The Use of Re-Refined Oil in Vehicle Fleets

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ABSTRACT

A literature search to identify deleterious effects of using re–refined oil did not disclose any validated occurrences. Significant engine testing using re–refined lubricating oil is reported and no cases were discovered in which engine operation was affected negatively by the use of re–refined oil. The American Petroleum Institute (API) allows the use of re–refined base stock oils in the blending of end use lubricants.

Based on oil sample testing performed in this research as well as other authoritative sources, it was determined that no significant chemical or physical differences exist between re–refined and virgin oils. Differences noted in this research were related to higher levels of poly–nuclear aromatics (PNA's) in the re–refined oil. PNA's are formed due to the extreme conditions of temperature and pressure during operation of an internal combustion engine. PNA components are essentially removed by the hydrogenation process during re–refining and the trace amounts detected in new re–refined oil do not affect the oil's physical performance characteristics. Similar levels of PNA's were detected in used re–refined and used virgin oil, thereby indicating that the chemical change during use in an internal combustion engine is independent of the oil used.

Lubricating fluid logistics and handling procedures were studied and recommendations related to the screening of suppliers and the use of purchasing specifications to insure the procurement of only qualified supplier's products are presented. Purchasing specifications are generally acceptable but specific requirements must be stringently enforced to ensure that only quality lubricating products are purchased.

Alternative contracting arrangements that offer lubricating fluid procurement and disposal cost savings are suggested. Suppliers have indicated interest in determining cost–effective approachs for supplying lubricants and collecting/disposing of used fluids. Although this research was performed for the Texas Department of Transportation (TxDOT) the recommendations presented are appropriate for other vehicle fleet operators.

INTRODUCTION

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 [4]. Used motor oil is primarily generated from lubricants used in vehicle engines and collected at commercial or fleet service centers, oil change and lubrication shops, and at used oil collection centers.

Americans buy 2.5 billion gallons of lubricating oil and generate 1.37 billion gallons of used oil each year [7]. Approximately 350 million gallons of used oil are improperly disposed of, and hence, are not available for recycling. Thus, a potential quantity of 1.02 billion gallons of oil are available for recycling each year. In addition, approximately 395 million oil filters, discarded each year in the US, constitute 264,000 tons of metal and contain 20 million gallons of oil [8]. Used oil recycling is a big business and is important to the US economy as well as to maintaining the quality of the environment.

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 sold to refiners and blenders or further processed into lubricating fluids by combining with additive packages. The portion of the used oil not suitable for full processing is sold as fuel oil and asphalt extender.

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 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 [7].

Reprocessors are reasonably well distributed across the US with collection service in most cities and reprocessing facilities in many of the larger metropolitan areas. However, there are only two re–refining facilities in the US: one in Indiana and one in California. 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 [7].

Another factor that led 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 [3]. 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 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.

A 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 [5] (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 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.

In 1976 the National Bureau of Standards (NBS) (now the National Institute of Science and Technology, NIST) initiated the Recycled Oil Program which was created under the 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 that time [6]. A detailed study conducted over a six year period by the NBS, showed that

