recordkeeping, to mix ignitable characteristic hazardous waste with used oil.		
New Hampshire	Used oil always classified as hazardous waste. Used oils recycled or burned for energy recovery subject to less stringent standards.	Use for road oil or dust suppressant, and mixing for use as automotive undercoating prohibited.	State-specified standards on composition of "off-spec used oil" fuel.	4¢/gal fee on new automotive lubricating oil imported into state to fund municipal grant program.	
New Jersey	Used oil regulated as hazardous waste.	Landfill disposal and use as dust suppressant or weed killer prohibited.	Motor oil must be clearly labeled as containing recyclable material. Used oil regulated as hazardous waste.		
New Mexico	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal of free liquids prohibited. Used oil with hazardous characteristics banned from use as road oil or dust suppressant.		1¢/lb/yr fee for used oil destined for disposal as hazardous waste.	

Table AI.1 State Waste Oil Regulations (continued) [24]

State	General Comments	Disposal Bans	Other Stringent Requirements	Fees or Taxes	Used Oil Filters
New York	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal and use as road oil, dust suppressant, or weed kilter prohibited.	Motor oil retailers and service establishments required to accept used oil at no charge.	10¢/quart fee on lubricating oil sales.	
North Carolina	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal; discharge into sewers or waters; and use as road oil, dust suppressant, or weed killer prohibited.	Registration and reporting requirements for collectors, transporters, and recyclers.	Collection facilities that receive greater than 6,000 gal/yr used oil, transporters, and recyclers pay $25/yr registration fee.	
North Dakota	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal and use as road oil dust suppressant or weed killer prohibited.		$75 fee for waste hauling permit; $5,000 permit fee for resource recovery facilities.	
Ohio	Used oil regulated as solid waste. Used oil destined for disposal must be tested to determine whether it is hazardous or ordinary solid waste.				
Oklahoma	Used oil is classified as a non–hazardous solid waste. Used oil destined for disposal must be tested for hazardous characteristics; if positive, it must be managed as hazardous waste.	Use as dust suppressant or road oil prohibited.	Motor oil retailers required to post locations of collection sites.		
Oregon	Used oil destined for recycling or energy recovery considered a recyclable material exempt from hazardous waste regulation. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal; discharge into sewers or waters; and use as dust suppressant, weed killer, or pesticide prohibited.	Residues from used oil burning classified as hazardous waste. Annual reposing required for used oil processors. Solvent burning in waste oil space heaters prohibited.		
Pennsylvania	Waste oil regulated under state hazardous waste regulations with some exemptions. Exempted waste oils are regulated as "residual waste."	Used oil must be recycled or deposited in a used oil collection site. Disposal in sewers, waters, or onto land prohibited.	Stricter parameters for off-- specification oil. Permitting and reporting required for collectors, transporters, and recyclers.		
Rhode Island	Used oil regulated as hazardous waste.	Disposal in sewers, waters, on land or by incineration only in accordance with regulations.	Used oil regulated as hazardous waste. Information posting requirements for motor oil retailers.	5¢/quart motor oil tax.	Filters must be sent to recyclers that recycle 90% of parts.
South Carolina	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal; discharge in sewers or waters; and use as road oil, dust suppressant, or weed killer prohibited.	Registration and reporting requirements for collectors, transporters, and recyclers.	8¢/gal motor oil sales tax.	

Table AI.1 State Waste Oil Regulations (continued) [24]

State	General Comments	Disposal Bans	Other Stringent Requirements	Fees or Taxes	Used Oil Filters
South Dakota	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal banned after 1997. Use as road oil or dust suppressant prohibited.			
Tennessee	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Discharge to sewers or waters and use as road oil, dust suppressant, or weed killer prohibited. Landfill disposal by special permit only.	Transporters, marketers, reprocessors, and re–refiners required to file annual reports and notify the state within 30 days of any operational status changes.	8¢/gal motor oil sales tax.	Used oil filter disposal in municipal landfills prohibited after April 1, 1994.
Texas	Used oil not regulated as hazardous waste; considered a municipal solid waste, except industrial used oil, which is regulated as hazardous waste if destined for disposal.	Municipal landfill disposal; discharge in sewers or waters; and use as road oil, dust suppressant, or weed killer prohibited.	Registration requirements for collection centers. Industrial used oil regulated as an industrial or hazardous solid waste.	8¢/gal sales tax on wholesale oil.	
Utah	Used oil defined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal; discharge in sewers or waters; and use as road oil, dust suppressant, or weed killer prohibited.	Collectors, transporters, and recyclers must be permitted or registered, demonstrate financial resources to cover potential liabilities, and submit annual reports.	Recycling fee of 4¢ per quart on sale of lubricating oil in state. Fee of $25 for permit or registration number.	
Vermont	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal and use as road oil or dust suppressant prohibited.	Stringent regulations for burning waste oil for energy recovery including air quality impact evaluation and compliance with state emission standards for new burners.		
Virginia	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal as free liquid, and use as road oil or dust suppressant prohibited.	Motor oil retailers required to post locations of collection sites.		
Washington	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal and use as dust suppressant or weed killer prohibited. Sale of adsorbent–based kits intended for home use as a means of collecting or disposing of used oil banned.	No person may knowingly dispose of used oil except by delivery to collector for recycling, treatment, or legal disposal.		
West Virginia	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal prohibited.			

Table AI.1 State Waste Oil Regulations (continued) [24]

State	General Comments	Disposal Bans	Other Stringent Requirements	Fees or Taxes	Used Oil Filters
Wisconsin	Used oil destined for recycling or energy recovery not regulated as hazardous waste. Used oil mixed with hazardous waste or destined for disposal regulated as hazardous waste.	Landfill disposal and use as road oil dust suppressant or weed killer prohibited. Waste oil cannot be burned in solid waste treatment facility without energy recovery.	Motor oil retailers must collect used oil for recycling or post signs to nearest collection site. Municipalities required to maintain a minimum number of collection sites based on population.		
Wyoming	Used oil regulated as said waste. Used oil not regulated as hazardous waste if destined for recycling and segregated to avoid contamination. Use oil destined for disposal must be tested to show that it does not exhibit hazardous waste characteristics.	Landfill disposal of free liquid and use of waste oil as road oil, dust suppressant, or weed killer prohibited.	Permit requirements for certain storage facilities transporters burners and recyclers.		

Table AI.2 State Waste Oil Incentives [24]

State	Collection Programs	State Purchasing Preferences
Alabama	Project Rose — public education on hazards of dumping used oil and assistance to establish and maintain collection sites.	
Alaska	Many municipalities have collection sites.	
Arizona	No official state program.	
Arkansas	No official state program. State Marketing Board for Recycling coordinates local programs and operates computer bulletin board on recycling and regulations.	
California	California Used Oil Recycling Fund — grants to establish DIY collection programs, to provide containers and supplies for DIY collection and for public education. Fund also sponsors "recycling incentive" of 16¢/gal oil for "certified" collection centers.	No exclusions of recycled oils. Requirements to purchase oils with greatest recycled content, provided product quality is equivalent to or better than virgin.
Colorado	No official state program.	
Connecticut	Municipalities required to provide for collection and recycle of used oil. Grant program for purchase of collection tanks by municipalities.	
Delaware	Delaware Solid Waste Authority sponsors collection sites and education.	
D.C.	Operates three collection sites for used oil, used oil filters, and antifreeze and sponsors education program.	
Florida	Used Oil Management Program — includes registration for used oil handlers, assistance to build state–wide collection network, and public education.	5% price preference for recycled and re–refined used oil.
Georgia	Project PETRO — encourages recycling through public education program (temporarily inactive).	
Hawaii	Monies assigned to counties to fund collection centers and public outreach programs. Hawaii Association of Retail Gas Dealers maintains used oil hotline.	
Idaho	No official state program.	
Illinois	Voluntary collection and recycling of oil encouraged. Feasibility study conducted regarding state collection and disposal assistance programs.	State vehicles use recycled oil whenever possible.

Table AI.2 State Waste Oil Incentives (continued) [24]

State	Collection Programs	State Purchasing Preferences
Indiana	No official state program.	
Iowa	Retailers must accept DIY oil or list locations of nearest collection sites. Grants for collection programs available through "Landfill Alternatives Grant Program."	5% price preference for recycled lubricating oil. Use of recycled oil promoted.
Kansas	No official state program.	
Kentucky	Encourages collection and reuse of waste oil through voluntary programs.	State encourages and requires (where possible) purchase of recycled oil, when available and competitively priced.
Louisiana	Used oil recycling program established but not funded.	Preference to re–refined oil (greater than 25% recycled content) that meets quality requirements and is priced within 5% of virgin oil cost.
Maine	Maine Oil Recycling Program — provides a subsidy for companies to purchase used oil burners to encourage recycling.	
Maryland	Used Oil Recycling Act — provides for public education program, establishment of a used oil information center, and technical assistance to used oil collection programs. State inspection centers and other locations required to collect used oil.	Purchase of re–refined oil is encouraged and required (when possible) by law.
Massachusetts	No official state program.	
Michigan	State used oil recycling law enacted to promote recycling. However, implementation of provisions stalled by lack of funding.	
Minnesota	Grants to local governments for collection site storage tank purchase. Provides fact sheets to assist public in oil recycling and curriculums for schools.	
Mississippi	No official state program.	
Missouri	No official state program.	
Montana	No official state program.	
Nebraska	No official state program.	Recycled material considered in purchasing.
Nevada	No official state program.	
New Hampshire	Beginning 1995, program will provide municipal grants for collection programs and training.	

Table AI.2 State Waste Oil Incentives (continued) [24]

State	Collection Programs	State Purchasing Preferences
New Jersey	Numerous municipalities sponsor collection sites or curbside collection programs. Service facilities with active used oil collection tanks required to accept DIY used oil up to 10 quarts/person/day.	
New Mexico	No official state program.	5% purchasing preference for recycled content.
New York	State requires oil retailers and service stations to install and maintain used oil retention and collection facilities.	Contracts for re–refined oil.
North Carolina	Department of the Environment is authorized to establish an incentives program to encourage DIY used oil recycling and to develop a grant program.	State law directs the Department of Environment to encourage procurement of recycled automotive, industrial, and fuel oils for all state and local government uses.
North Dakota	No official state program.	
Ohio	No official state program. State districts are required to prepare plan for managing household generated used oil.	
Oklahoma	No official state program.	Preference given to recycled products purchasing bids.
Oregon	Goal to collect 50% of DIY used oil by 1996, 70% by 2000. Recycling Opportunity Act dictates public education initiatives and curbside or drop off collection, based on population.	5% preference for re–refined lube oil and preference for used oil fuel.
Pennsylvania	Voluntary collection sites, registration with state. State sponsors hotline and promotes recycling through Used Oil Recovery Program.	5% preference for materials with recycled content. Recycled oil to be purchased to extent possible.
Rhode Island	Used Oil Recycling Act — requires state to conduct public education program and establish used oil information center. State motor vehicle inspection facilities and other facilities required to collect used oil, with costs covered by state.	Purchases used oil whenever possible.
South Carolina	5¢/gal incentive for retail facilities to establish separate tanks for DIY oil. Other programs under development.	Mandate to procure used oil products where practicable.

Table AI.2 State Waste Oil Incentives (continued) [24]

State	Collection Programs	State Purchasing Preferences
South Dakota	State–wide pilot program conducted in 1993 established voluntary collection sites at service stations.	
Tennessee	Used Oil Collection Act (based on API model legislation) — includes funds for grants, education, hotline, and oil collection site subsidies.	
Texas	Grant program to encourage oil recycling. Reimbursements for costs of proper disposal of contaminated DIY oil.	Mandated preference for recycled products.
Utah	State fund established to pay quarterly incentives to approved DIY collection centers and curbside programs.	
Vermont	Grants for purchase of collection tanks and proper disposal of contaminated oil generated by DIY oil changers.	
Virginia	No official state program.	
Washington	Local governments required to include used oil recycling "element" as part of hazardous waste plans.	State agencies purchase motor oil containing re–refined oil.
West Virginia	Program under development.	
Wisconsin	Large municipalities required to set up used oil collection sites.	
Wyoming	No official state program.	

Table AI.3 Waste Oil Study Contacts [24]

State	Contacts
Alabama	Sheri Powell, Project ROSE Coordinator, Tuscaloosa Karen Schoening, Recycling Coordinator, Huntsville
Alaska	Dan Garcia, Department of Environmental Conservation, Solid and Hazardous Waste Management, Juneau
Arizona	Robert Verville, Used Oil Compliance Manager, Department of Environmental Quality, Phoenix
Arkansas	Paul Carson, Mid America Distillations, Inc., Hot Springs
California	Fernando Berton, California Integrated Waste Management Board, Sacramento Bob Boughton, California Integrated Waste Management Board, Sacramento Jane Bryne, Evergreen Oil, Newport Beach Stuart M. Cannes, Unocal, City of Industry John L. Cooper, Chevron Products Company, San Francisco Bruce DeMenno, Demenno/Kerdoon, Compton Larry Levenstein, Clark Technology Systems Inc., Santa Paula Rich Loveton, Full Prime System, Inc., Penn Valley Don Peri, California Integrated Waste Management Board, Sacramento Jeff Underhill, Evergreen Oil, Newport Beach
Canada	Dave McIntyre, Oil Recovery Division of Safety–Kleen Canada, Inc., Breslau, Ontario Matt Waldner, Mohawk Lubricants Ltd., North Vancouver, British Columbia
Connecticut	Judy Belaval, Connecticut Dept of Environmental Protection, Bureau of Waste Management, Hartford Tom Metzner, Connecticut Dept of Environmental Protection, Bureau of Waste Management, Hartford
Delaware	Bob Palmer, Delaware Solid Waste Authority, Dover Donald Short, Delaware Natural Resources and Environmental Control, Hazardous Waste Management Branch, Dover Bill Tanzey, Star Enterprises, Delaware City
District of Columbia	Dana Amold, EPA Bradley Jones, Used Oil Program Coordinator, American Petroleum Institute Carl Williams, D.C. Energy Office
Florida	Joan Flint, Department of Environmental Regulation, Tallahassee Bob Foster, Permafix Environmental, Gainesville
Georgia	Rick Cothran, Project PETRO Coordinator, Georgia Department of Natural Resources, Environmental Protection Division, Atlanta
Illinois	Dennis Brinkman, Safety Kleen Corp., Elk Grove Village Tom Kalnes, UOP, Inc., Des Plaines Frank Lappin, Enviropur Waste Refining and Technology, McCook Fred Quam, Marketing Manager, Energy Division, Growmark, Bloomington David J. Shipley, Amoco Oil Corporation, Chicago
Indiana	Dave Carson, Consolidated Recycling, Troy
Iowa	Michael Berkshire, East Central Iowa Council of Governments, Cedar Rapids Christoffer Frantsvog, Spectrum Industries, Decorah Marilyn Krogulski, Waste Management Assistance Division, Iowa Dept of Natural Resources, Des Moines Amy Rogers, Amana Refrigeration, Inc., Amana
Kansas	Jack Beachey, Franklin Associates, Manhattan
Kentucky	Charles Pctcrs, Kentucky Dept of Environmental Protection, Waste Management Division, Frankfort Tony Puckett, Valvoline Environmental Services, Lexington
Louisiana	John Rogers, Dept of Environmental Quality, Office of Solid and Hazardous Waste, Baton Rouge
Maine	Rick Kaselis, Bureau of Hazardous Material and Solid Waste Control, Department of Environmental Protection, Augusta

Table AI.3 Waste Oil Study Contacts (continued) [24]

State	Contacts
Maryland	Cheryl Kidwell, Maryland Environmental Service, Annapolis Larry Northrup, Convenient Automotive Services Institute, Bethesda
Massachusetts	Kevin Dietly, Northbridge Environmental Consultants, Lexington Dikran Kaligian, Bureau of Waste Prevention, Dept of Environmental Protection, Boston
Michigan	Brian Burke, Michigan Dept of Natural Resources, Waste Management Division, Lansing Pat Casey, Savant, Inc., Midland
Minnesota	Tony Hainault, Office of Waste Management, St. Paul Julie MacKenzie, Minnesota Pollution Control Agency, St. Paul
Missouri	Clark Duffy, Missouri Oil Council, Jefferson City Karen Northrup, Missouri Dept of Natural Resources, Hazardous Waste Program, Jefferson City
Montana	Pierre Amicucci, Dept of Health and Environmental Sciences, Helena
Nebraska	Teri Swarts, Hazardous Waste Section, Dept of Environmental Quality, Lincoln
Nevada	Kris Kuiper, Nevada Division of Environmental Protection, Bureau of Waste Management, Carson City
New Hampshire	Christopher Way, Waste Management Specialist, Dept of Environmental Services, Concord
New Jersey	Ann Pfaff, New Jersey State Dept of Environmental Protection, Trenton
New York	Tom Gibbons, Pall Corporation, BaySide Bill Mirabile, New York State Dept of Environmental Conservation, Bureau of Waste Reduction and Recycling, Albany
North Carolina	Paul Chrisman, Dept of Environment, Health and Natural Resources, Raleigh Linda Culpepper, Dept of Environment, Health and Natural Resources, Raleigh Greg Griggs, Filter Manufacturers Council, Research Triangle Park
Ohio	Alan Gressel, Research Environmental Industries, Cleveland Dr. Bruce Perlson, Quantum Chemical, Cincinnati Dann R. Stapp, BP Oil America, Cleveland
Oregon	Peter Spendelow, Department of Environmental Quality, Portland
Pennsylvania	Joe Brancato, Quaker State Corporation, Oil City Ben Briseno, Sun Co., Inc., Philadelphia Jerald Claes, Graham Packaging, York William D. LaCour, Used Oil Recovery Coordinator, Dept of Environmental Resources, Harrisburg Vasil Mriz, Quaker State Corporation, Oil City
Rhode Island	Tom Armstrong, Dept of Environmental Management, Office of Environmental Coordination, Providence Tony Caronia, Allied Signal Automotive, East Providence Tim Warren, Allied Signal Automotive, East Providence
South Carolina	Richard Chesley, Dept of Health and Environmental Control, Columbia Willard Strong, Santee Cooper Utility, Moncks Corner
South Dakota	Carrie Jacobson, Dept of Environment and Natural Resources, Division of Environmental Regulation, Pierre Terry Keller, General Recycling Coordinator, Dept of Environment and Natural Resources, Pierre
Tennessee	Alan Ball, Dept of Environment and Conservation, Division of Solid Waste Assistance, Nashville Don Manning, Dept of Environment and Conservation, Division of Solid Waste Assistance, Nashville
Texas	Gary Davis, TNRCC, Recycling and Waste Minimization Section, Austin Steve Eisenstein, Shell Development Company, Houston Brett Morton, Pennzoil, Inc., Houston Claude J. Roberts, Jr., Texaco Lubricants Company, Houston Sam Walker, Nalco Chemical Company, Sugar Land Tom Wulfers, Lyondell Lubricants, Houston

Table AI.3 Waste Oil Study Contacts (continued) [24]

State	Contacts
Utah	Curt Morgan, Interline Resources Corporation, Alpine Steve Yeoman, Interline Resources Corporation, Alpine
Vermont	Doug Elliot, Dept of Environmental Conservation, Agency of Natural Resources, Waterbury John Miller, Dept of Environmental Conservation, Waterbury
Virginia	Dave Greer, Mobil Oil Corporation, Fairfax Nancy Williams, Dept of Environmental Quality, Richmond William Vehrs, Mobil Oil Corporation, Fairfax
Washington	William Green, Solid Waste Services, Dept of Ecology, Olympia Mike Porter, Partec Corporation, Vancouver David Stitzel, Stitzel Environmental Consulting, Seattle
Wisconsin	Andy Swartz, Recycling Section, Bureau of Solid and Hazardous Waste Management, Dept of Natural Resources, Madison

APPENDIX II

More Than You Ever Wanted to Know About Motor Oil

More Than You Ever Wanted to Know About Motor Oil

By **Ed Hackett**
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Choosing the best motor oil is a topic that comes up frequently in discussions between motorheads, whether they are talking about motorcycles or cars. The following article is intended to help you make a choice based on more than the advertising hype.