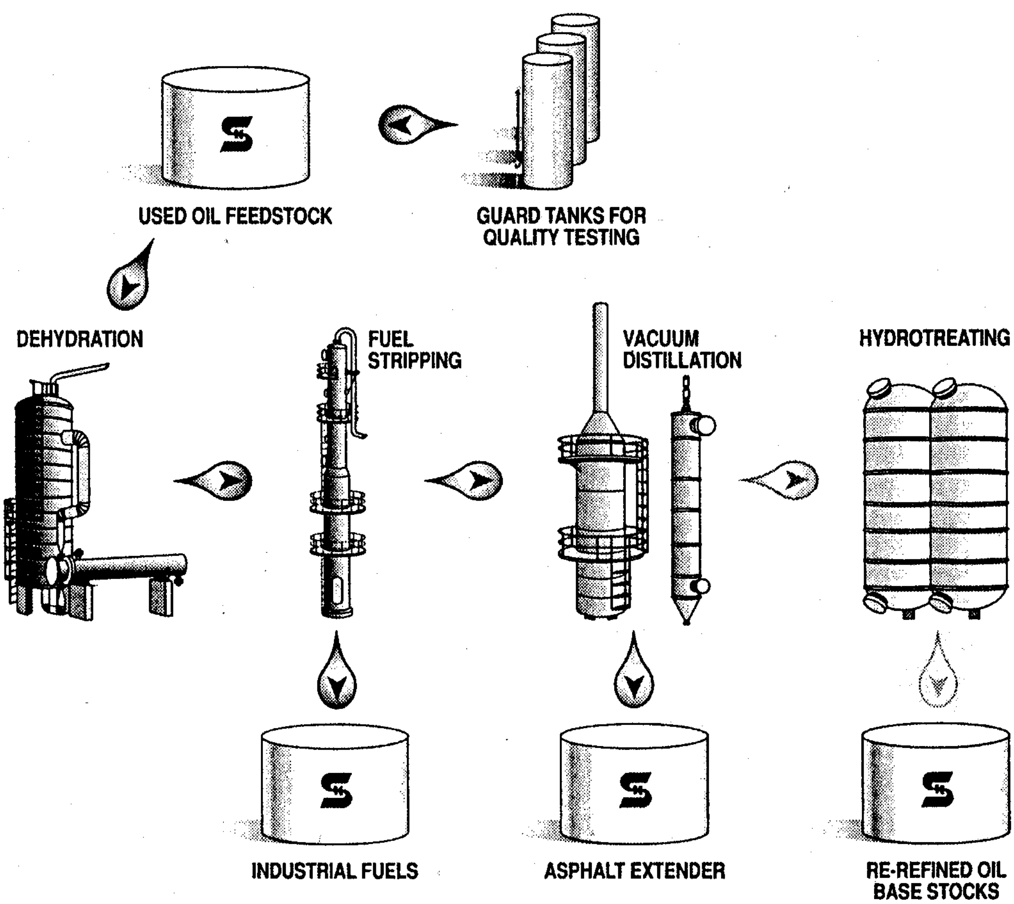


Figure 1 Schematic Diagram of Oil Re–Refining Process
(Taken from *The next step in oil evolution...Renewing our non–renewable resources*, Safety–Kleen Brochure, 1991 [8])

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 [6].

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 base oil that is 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 (and lubricants formulated from it) have been undertaken by several of the major suppliers to assess their performance. No difference in their performance was detected when compared to base oils and lubricants formulated from virgin crude oil.

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. Statistical process quality control testing must be performed at each step in the process. If quality control is properly implemented the resulting end product will be paraffinic 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 [5]. 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 1. 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 2).

SURVEY OF TxDOT DISTRICTS

Questionnaires were sent to the 26 TxDOT districts to solicit information on the use of re–refined oils and lubricants and the current procedure used by each district to dispose of used oil. The questionnaire results, summarized in Table 3, showed that approximately 7,719 TxDOT vehicles are using re–refined oil: 3,672 gasoline fueled vehicles, 2,328 diesel fueled vehicles, and 1,719 alternatively fueled vehicles.

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 used some re–refined oil in their vehicles; however, in some cases the amount of re–refined oil used is very small. The remaining districts felt 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 indicated that a stronger endorsement by the vehicle and engine manufacturers would help their confidence in re–refined oil.

Only 7 districts 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 or abrasive wear; both of which could

Table 1 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 [4])

	Reuse Option				
Energy Balance (btu/bbl waste oil)	**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 & energy saved are estimated for upstream of coker only; downstream process energies consumed and saved cancel.
[b] Processing energy saved is the energy required to manufacture subsitute desulfurized oil (for burning) or lubricating oil (for re–refining).