Oil companies provide data on their oils most often referred to as *typical inspection data*. This is an average of the actual physical and a few common chemical properties of their oils. This information is available to the public through their distributors or by writing or calling the company directly. I have compiled a list of the most popular, premium oils so that a ready comparison can be made. If your favorite oil is not on the list get the data from the distributor and use what I have as a data base.

This article is going to look at six of the most important properties of a motor oil readily available to the public: viscosity, viscosity index (VI), flash point, pour point, % sulfated ash, and % zinc.

Viscosity is a measure of the *flowability* of an oil. More specifically, it is the property of an oil to develop and maintain a certain amount of shearing stress dependent on flow, and then to offer continued resistance to flow. Thicker oils generally have a higher viscosity, and thinner oils a lower viscosity. This is the most important property for an engine. An oil with too low a viscosity can shear and lose film strength at high temperatures. An oil with too high a viscosity may not pump to the proper parts at low temperatures and the film may tear at high rpm.

The weights given on oils are arbitrary numbers assigned by the S.A.E. (Society of Automotive Engineers). These numbers correspond to *real* viscosity, as measured by several accepted techniques. These measurements are taken at specific temperatures. Oils that fall into a certain range are designated 5, 10, 20, 30, 40, 50 by the S.A.E. The W means the oil meets specifications for viscosity at 0°F and is therefore suitable for Winter use.

Figure AI.1 shows the relationship of *real* viscosity to their SAE assigned numbers. The relationship of gear oils to engine oils is also shown.

Multi viscosity oils work like this: Polymers are added to a light base (5W, 10W, 20W), which prevent the oil from thinning as much as it warms up. At cold temperatures the polymers are coiled up and allow the oil to flow as their low numbers indicate. As the oil warms up the polymers begin to unwind into long chains that prevent the oil from thinning as much as it normally would. The result is that at 100 degrees C the oil has thinned only as much as the higher viscosity number indicates. Another way of looking at multi–vis oils is to think of a 20W–50 as a 20 weight oil that will not thin more than a 50 weight would when hot.

Multi viscosity oils are one of the great improvements in oils, but they should be chosen wisely. Always use a multi grade with the narrowest span of viscosity that is appropriate for the temperatures you are going to encounter. In the winter base your decision on the lowest temperature you will encounter, in the summer, the highest temperature you expect. The polymers can shear and burn forming deposits that can cause ring sticking and other problems. 10W–40 and 5W–30 require a lot of polymers (synthetics excluded) to achieve that range. This has caused problems in diesel engines, but fewer polymers are better for all engines. The wide viscosity range oils, in general, are more prone to viscosity and thermal breakdown due to the high polymer content. It is the oil that lubricates, not the additives. Oils that can do their job with the fewest additives are the best.

Very few manufactures recommend 10W–40 any more, and some threaten to void warranties if it is used. It was not included in this article for that reason. 20W–50 is the same 30 point spread, but because it starts with a heavier base it requires less viscosity index improvers (polymers) to do the job. AMSOIL can formulate their 10W–30 and 15W–40 with no viscosity index improvers but uses some in the 10W–40 and 5W–30. Mobile 1 uses no viscosity improvers in their 5W–30, and I assume the new

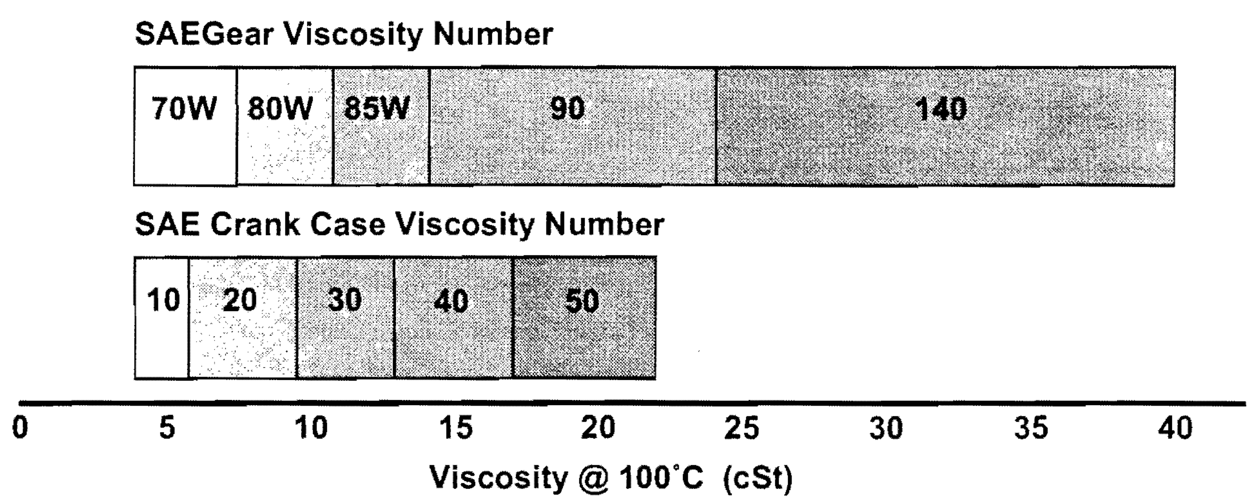


Figure AI.1 Relationship Between *the Real* Viscosity of Oils Greases and the SAE Viscosity Designations

10W–30. Follow your manufacturer's recommendations as to which weights are appropriate for your vehicle.

Viscosity Index is an empirical number indicating the rate of change in viscosity of an oil within a given temperature range. Higher numbers indicate a low change, lower numbers indicate a relatively large change. The higher the number the better. This is one major property of an oil that keeps your bearings happy. These numbers can only be compared within a viscosity range. It is not an indication of how well the oil resists thermal breakdown.

Flash point is the temperature at which an oil gives off vapors that can be ignited with a flame held over the oil. The lower the flash point the greater tendency for the oil to suffer vaporization loss at high temperatures and to burn off on hot cylinder walls and pistons. The flash point can be an indicator of the quality of the base stock used. The higher the flash point the better. 400°F is the minimum to prevent possible high consumption. Flash point is in °F.

Pour point is 5°F above the point at which a chilled oil shows no movement at the surface for 5 seconds when inclined. This measurement is especially important for oils used in the winter. A borderline pumping temperature is given by some manufacturers. This is the temperature at which the oil will pump and maintain adequate oil pressure. This was not given by a lot of the manufacturers, but seems to be about 20°F above the pour point. The lower the pour point the better. Pour point is in °F.

% sulfated ash is how much solid material is left when the oil burns. A high ash content will tend to form more sludge and deposits in the engine. Low ash content also seems to promote long valve life. Look for oils with a low ash content.

% zinc is the amount of zinc used as an extreme pressure, anti– wear additive. The zinc is only used when there is actual metal to metal contact in the engine. Hopefully the oil will do its job and this will rarely occur, but if it does, the zinc compounds react with the metal to prevent scuffing and wear. A level of .11% is enough to protect an automobile engine for the extended oil drain interval, under normal use. Those of you with high revving, air cooled motorcycles or turbo charged cars or bikes might want to look at the oils with the higher zinc content. More doesn't give you better protection, it gives you longer protection if the rate of metal to metal contact is abnormally high. High zinc content can lead to deposit formation and plug fouling. Table A1.1 presents data for several oils.

All of the oils listed in Table AI.1 meet current SG/CD ratings and all vehicle manufacture's warranty requirements in the proper viscosity. All are *good enough*, but those with the better numbers are icing on the cake. The synthetics offer the only truly significant differences, due to their superior high temperature oxidation resistance, high film strength, very low tendency to form deposits, stable viscosity base,

Table AII.1 Properties of Various Oils

Grade	Brand	Viscosity Index	Flash Point (°F)	Pour Point (°F)	% Ash	% Zinc
20W–50	AMSOIL (old)	136	482	–38	–	–
	Multi–Grade	110	440	–15	0.85	0.12
	Quaker State	121	415	–15	0.9	–
15W–50	Chevron	204	415	–18	0.96	0.11
	Mobil 1	170	470	–55	–	–
	Mystic JT8	144	420	–20	1.7	0.15
	Red Line	152	503	–49	–	–
5W–50	Castrol Syntec	180	437	–45	1.2	0.10
	Quaker State Synquest	173	457	–76	–	–
	Pennzoil Performax	176	–	–69	–	–
5W–40	Havoline	170	450	–40	1.4	–
15W–40	AMSOIL (old)	135	460	–38	0.85	0.13
	Havoline Formula 3	139	430	–30	1.0	––
	Kendall GT–1	139	390	–25	1.0	0.16
	Mobil 1	160	450	–65	–	–
	Pennzoil PLZ Turbo	140	410	–27	1.0	–
	Quaker State	156	410	–30	0 .9	–
	Red Line	139	475	–40	–	–
	Shell Fire and Ice	155	410	–35	0.9	0.12
	Shell Super 2000	155	410	–35	1.0	0.13
	Shell Truck Guard	155	405	–35	1.0	0.15
	Spectro Golden M.G.	175	405	–40	–	–
	Unocal Super	153	428	–33	0.92	0.12
	Valvoline All Climate	130	410	–26	1.0	0.11
	Valvoline Turbo	135	410	–26	0.99	0.13
	Valvoline Race	130	410	–26	1.2	0.20
	Valvoline Synthetic	140	450	–40	–	–

and low temperature flow characteristics. Synthetics are superior lubricants compared to traditional petroleum oils. You will have to decide if their high cost is justified in your application.

The extended oil drain intervals given by the vehicle manufacturers (typically 7500 miles) and synthetic oil companies (up to 25,000 miles) are for what is called normal service. Normal service is defined as the engine at normal operating temperature, at highway speeds, and in a dust free environment. Stop and go, city driving, trips of less than 10 miles, or extreme heat or cold puts the oil change interval into the severe service category, which is 3000 miles for most vehicles. Synthetics can be run two to three times the mileage of petroleum oils with no problems. They do not react to combustion and combustion by–products to the extent that the dead dinosaur juice does. The longer drain intervals possible help take the bite out of the higher cost of the synthetics. If your car or bike is still under warranty you will have to stick to the recommended drain intervals. These are set for petroleum oils and the manufacturers make no official allowance for the use of synthetics.

Oil additives should not be used. The oil companies have gone to great lengths to develop an additive package that meets the vehicle's requirements. Some of these additives are synergistic, that is the effect of two additives together is greater than the effect of each acting separately. If you add anything to the oil you may upset this balance and prevent the oil from performing to specification.

The numbers above are not, by any means, all there is to determining what makes a top quality oil. The exact base stock used, the type, quality, and quantity of additives used are very important. The given data combined with the manufacturer's claims, your personal experience, and the reputation of the oil among others who use it should help you make an informed choice.

APPENDIX III

Statements from Engine Manufacturers on the Use of Re–Refined Oils

Ford

Ford Motor Company position on engine oils made with re-refined base oils

Ford Motor Company does not specify the type of base oils to be used for engine oil meeting Ford's requirements. Regardless of the origin of the base oils, a non-Ford engine oil is acceptable for use if manufacturing and quality control practices ensure the oil continuously meets Ford's performance requirements.

Ford recommends using engine oil meeting Ford Specification ESE-M2C153-E and licensed as CERTIFIED FOR GASOLINE ENGINES by the AMERICAN PETROLEUM INSTITUTE (API Certification) Both virgin and re-refined engine oils are capable of meeting these requirements by qualifying against a series of rigorous tests designed to ensure their suitability for modern gasoline engines. While these tests confirm a specific sample of the oil qualifies with acceptable performance, it is the responsibility of the oil marketers to ensure that their products meet the requirements consistently and continuously.

In general, vehicle operation, adjustments and maintenance procedures, such as oil changes, performed contrary to recommended manufacturer specifications may, but do not automatically, void the applicable warranty. Each warranty claim is reviewed on its own merits If, however, the use of a non-Ford product causes or contributes to the failure of a Ford component, the cost of repairing the affected component is not covered by the Ford vehicle warranty. In such cases, the vehicle owner would have to look to the seller or installer of the non-Ford product for the replacement of the affected components and for any related damage to the vehicle.

Based on recent engine oil market surveys, Ford has concerns that some engine oils made with re-refined base oils may not consistently meet Ford's engine oil requirements. Test results show viscosity characteristics and low temperature performance of some engine oils made with re-refined base oils are unacceptable. However, there are other engine oils made with re-refined base oils which have met API Certification requirements and have met viscosity and low temperature characteristics.

Customers considering the use of engine oils made with re-refined base oils should be aware that the final product quality may vary if improper manufacturing controls are used. Marketers of engine oils made with re-refined base oils must adhere to standards for their base oils which ensure variations in re-refining processes or incoming raw materials do not adversely affect performance. In addition to a standard for the base oil properties, it is Ford's view that a re-refined oil produced with stringent manufacturing controls and batch to batch testing of low temperature viscosity performance and other significant characteristics would comply with Ford's recommendations.

FOR GASOLINE ENGINES CERTIFIED

Look for this
CERTIFICATION MARK

General Motors Position on Use of Re-refined Engine Oils

General Motors recommends for use in its vehicles engine oils which meet the performance requirements specified in the latest International Lubricant Standardization and Approval Committee (ILSAC) Minimum Performance Standard (currently ILSAC GF-1), and which are certified by the American Petroleum Institute for use in gasoline engines. Such oils may be identified in the marketplace by looking for the Certification Mark shown below on the front of the engine oil container.

Engine oils meeting these requirements can be made with either virgin or re-refined base oils. In both cases it is the oil marketer's responsibility to ensure that the product satisfies the performance requirements specified above both during initial product approval, and during the time that the product is being manufactured for sale. It is particularly important that steps be taken by marketers of engine oils made from re-refined base oils to ensure that variations in re-refining processes or raw materials do not adversely affect oil performance.

General Motors encourages the use of properly qualified re-refined products which consistently satisfy recommended performance requirements as a means of conserving vital petroleum resources. Use of re-refined products that have not been properly qualified or do not consistently meet performance requirements, however, could result in engine damage, and could harm the reputation of all re-refined products. Engine damage caused by the use of an engine oil which does not meet the recommended performance specifications may not be covered by the General Motors new vehicle warranty.

Look for this
Certification Mark

December 1, 1994

CHRYSLER CORPORATION

Chrysler Corporation

CHRYSLER CORPORATION
POSITION ON RE-REFINED ENGINE OILS

Chrysler Corporation supports all efforts leading to conservation of our natural resources and protection of the environment. Recycling of waste materials can be an effective way of accomplishing both of these objectives.

We recognize that used petroleum based lubricants are a problem if they are not disposed of properly. Appropriate recycling of these oils is desirable.

The primary purpose of engine oil is to protect the engine from harmful wear and deposits. The ability to perform these tasks is measured by Engine Sequence Tests and by bench tests. The American Petroleum Institute (API) has established a classification system that defines service quality categories based on performance of the oil in the Engine Sequence Tests (e.g., SG/CD).

The performance of the oil in these tests does not solely depend on the additive package, but rather on the additive package in the base oil. Changing the base oil (e.g., crude source, refinery process) will affect performance. There is great variability in both crude oils and in refining processes. The base oils, therefore, differ in composition and in response to the additives used to impart desired properties. A refinery that uses only one, or a limited number of crude sources, can be adjusted to produce a base oil that responds equivalently to a particular additive package, or an additive package can be tailored for each of the limited number of base oil types produced.

Due to the variety of base oils in the feedstream and to the widely different processes used to "re-refine" used engine oils, Chrysler can not endorse or condemn "re-refined oils." While some products have met current industry standards, others probably do not. There is, as yet, no qualification or identification system in place to identify consistently acceptable re-refined oils.

Chrysler currently recommends engine oils meeting the requirements of API Service Category SG or SG/CD and of SAE 5W-30 or 10W-30 for the gasoline engines it sells. If the oil is not of this quality, Chrysler may, at its option, not pay for repairs under the New Vehicle Warranty.

Chrysler is constantly reviewing the re-refined oil technology. As more information becomes available, Chrysler will review its recommendations.

DETROIT DIESEL

Service Information

NUMBER: 9-D-92 **S.M. REF.:** 13.3 **ENGINE:** 53, 71, 92 **DATE:** June 1992

SUBJECT: LUBRICATING OIL, FUEL, AND FILTER REQUIREMENTS FOR SERIES 53, 71, AND 92 DIESEL FUELED ENGINES

This bulletin identifies the type of fuels, lubricants, filters, and related maintenance intervals required for all Series 53, 71, and 92 diesel-fueled engines manufactured and marketed by Detroit Diesel Corporation. For a more detailed description of fuel, lubricating oil, and filter requirements, see publication "Engine Requirements–Fuel, Lubricating Oil, and Filters" (7SE 270), available from Detroit Diesel distributors.

Selection of the proper quality of fuel, lubricating oil and filters in conjunction with required oil and filter maintenance is required to achieve the long and trouble-free service which Detroit Diesel engines are designed to provide. Conversely, operation with improper fuels, lubricants, and filters can degrade engine performance and may void the manufacturer's warranty.

It is Detroit Diesel Corporation policy to build engines which will operate satisfactorily with fuels and lubricants generally available in the commercial market. However, not all fuels and lubricants are adequate. Product selection should be based on these requirements and in consultation with a reliable supplier who understands the equipment and its application.

Lubricating Oil Requirements

Hundreds of commercial oils are marketed today, but labeling terminology differs among suppliers and can be confusing. Some marketers may claim that their lubricant is suitable for all makes of diesel engines and may list engine makes and types, including Detroit Diesel, on their containers. Such claims by themselves are insufficient as a method of lubricant selection for Detroit Diesel engines.

The proper lubricating oil for all Detroit Diesel engines is selected based on SAE Viscosity Grade and API (American Petroleum Institute) Service Designation. Both of these properties are displayed in the API symbol which is illustrated within the specific requirements. For two-cycle Detroit Diesel engines, the proper lubricant must also possess a sulfated ash content below 1.0% mass. Refer to the following specific requirements.

Two-Stroke Cycle Engines
Detroit Diesel Series 53, 71, 92

Lubricant Requirements

API Symbol:

SAE Viscosity Grade: 40
API Classification: CF-2
Sulfated Ash: less than 1.0%

Lubricants meeting these criteria have provided maximum engine life when used in conjunction with recommended oil drain and filter maintenance schedules.

API Performance category CF-2 represents an enhanced level of lubricant performance over the CD-II category which it replaces. Lubricants meeting this new performance level may not be readily available for some time. During this interim period oils labeled as API CD-II may be used.

Only oils licensed by API should be used in Detroit Diesel engines. Certain engine operating conditions may require exceptions to these requirements:

1. For continuous high temperature operation (over 200°F or 94°C Coolant Out), the use of an SAE grade 50 lubricant in all two-stroke cycle engines is required.