Table 2 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 [4])

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.

be caused by dirty oil. One district 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. Another district reported the failure of a 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 thought that it was definitely related to the use of re–refined oil and others were not sure. Several 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.

Table 3 Summary of Questionnaire Responses

Topic	Result
Virgin engine oil used	4,668 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

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 was 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 lower production quantities and associated problems. Smaller suppliers, who do not have the capability to ensure adequate quality control of the blending and packaging operations, may generate problems that slow the acceptance of re–refined oil.

RESULTS OF OIL SAMPLING AND TESTING

Used oil samples were collected from TxDOT and Texas Department of Safety vehicles, tested, and compared to test results from new oil samples. The samples received are listed in Table 4.

Table 4 Oil Samples Received

Dist #	District Location	Number of Samples	Vehicle Type	Fuel Type
5	Lubbock	11	Pickup trucks Pursuit vehicles	Gasoline/LPG Gasoline
15	San Antonio	11	Pickup trucks	Gasoline/LPG
20	Beaumont	1	Aerial truck	Diesel
	DPS Austin	3	Pursuit vehicles	Gasoline

Gas chromatography/mass spectrophotometry (GC/MS) was used as the primary screening technique. 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.

To ensure that a complete and thorough analysis of the hydrocarbon content of the oil samples was obtained, standard EPA approved methods were adopted to prepare the oil samples for analysis. Each oil sample was placed in a separatory funnel with solvent and mixed well. After separation was accomplished and the sludge removed, the liquid mixture of oil and solvent was transferred to a flask. Triplicate 10 to 1 mixtures of the extract and additional solvent were prepared for GC/MS analysis. Initially methylene chloride and hexane were evaluated as the solvent candidates using virgin unused lubricating oil to assure that the above procedure resulted in a reproducible technique. Hexane was selected as the solvent for all samples. The extracted samples were analyzed using a Hewlett–Packard Model 5980 GC/MS system.

Figures 2 and 3 illustrate the chromatograms obtained from the GC/MS runs for a pair of unused virgin and re–refined oil samples and 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