2. At ambient temperatures below freezing (32°F or 0°C) sufficient starter cranking speed may not be achieved to start the engine with SAE 40 grade oils. Where starting aids are not available or at very cold temperatures (0 to -25°F or -18 to -32°C) even if starting aids are available, the use of multigrade SAE 15W-40 or monograde SAE 30 lubricants will improve startability. Multigrade SAE 15W-40 lubricants must possess a High Temperature - High Shear Rate Viscosity (measured by ASTM D 4741 or equivalent) of 3.7 cP minimum. **These oils must be replaced with monograde SAE 40 lubricants as soon as ambient conditions permit.**

   Exception: Do not use multigrade or SAE 30 grade lubricants in two-stroke cycle marine engines under any circumstances.

3. When the use of high sulfur fuel (greater than 0.5% mass) is unavoidable, the use of lubricants with higher alkalinity is recommended. Be aware that such lubricants may have a sulfated ash content above 1.0% mass. The use of high sulfur fuels also requires modification to oil drain intervals. For further information refer to section "The Use of High Sulfur Fuels" on page 6.

4. The use of multigrade and/or greater than 1% sulfated ash oils are exceptions for special circumstances. The use of such lubricants under normal circumstances may not provide satisfactory service.

Sulfated Ash and Total Base Number

Sulfated ash is a lubricant property obtained by a laboratory test (ASTM D 874) to determine the potential for formation of metallic ash. The ash residue is related to the oil's additive composition and is significant in predicting lubricants which may cause valve distress under certain operating conditions. Sulfated ash is related to Total Base Number (TBN), also a laboratory test (ASTM D 2896 or D 4739) which measures an oil's alkalinity and ability to neutralize acid. As TBN increases, sulfated ash also increases to where lubricants with TBN's above 10 will likely have sulfated ash contents above 1.0% mass.

Total Base Number is important to deposit control in four-stroke cycle diesel engines and to neutralize the effects of high sulfur fuel in all diesel engines. For two-stroke cycle engines Detroit Diesel recommends lubricants with a sulfated ash content below 1.0% mass and TBN's between 6 and 10 for engines operating on less than 0.5% sulfur fuel.

When the use of a high ash oil is required, such as with high sulfur fuel, the oil selected should have the highest TBN (D 4739) to Ash (D 874) ratio possible. For example, an oil with a TBN of 10 and an Ash of 1.2% mass is less desirable than an oil with the same TBN and 1.0% Ash. Also refer to the section on "Oil Changes" (pages 5 and 6).

Synthetic Oils

Synthetic oils may be used in Detroit Diesel engines provided they are API licensed and meet the performance and chemical requirements of non-synthetic oils outlined in this publication. Synthetic oils offer improved low temperature flow properties and high temperature oxidation resistance. However, they are generally more costly than non-synthetic oils.

Product information about synthetic oils should be reviewed carefully. Performance additive systems often respond differently in synthetic oils. Only synthetic oils that do not contain viscosity improver additives may be used in Detroit Diesel two-stroke cycle engines. Their use does not permit extension of recommended oil drain intervals.

Marine Lubricants, Railroad Diesel Lubricants

The petroleum industry markets specialty lubricants for diesel engines designed specifically for marine propulsion or railroad locomotive use. These oils are characterized by their high TBN and the absence of magnesium and zinc in their composition. These lubricants take into consideration the unique environments and operational characteristics of this type of duty, and consequently, they are formulated quite differently from the types of lubricants specified by Detroit Diesel.

Marine and railroad lubricants may be used in two-stroke cycle engines provided they are SAE 40 viscosity grade and API CD-II (CF-2 when available). These oils may be selected for use when one of the following situations exists:

1. They are required in other equipment and only a single engine lubricant can be inventoried.
2. Where a high sulfur fuel is anticipated and there is a risk of resulting valve distress.

Specific product selection should be based on demonstrated performance provided by the oil supplier.

The Use of Supplemental Additives

Lubricants meeting the Detroit Diesel specifications outlined in this publication already contain a balanced additive treatment. The use of supplemental additives such as break-in oils, top oils, graphitizers and friction-reducing compounds, are generally not necessary and can even be harmful. These additives may be marketed as either oil treatments or engine treatments and are discouraged from use in Detroit Diesel engines. *Engine damage resulting from the use of such materials is not covered by your Detroit Diesel Corporation warranty.* Detroit Diesel will not provide statements beyond this publication relative to their use.

Lubricant Selection Worldwide

Although the API service classification system is generally utilized worldwide, lubricants meeting Detroit Diesel requirements may not be marketed in all areas of the world. Selection of lubricants in these situations should be made based on viscosity grade first, ash content second, and performance specification third. Oils meeting API CD or CC may be used if they also meet military specification Mil-L-2104 D or E. Oils which meet European CCMC D4 may also be used. Modification of oil drain interval may be necessary, depending on fuel quality. Contact Detroit Diesel Corporation for further guidance.

Waste Oil Disposal and Rerefined Oils

With over one billion gallons of waste oil generated annually in the U.S. alone, disposal of waste oil has become a serious environmental concern. Rerefining waste oils provides an environmentally viable way of handling this material. Several states have established collection and recycling programs. A few states have also designated used oil as a hazardous waste requiring special handling and disposal. Detroit Diesel favors the recycling of waste oil and permits the use of rerefined oils in all engine product lines, provided the rerefined oils meet the SAE Viscosity and API specifications previously mentioned.

Oil Changes

During use, engine lubricating oil undergoes deterioration from combustion by-products and contamination by the engine. Certain components in a lubricant additive package are designed to deplete with use. For this reason, regardless of the oil formulation, regular oil drain intervals are necessary. These intervals may vary in length, depending on engine operation, fuel quality, and lubricant quality. Generally, shorter oil drain intervals extend engine life through prompt replenishment of the protection qualities in the lubricant.

The oil drain intervals listed in the following tables should be considered **maximum** and should not, under any circumstances, be exceeded. Always install new engine oil filters when the oil is changed.

MAXIMUM ALLOWABLE OIL DRAIN INTERVALS Series 53, 71, 92 (Normal Operation)	
Service Application	**Oil Drain Interval**
Highway Truck & Motor Coach	15,000 Miles (24,000 km)
City Transit Coaches	6,000 Miles (9,600 km) or 1 month*
Pick-up & Delivery, Stop & Go, Short Trip	12,000 Miles (19,000 km)
Industrial, Agricultural and Marine	150 Hours
Stationary Units Continuous	300 Hours or 1 Month*
Stationary Units Standby	150 Hours or 1 Year*

* Whichever comes first

The Use of High Sulfur Fuels

The combustion of high sulfur fuels (greater than 0.5% sulfur) will shorten engine life through accelerated wearout of piston rings. High fuel sulfur forms acids during combustion, particularly during idling and low temperature operation. The best defense against the effects of high sulfur fuel is to shorten oil drain intervals. The proper drain interval may be determined by oil analysis or by using the table below. A reduction in TBN (ASTM D 4739) to one-third of the initial value provides a general drain interval guideline.

Should it be determined that the oil drain interval is unacceptably short, then the selection of a lubricant with a Total Base Number (TBN per ASTM D 2896) above 10 may be appropriate. Experience has shown, however, that a higher TBN oil with a longer oil change interval is not as effective in protecting the engine from wear. The table below should be used until the best practical oil drain interval can be established by oil analysis.

SUGGESTED MAXIMUM OIL DRAIN INTERVALS
Series 53, 71, 92—Fuel Sulfur Above 0.5%
(Use oil analysis to determine optimum drain interval)

Service Application	Oil Drain Interval TBN (D 2896) Above 10
Highway Truck & Motor Coach	10,000 Mi. (16,000 kM)
City Transit Coaches	4,000 Mi (6,400 kM) or 1 Month Maximum*
Pick-up & Delivery, Stop & Go, Short Trip	8,000 Mi (12,500 kM)
Industrial, Agricultural and Marine	150 Hrs or 1 Year Maximum*
Stationary Units Continuous	150 Hrs or 1 Month Maximum*
Stationary Units Standby	100 Hrs or 1 Year Maximum*

* Whichever comes first

Service Bı ·tln

Subject: CUMMINS ENGINE OIL RECOMMENDATIONS

Bulletin No 3810340-01 | Date December, 1992

CONTENTS:

Cummins Engine Company, Inc., Columbus, Indiana 47202-3005
Cummins Engine Company Ltd., Daventry Northants, England NN11 SNU
Registered Office: 46-50 Coombe Road New Malden, Surrey KT3 4QL
Registered No. 573951 England

Form 5

DIESEL ENGINE OIL RECOMMENDATIONS

Cummins Engine Company, Inc. recommends the use of SAE 15W-40 heavy duty diesel engine oil.

These oils must meet American Petroleum Institute (API) performance categories of CE, CF-4, CE/SG, CF-4/SG. Consult your Operation and Maintenance manual to determine the performance category of oil which should be used in your specific engine. CE/SF performance category oils as well as CC and CD categories can be used in areas of the world outside of North America where oils meeting the current API categories are not available, but if used they must be changed at one half the normally recommended service intervals.

The oil supplier is primarily responsible for the quality and performance of his product.

Cummins Engine Company, Inc. recommends engine oil with a nominal ash content of 1 to 1.5 percent mass. Oils with higher ash contents, up to 1.85 percent mass, can be used in areas where the sulphur content of the fuel is normally 1 to 1.5 percent mass. Ash content is critical to the prevention of valve and piston deposit formation.

The primary recommendation is for multigrade oil of the viscosity grade indicated in Table 1, Page 4. For normal ambient temperature operating conditions (temperatures above -18°C [0°F]) SAE 15W-40 is preferred. The use of multigrade oils reduces deposit formation, improves engine cranking in low temperature conditions and increases engine durability by maintaining lubrication during high temperature operating conditions. Since multigrade oils have been shown to provide approximately 30 percent lower oil consumption, compared with monograde oils, it is important to use multigrade oils in order to ensure your engine will meet its emissions requirements. While the preferred viscosity grade is 15W-40, lower viscosity multigrades can be used in colder climates. Refer to Table 1. However, use 15W-40 as soon as the ambient temperature conditions will permit.

Synthetic engine oils, API category III, are recommended for use in Cummins engines operating in ambient temperature conditions consistently below -25°C [-13°F]. Above this temperature it is recommended that mineral oil based multigrade lubricants be used.

Rerefined lubricating oils may be used in Cummins engines if they have an API quality designation signifying they have been tested and meet the minimum standards for that quality level. It is important to be certain these oils are actually rerefined and not just reclaimed. Rerefined oils have been treated to remove additive and wear metal debris, distilled and finally refortified with additives.

Friction modified oils must not be used in Cummins diesel engines unless the oil supplier can provide evidence of satisfactory performance. If there is any doubt about the suitability of the oil, consult your oil supplier to obtain data to establish that the oil has performed satisfactorily in Cummins engines. Obtain the supplier's commitment that they will work with you to make sure the oil is satisfactory, or do not use the product.

Special "break-in" oils are not recommended for use in new or rebuilt Cummins engines. Use the same lubricating oils that will be used in normal engine operation.

Correct oil and filter change intervals must be maintained for each specific Cummins engine model. A sharp increase in component wear and damage can occur if the drain interval is extended beyond the recommended change guidelines.

Use of the full flow engine oil filter is mandatory on all Cummins diesel engines. Except for B Series engines, bypass filters are mandatory on all turbocharged engines and are recommended for naturally aspirated engines. The alternative recommendation is to use a combination filter that meets both the specified full flow and bypass standards.

NATURAL GAS ENGINE OIL RECOMMENDATIONS

The use of quality engine oils combined with appropriate oil drain and filter change intervals is a critical factor in maintaining engine performance and durability.

Cummins Engine Company, Inc. recommends the use of a high quality SAE 15W-40 heavy duty engine oil for natural gas engines.

The specification meeting Cummins' recommended 15W-40 oil blends are as follows:

API CD Quality
SAE 15W-40 Viscosity
Less than 0.5% Sulfated Ash
250 to 350 PPM Phosphorous
250 to 350 PPM Zinc
1200 PPM Calcium
TBN (ASTM D2896) - 5 to 5.5
TAN (ASTM D664) - 0.5 to 0.7

A sulfated ash limit of 0.5 percent mass has been placed on all engine lubricating oils recommended for use in Cummins natural gas engines. Higher ash oils can cause valve and/or piston damage, and lead to excessive oil consumption and degradation of the catalyst.

FUNCTION OF ENGINE OIL

If an oil is to serve the engine adequately, it must perform these functions:

Lubrication:
The primary function of the engine oil is to lubricate moving parts. The oil forms a film between metal surfaces preventing contact and reducing friction. Preventing moving metal to metal contact is the most important function of lubricating oil. A failure to lubricate can permit such rapid engine destruction that any other potential capability of the oil will not have sufficient time to perform its function. When moving metal parts are allowed to come in contact, the following occurs:

- Heat is generated through friction.
- Local welding occurs.
- Metal transfer results in scuffing or seizing.

Cleaning:
Oil acts as a cleaning agent in the engine by flushing contaminants from critical components. Sludge, varnish and oxidation buildup on the pistons, rings, valve stems, and seals will lead to rapid engine failure if not controlled by the oil. An oil formulated with the optimal additives will hold these contaminants in suspension until removed by the oil filtration system or during the course of an oil change.

Protection:
Oil provides a protective barrier, isolating non-like metals to prevent corrosion. Corrosion, like wear, results in the removal of metal from engine parts. Corrosion works like a slow acting wear mechanism.

In addition, modern diesel engines are designed around a reliance on the lubricating oil to perform various non-lubricating functions.

Cooling:
Engines require the cooling of internal components the primary cooling system cannot provide. The lubricating oil provides an excellent heat transfer media. Heat is transferred to the oil through contact with various components then transferred to the primary cooling system at the oil cooler.

Sealing:
Oil acts as a combustion seal filling the uneven surfaces of the cylinder liner, piston, valve stem, and other internal engine components.

Shock - Dampening:
The oil film between contacting surfaces provides cushioning and shock-dampening. The dampening effect is essential to highly loaded areas such as the bearings, pistons, connecting rods, and gear train.

Hydraulic Action:
Oil acts as a working hydraulic media within the engine. Examples of this are the use of oil to operate engine brakes and STC injector tappets.

Engine oil must be formulated in such a manner that it does not foam as a result of the mechanical agitation associated with its many functions. Foaming results in the overfilling of the sump as well as subjecting various heavily loaded surfaces to temporary oil starvation.

VISCOSITY

Viscosity is a measure of the resistance offered when one layer of oil moves relative to an adjacent layer. The resistance comes from the friction generated by the oil molecules as they move past each other. This shearing action occurs constantly in the oil films lubricating all moving parts of an engine.

The viscosity characteristics of all fluids are affected by temperature. Multigrade oil viscosities tend to be less sensitive to temperature changes due to the addition of viscosity enhancements in their formulation. The viscosity of multigrade oils is also a function of their rate of shear, or the relative speed of moving parts. The lower the relative speed, the greater the apparent viscosity of most multigrade oils.

Oils have traditionally been selected for use with viscosities appropriate for the expected operating temperature which often required the use of very heavy engine oils. Most of the wear an engine ordinarily experiences occurs at initial startup in some applications before oil has time to fully circulate.

The correctly formulated multigrade oil is the ideal engine lubricant for a heavy duty diesel engine. Relatively thin oil is available for rapid lubrication and easy cranking while starting. To combat oil consumption, multi-viscosity oils exhibit higher viscosity in the piston ring grooves which blocks this leakage path, and lower viscosity at the liner wall which results in better ring wiping action. The overall result is less oil reaching the high temperature zone where deposits can form, and cause excessive oil consumption.

Oil Viscosity and Engine Performance:
The selection of oil of the correct viscosity is extremely important for performance and for engine life. If the oil is too viscous, engine drag is increased with the following effects:

- Engine hard to start.
- Engine power output reduced.
- Engine cooling reduced.
- Internal wear increased.
- Engine parts run hotter.
- Increased fuel consumption

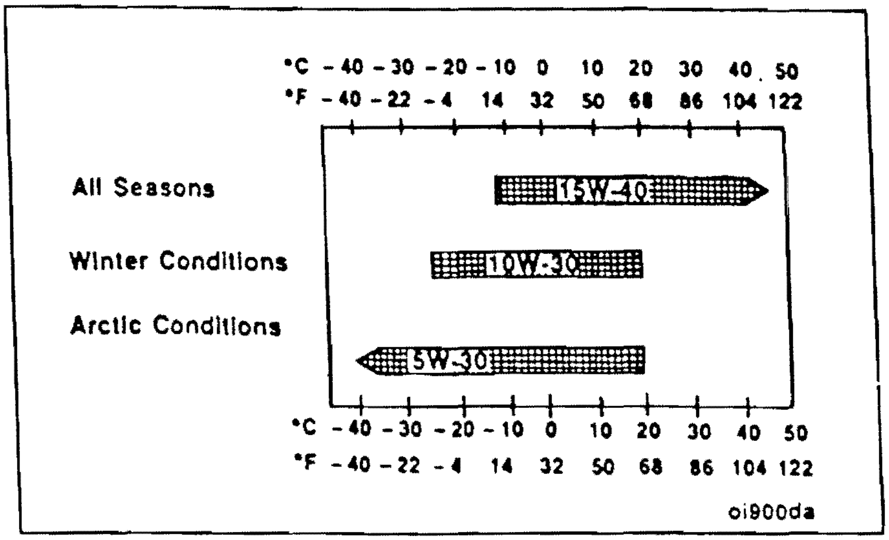
If the oil is too thin, the engine experiences:
- Increased wear-increased metal to metal contact.
- Increased oil consumption and leakage.
- Increased engine noise.

Viscosity Recommendations:
Cummins Engine Company, Inc. recommends the use of multigrade lubricating oils with viscosity grades shown in Table 1 for the ambient temperatures indicated. Only the preferred oil grades are those shown in the table. Single grade oils can be substituted for multigrade in areas where multigrades are not currently available.

Caution: When single grade oil is used, make sure the oil will be operating within the temperature ranges indicated in Table 2, and will be drained at one half the normally recommended service interval.

The Society of Automotive Engineers (SAE) has developed a system of classifying engine oils by viscosity grades. Table 3 indicates the viscosity ranges for those grades.

Table 1: Cummins Recommended SAE Oil Viscosity Grades vs. Ambient Temperatures*



NOTE: Limited use of low viscosity oils, such as 10W-30 may be used for easier starting and providing sufficient oil flow at ambient temperatures below -5°C [23°F]. However, continuous use of low viscosity oils can decrease engine life due to wear. Refer to the Table 1.

Table 2: Alternate Oil Grades

10W	-20°C to -6°C	[-4°F to 20°F]
20W	-10°C to 20°C	[14°F to 68°F]
30	4°C to 32°C	[39°F to 90°F]
40	10°C and above	[50°F and above]

Table 3: SAE Viscosity Grades for Engine Oils J300 (1992 Handbook)

SAE Viscosity Grade	Low Temperature Viscosities		High Temperature Viscosities		
	Cranking (cP)	Pumping (cP)	Kinematic (cSt) at 100°C [212°F]		High-Shear (cP) at 150°C [302°F] $10^6 s^{-1}$
	Max	Max with No Yield Stress	Min	Max	Min
0W	3250 at -30	30 000 at -35	3.8	—	2.4
5W	3500 at -25	30 000 at -30	3.8	—	2.9
10W	3500 at -20	30 000 at -25	4.1	—	2.9
15W	3500 at -15	30 000 at -20	5.6	—	3.7
20W	4500 at -10	30 000 at -15	5.6	—	3.7
25W	6000 at - 5	30 000 at -10	9.3	—	3.7
20	—	—	5.6	<9.3	—
30	—	—	9.3	< 12.5	—
40	—	—	12.5	< 16.3	—
50	—	—	16.3	<21.9	—
60	—	—	21.9	<26.1	—

NOTE: 1 cP = 1mPa•s; 1 cSt = 1mm²/s

Oils that meet the low temperature viscosity specifications are identified by a "W" (winter) designation. Oils that meet only the 100°C [212°F] requirements have no suffix. Oils that meet both the high and low temperature requirements are referred to as multigrade or multi-viscosity oils.