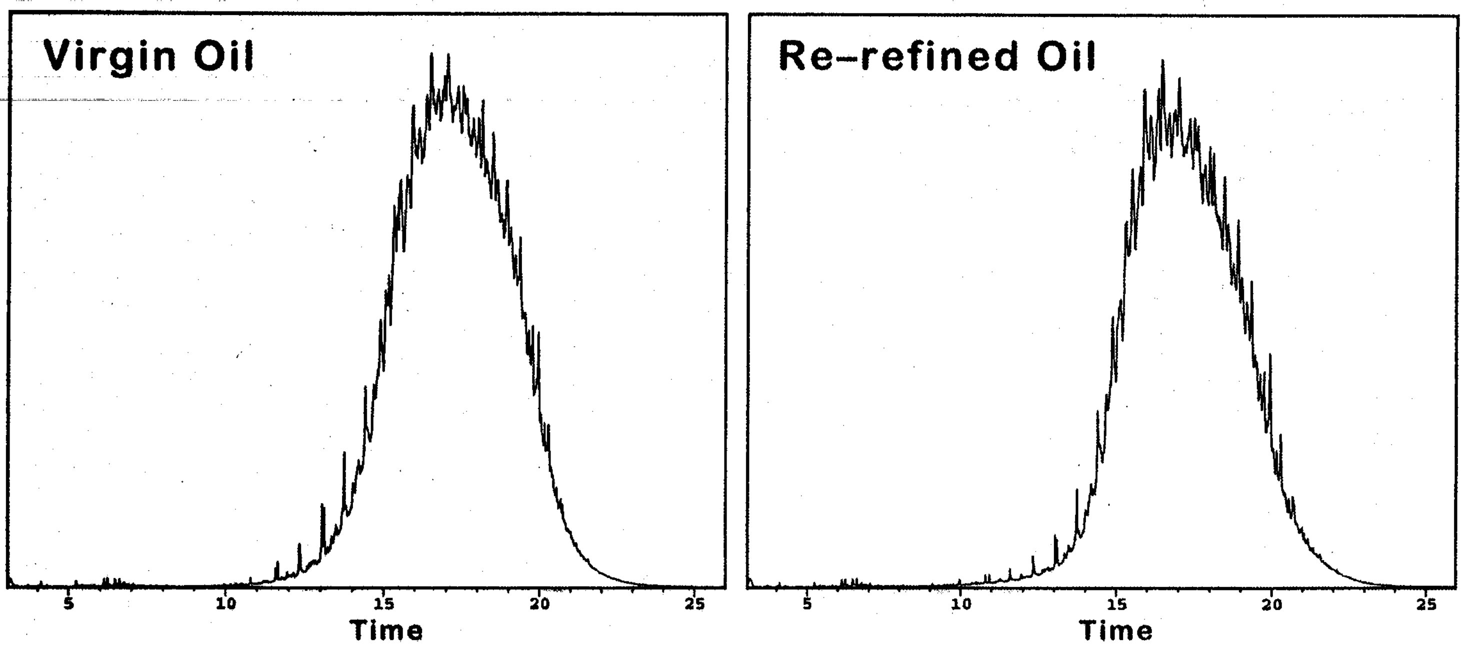


Figure 2 Comparison of Virgin and Re–Refined Oil Sample Test Results for Unused Oils