The viscosity of multigrade oils is also a function of their rate of shear or the relative speed of moving parts. The lower the relative speed, the greater the apparent viscosity of most multigrade oils. High shear/high temperature viscosity measures the viscosity characteristics of the oil under conditions similar to those experienced by the oil in an operating engine.

The Engine Manufacturers Association (EMA) publishes a book entitled "Lubricating Oils Data Book." Copies of this publication can be purchased from the Engine Manufacturers Association, 111 East Wacker Drive, Chicago, Illinois 60601. This publication lists commercially available oils by oil company and brand with the API performance categories and other technical data on each brand.

Synthetic Engine Oils:
Synthetic oils are blended from synthesized hydrocarbon and/or ester base oils. These base oils are manufactured by chemically reacting lower molecular weight materials to produce lubricants with the desired properties.

Synthetic oil was developed for use in extreme environments where the ambient temperature can be as low as -45°C [-50°F]. Under these extreme conditions, petroleum base oils will not perform satisfactorily in diesel engines.

Cummins Engine Company, Inc. recommends synthetic engine oil only for use at ambient temperatures consistently lower than -25°C [-13°F]. All oils must meet API category III classification and SAE viscosity grades.

Cummins Engine Company, Inc. recommends that the same oil change interval be observed for synthetic engine oils that are applied to petroleum based (mineral) engine oils.

OIL PERFORMANCE CLASSIFICATION

Performance Recommendations:
Cummins Engine Company, Inc. recommends the use of engine oils designed to meet the following API categories:

CE, CF-4, CE/SG, or CF-4/SG.

Dual categories are used where more protection is required than which is offered by a single category. For example, CF-4/SF indicates the oil has been formulated to meet the performance level required of each single category.

Cummins engine Company, Inc. has found that overhead wear in high soot applications can be significantly reduced by using oils which successfully pass the Cummins High Soot Test. Contact your oil supplier to obtain the 14L high soot test results for your oil.

The API, SAE, and the American Society for Testing and Materials (ASTM) have jointly developed and maintained a system for classifying lubricating oils by performance categories. The following are brief descriptions of some of the API categories used in oil performance recommendations:

- CE Oils of this category are formulated to be used in certain turbocharged heavy duty diesel engines manufactured since 1983, and operated under both low speed/high load and high speed/high load conditions.
- CF-4 Oils assigned to this category provide improved control of oil consumption and piston deposits relative to CE oils.
- SG Oils of this category are formulated for use in engines powering passenger cars, vans and light duty trucks. These oils provide improved control of engine deposits, oil oxidation and engine wear relative to oils developed for previous categories. They also provide protection against rust and corrosion.
- CB These oils are usually referred to as Supplement 1 oils. Oils assigned to this category meet the requirements of obsolete military specifications MIL-L-2104A where the diesel engine test was run using fuel with a high sulphur content. These oils were intended for moderate duty service. Oils of this performance category are not recommended for use in Cummins engines.

Cummins Engine Company, Inc. recommends the use of high quality SAE 15W-40 CE, CF-4, CE/SG or CF-4/SG heavy duty diesel engine lubricating oils. Oils such as 'Premium Blue' or its equivalent will provide improved engine durability relative to the average CE or CF-4 oil.

CC and CD category oils can be used in areas where CE and CF-4 oils are not currently available, but they must be drained at one half the normally recommended service interval.

OIL CONTAMINATION

The engine oil should be changed when it can no longer adequately perform its intended functions within an engine. Technically oil does not wear out, but it does become contaminated. Additives deplete to the point that the oil and additive combination can no longer satisfactorily protect the engine. Progressive contamination of the oil between drain intervals is normal, and can vary as a function of engine operation and the load factor involved.

Oil Contaminants:
In normal diesel engine operation a wide variety of contaminants are introduced to the lubricating oil. These include:

1. Combustion by-products (exhaust gases or blowby gases) that leak past the piston rings, valve guides and turbocharger seals into the crankcase. These gases contain particles of carbon, water, acids, partially burned fuels, varnish and lacquers, all of which contaminate the oil.
2. Acids, varnish and sludge. As the lubricating oil comes in contact with hot engine components, or when heated oil comes in contact with entrapped air, oxidation and decomposition occur creating contaminants such as acids, varnish and sludge.
3. Abrasives or foreign material can enter the engine through the combustion air, fuel, worn engine parts and inadequate service practices. They find their way to the crankcase with the combustion by-products.
4. Fuel dilution or coolant contamination generally associated with engine malfunction. Fuel dilution, however, can be caused by excessive engine idling or stop-and-go operation.
5. Soot is caused by retarded injection timing, and burning fuel mixing with oil on the liner. Soot causes abnormal valve and injector train wear.
6. Other contaminants introduced by the specific operating environment, for example, dust and abrasives such as grit and road salt.

Oil Additives:
Lubricating oil is formulated with additives designed to combat the specific contaminants listed in the previous section throughout its usable life. The additives used are more important to overall engine performance than the oil itself. Without additives, even the highest quality oil will not be able to satisfy engine requirements. Additives include:

1. Detergents or dispersents which keep insoluble matter in suspension until such time that the oil is changed. They are not removed by the oil filtration system. Excessively long oil drain intervals result in sludge and carbon deposit formation in the engine.
2. Inhibitors that maintain the stability of the oil, prevent acids from attacking metal surfaces and prevent rust formation during periods when the engine is not in operation.

3. Other lubricating oil additives assist the oil in lubricating highly loaded areas of the engine (such as valves and injector train), prevent scuffing and seizing, control foaming, and prevent air retention in the oil.

Friction Modifiers:
There are generally two ways of improving engine oil frictional characteristics. One of these involves adjustments in oil viscosity or viscosity temperature characteristics. A second consists of including additives in the oil formulation which modify the metal surface frictional characteristics. These additives are known as friction modifiers.

The performance of the chemical additives used to change surface frictional characteristics is influenced by the engine materials, the loads the part will carry, the oil contaminants introduced by the blowby process and the operating temperatures.

There is firm evidence that certain friction modifiers, molybdenum dithiophosphate for example, can in certain formulations result in cam follower roller pin failure at relatively low mileage. Although other friction modifiers or formulations are not necessarily harmful, there is no definitive way to make certain oil performance is satisfactory other than running the oil in the engine.

While friction modifiers, such as graphite, can reduce friction by plating the working surfaces of an engine, there is a high probability of these chemicals dropping out on the filtering media. If this occurs, it can result in plugging of the filter and other associated problems.

Cummins Engine Company, Inc. neither approves nor disapproves of any additives not manufactured or sold by Cummins or its subsidiaries. Engine failure or performance problems which result from the use of such additives are not warrantable by Cummins Engine Company, Inc.

OIL FILTRATION

Maximum engine life is dependent upon the correct use and maintenance period of full flow, bypass or combination lubricating oil filters that protect vital engine components from the abrasive contaminants which are held in suspension in the lubricating oil. Cummins Engine Company, Inc. requires the use of full flow filters on all of its engine models.

Except for B Series models, bypass filters are mandatory on all turbocharged engines and are strongly recommended for use on all naturally aspirated engines.

The full flow filter will remove contaminant particles of 30 microns and larger which can be suspended in the bearing damage

The bypass filter receives approximately ten percent of the total pump output, filters it, and returns it to the oil pan. The purpose of the bypass filter is to remove the smaller abrasive particles, down to ten microns, which the full flow filter does not capture, and to maintain the oil contaminant concentration at a level low enough to prevent engine wear.

Many Cummins engines use a combination lubricating oil filter which contains both a full flow and a bypass filter in one filter can.

Filter Plugging:
During normal engine operation, the engine oil becomes contaminated from the combustion process as well as from wear debris and oxidation products. Engine oil filters do not plug as long as the engine oil remains suitable for use in an engine. A filter that plugs is performing its intended function of removing particulate matter from the oil. Filter plugging is the result, not the cause, of an engine or lubricating oil problem.

There are several types of filter plugging. The most frequently observed are:

Excessive Oil Contamination - This occurs when the oil's limit for handling combustion contaminants is exceeded. Filters plugged in this way have a heavy buildup of loosely held sludge. This type of contamination is caused by fuel soot, oxidation products, and products of combustion which have accumulated in the oil to the point that the filter is no longer able to function. Causes of this type of plugging include excessive oil change intervals, poor maintenance practices, and high blowby.

Impaired Dispersancy - This is caused by coolant leaks into the crankcase, or a buildup of condensed moisture. This moisture impairs the operation of the oil's dispersant, so that fuel soot and carbon cling together and dropout takes place. Coolant or moisture in the crankcase can also cause part of the oil's additive package to precipitate from the oil and plug the filter.

Gel or Emulsion Formation - This is a form of plugging caused when water or coolant contaminates oil. It often occurs when oil in a bulk storage tank contains a small amount of water, less than 0.5 percent. Filter plugging can take place rapidly after such oil has been added to the engine.

OIL CHANGE INTERVAL

Cummins Engine Company, Inc. bases its oil drain specifications on oil contamination. This contamination occurs in all diesel engines at varying

Maintaining the correct oil and filter change interval is a vital factor in preserving the integrity of an engine. Filters must be changed when the oil is changed.

Oil contamination is the direct result of normal engine operation, the load factor involved, the fuel used, and the environmental conditions. Laboratory and field tests confirm there is a positive relationship between the amount of fuel consumed by an engine, and the level of contamination generated in its oil system. Oil has limitation on the amount of contamination it can absorb and still function as designed. The relationship between fuel consumption and oil contamination forms a basis of establishing the oil change interval.

Acceptable methods for determining lubricating oil and filter change intervals include:

- Fixed Method (Mileage/Hours)
- Chart Method (Alternate Method)

Note: The chart method does not apply to all Cummins engines. The appropriate Operation and Maintenance manual should be consulted for detailed instructions and specific charts.

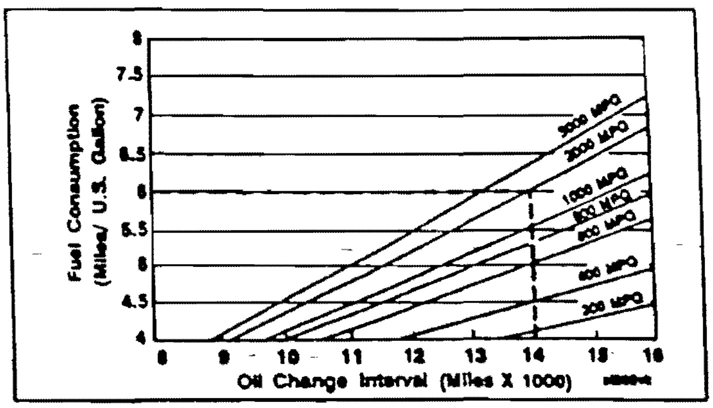
Fixed Method (Mileage / Hours):
This information is documented in the Operation and Maintenance manual for your specific engine model.

Chart Method (Alternate Method):
The chart method for calculating oil drain intervals allows for establishing individual baseline oil drain intervals. Since engines and applications are different, the rate at which they consume fuel and, therefore, the rate at which lubricating oil contamination levels are generated will also differ. In order to calculate oil drain intervals using the chart method, it is necessary to consider the application, fuel and oil consumption rates, and the actual lubricating system capacity of the specific engine model.

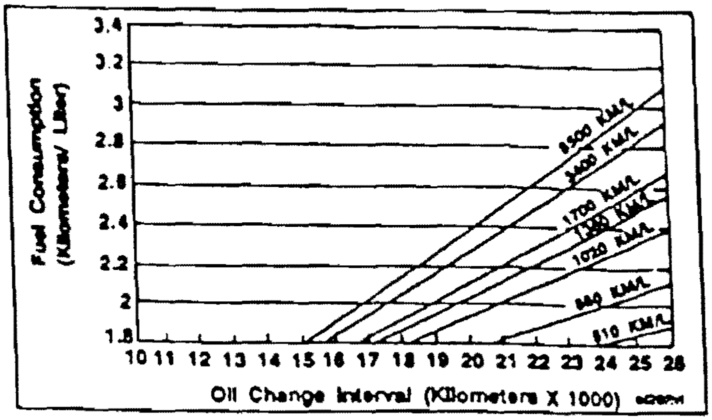
Chart Method Example:
The following example demonstrates the use of the chart method in determining the recommended oil change interval. Consult your Operation and Maintenance manual for the chart that applies to your specific engine. The chart below is used for the example given on the next page. A metric chart is also included on the next page.

Table 5: Chart Method Example

OIL DRAIN INTERVAL CHART - U.S. STANDARD



OIL DRAIN INTERVAL CHART - METRIC



Assume the average fuel consumption for the engine is 6.0 miles per gallon, and the average oil consumption is 2,000 miles per quart. The chart needs to be applied in the following manner:

1. The vertical axis represents fuel consumption (fuel economy) in miles per gallon. The horizontal axis represents the recommended oil change interval in miles X 1,000.

2. Draw a horizontal line across the chart from the point representing fuel consumption of 6.0 miles per gallon until it intersects with the curve representing oil consumption of 2,000 miles per quart.

3. From the intersection point established in (2) above, draw a perpendicular line downwards until it reaches the horizontal axis of the chart. The numbers across the horizontal axis represent the change interval in miles X 1,000.

4. In this example the perpendicular line intersects the horizontal axis at 14. This process will yield a recommended oil change interval of 14,000 miles. The oil change interval cannot be extended beyond the limits of the horizontal axis on the chart (16,000 miles in this example).

Caution: A sharp increase in engine component wear will occur if the oil drain interval is extended beyond the safe limit. If the drain interval is extended beyond the safe limits as calculated by the chart method, the oil's additive package will be depleted.

Chart Method - Fleet Application:
The chart method needs to be tailored to the requirements of a fleet operation as it is not practical to have a different oil change interval for each engine in a fleet. Cummins recommends that fleets employ the chart method in the following manner:

1. The fleet must first be divided by engine model (engines with the same lubricating oil system capacity), rated horsepower, and type of service. The horsepower range of any group **must not** exceed 25 HP. For example, a L10-310 and a L10-330 can be in the same group, while a L10-260 and a L10-310 cannot be placed in the same group.

2. Determine the average fuel consumption rate for all the engines in each group or sub-group as established by (1) above.

3. Select an appropriate fuel consumption figure that is approximately halfway between the average fuel consumption rate and the highest fuel consumption rate in the group.

4. Determine the average oil consumption rate for all the engines in the group.

5. Select a group lubricating oil consumption rate that is halfway between the average consumption rate and the lowest consumption rate in the group.

6. Use the appropriate chart for each engine group using the fuel consumption rate determined in (3) and the lubricating oil consumption rate determined in (5). Apply the change interval determined in this manner to the entire group.

7. Most large fleets will have more than one group of engine models. In this case a different change interval will be necessary for each group.

8. From a practical standpoint the fleet maintenance manager should review the recommended oil change interval for each engine group and sub-group in his fleet. The fleet maintenance manager should consider the oil change interval, preventative maintenance schedule, and past maintenance practices to select an oil change interval that is the best compromise for the fleet.

APPENDIX IV

Questionnaire Sent to Each TxDOT District

Re–Refined Oil and Used Oil Questionnaire

Please provide all information requested below and any additional comments relevant to the use of re–refined lubricating oil and fluids or to the disposal of used oil and fluids. Return the completed questionnaire to:

Professor Atila Ertas
Mechanical Engineering Department
Texas Tech University
Box 41021
Lubbock, TX 79409–1021

Phone (806) 742–3563
FAX (806) 742–3540

District number ______________

Person completing questionnaire: ______________________________
Telephone ( ) – ______________ FAX ( ) – ______________
E–Mail ______________________________

Other persons we should contact: ______________________________
Telephone ( ) – ______________ FAX ( ) – ______________
E–Mail ______________________________

DISPOSAL OF USED OIL SECTION

Total used engine oil generated each month? ______ gals

Total used hydraulic fluid generated each month? ______ gals

Total other recyclable fluids generated each month? ______________ ______ gals

Company that picks up used fluids? ______________________________
Representative ______________________________
Address ______________________________
____
Telephone ( ) – ______________ FAX ( ) – ______________

Is pick up service by contract or *as necessary*? ______________________________

How much does the pick up service cost?
Service pays $_______ per gallon or District pays $_______ per gallon

How often (average if necessary) are fluids picked up? ______________________

Are the used fluids tested before they are picked up? Yes _______ No _______

What do they test for? ______________________________ (if known)

Has the pick up service ever refused to take used oil (or other fluid)? Yes ______ No ______

If *yes*, why was oil pick up refused? ______________________________

____

____

Have you had any problems disposing of used fluids? (use additional pages as necessary)

____

____

____

Are used oil filters crushed/drained to recover additional recyclable oil? Yes _____ No _____

How are used oil filters disposed of? ______________________________

____

____

Do you know how the used oil is used after it is picked up? Yes _______ No _______

Is it made into re–refined oil? Yes _______ No _______

Is it made into fuel oil and asphalt? Yes _______ No _______

Do you have any comments or suggestions about the subject of used oil disposal? (use additional pages as necessary) ______________________________

____

____

USE OF RE–REFINED OIL SECTION

Is your District regularly using re–refined oil in it's vehicles? Yes ________ No ________

If *no* would you briefly explain why. (poor availability, bad experiences, etc.) (use additional pages as necessary) ______________________________

____

____

Are oil changes performed in–house or by a service? In–house _______ Service _______

If you use a commercial service for oil changes

Does service require or use re–refined oil? Require ____ Use ____ Does not use ____

Service re–refined oil policy ______________________________

____

Service (if not in–house) ______________________________

Representative ______________________________

Address ______________________________

____

Telephone ( ) – __________ FAX ( ) – __________

How many of the vehicles using re–refined oil are gasoline fueled? ____________

Diesel fueled? ____________

Natural gas fueled? ____________

Propane fueled? ____________

Other? ____________

How many of these vehicles are off road? ________ On road (licensed) ________

How many gal–per–month of ***all engine oils*** do you use? ________ gals

How many gal–per–month of ***all hydraulic fluids*** do you use? ________ gals

How many gal-per-month of ***re–refined oil*** do you use? ________ gals

How many gal-per-month of ***re–refined hydraulic fluid*** do you use? ________ gals

Have you found any problems with the use of re–refined oil? (use additional pages as necessary) ____________

Are you purchasing re–refined oil through State Contract or spot purchase? ____________

If your re–refined oil is acquired through spot purchase how much more or less than state contract rate does it usually cost? Less $ ________ More $ ________

Do you purchase re–refined oil in quart containers or by the drum? Qt. _____ Drum _____

Why did your District make the a decision to use either quarts or drums? (use additional pages as necessary) ____________

If oil is purchased by the quart how do you dispose of the empty plastic bottles? (use additional pages as necessary) ____________

Have you had problems with the cleanliness of oil purchased in drums? Yes _____ No _____

Do you have any comments or suggestions about the use of re–refined oil? (use additional pages as necessary) ____________

Please identify all vehicles that are using re–refined oil.

Vehicle Make	Year	Body Style	VIN	Mileage	Oil change Interval
			EXAMPLES		
Chevy	86	Dump	123456789)	34567	4000 mi
Big Air	78	Compressor	abcdefg12345	23400 hr	120 hr
Ford	90	Sedan	987654321aabbcc	123456)	3000 mi