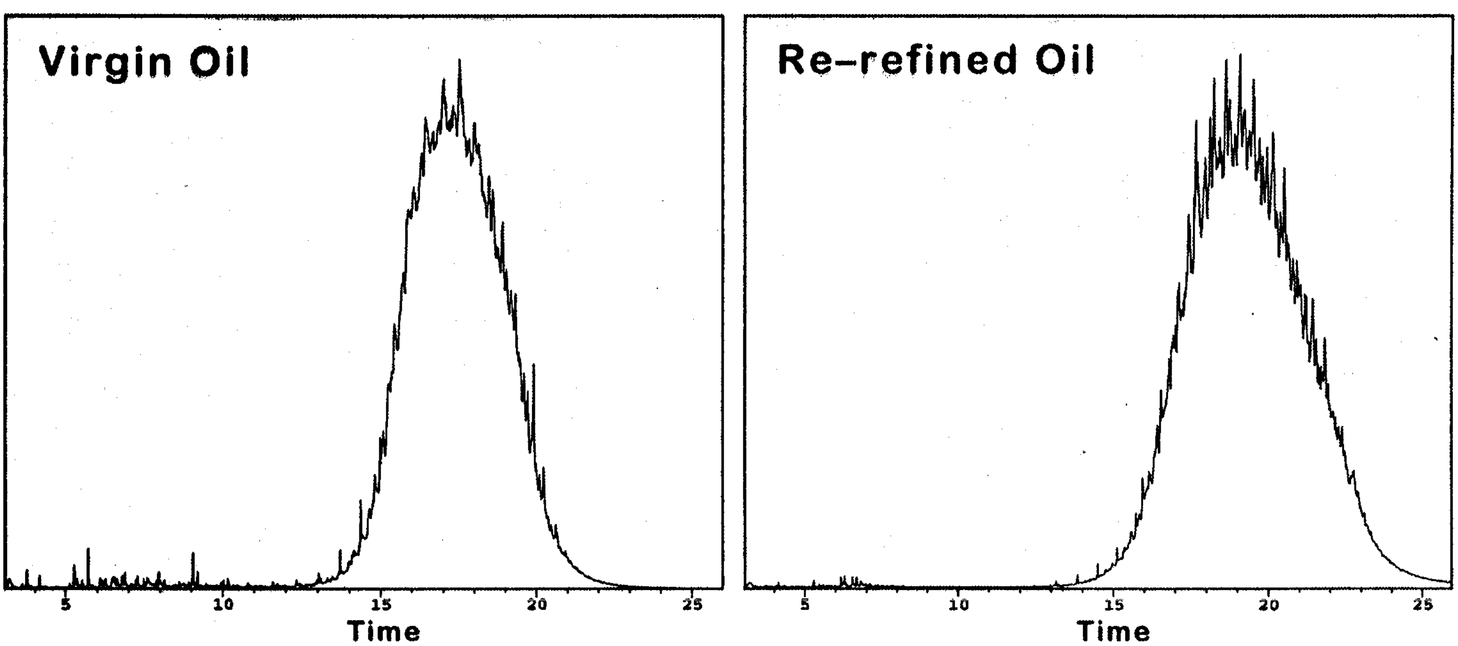


Figure 3 Comparison of Virgin and Re–Refined Oil Sample Test Results for Used Oils

capillary column. As can be seen from Figures 2 and 3, lubricating oil is a blend of a considerable number of compounds; some of these compounds are listed in Tables 5, 6, and 7. Examination of the chromatograms of the virgin and unused re–refined oil 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 essentially demonstrates a one–for–one equivalence between the two oil samples.

Examination of the chromatograms of the used virgin and re–refined oils indicate differences near 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 the branched paraffinic and naphthenic species that are typically present in the base oil from which lubricating oils are formulated.

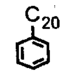
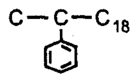
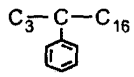
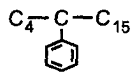
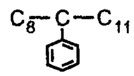
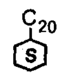
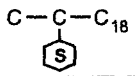
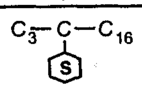
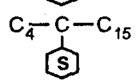
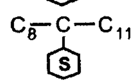
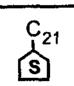
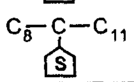
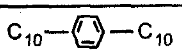
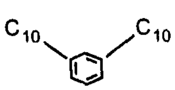
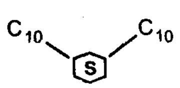
The comparative used oil analysis indicated that the relative differences in the chemical composition between new virgin oil and new re–refined oil was only in the level of poly–nuclear aromatics (PNA). A list of the observed PNA's is shown below:

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

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

Tables 5, 6 and 7 and Figures 4 and 5 illustrate the influence of molecular structure on viscosity and pour point, two extremely important properties of lubricating oils. Table 5 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, but with a much lower number of hydrogen atoms has a viscosity index of 61. Figures 4 and 5 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.

Table 5 Monocyclic Hydrocarbons [2]

Serial No.	Molecular Formula	Structural Formula	Designation	Viscosity (mm²/s) 40°C	Viscosity (mm²/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

Used oil when decontaminated, distilled, and re–refined by catalytically treating 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 based on the PNA levels.

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 re–refined oil of the same grade and certification as virgin oil is received, 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 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 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

Table 6 Hydrocarbons with Two or More Fused Rings [2]

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	$C_{26}H_{54}$	$C_6{-}C(C_4){-}C_{15}$	*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

No. RR:DO2:1204. Those who wish to use re–refined oil should 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 to insure that only reputable blenders and packagers are considered. 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 blenders and packagers that have had such testing performed on their motor oil are qualified to bid.

Most major vehicle and engine manufacturers state in writing that equipment operators may use re–refined oil in their vehicles without affecting warranties. 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 in ensuring that only qualified products are procured. Documentation should be requested 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 exercised 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 procurement specifications could be strengthened by including a requirement for compliance with ISO 9000 or Total Quality Management (TQM) practices. 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.

Table 7 Influence of Side Chains on Hydrocarbons Properties [2]

Serial No.	Molecular Formula	Structural Formula	Designation	Viscosity (mm^2/s) 40°C	Viscosity (mm^2/s) 100°C	VI	Pour Point (°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	$C_{26}H_{54}$	$C_6-C(C_4)-C_{15}$	*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

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

Another way to improve 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.

The end user'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

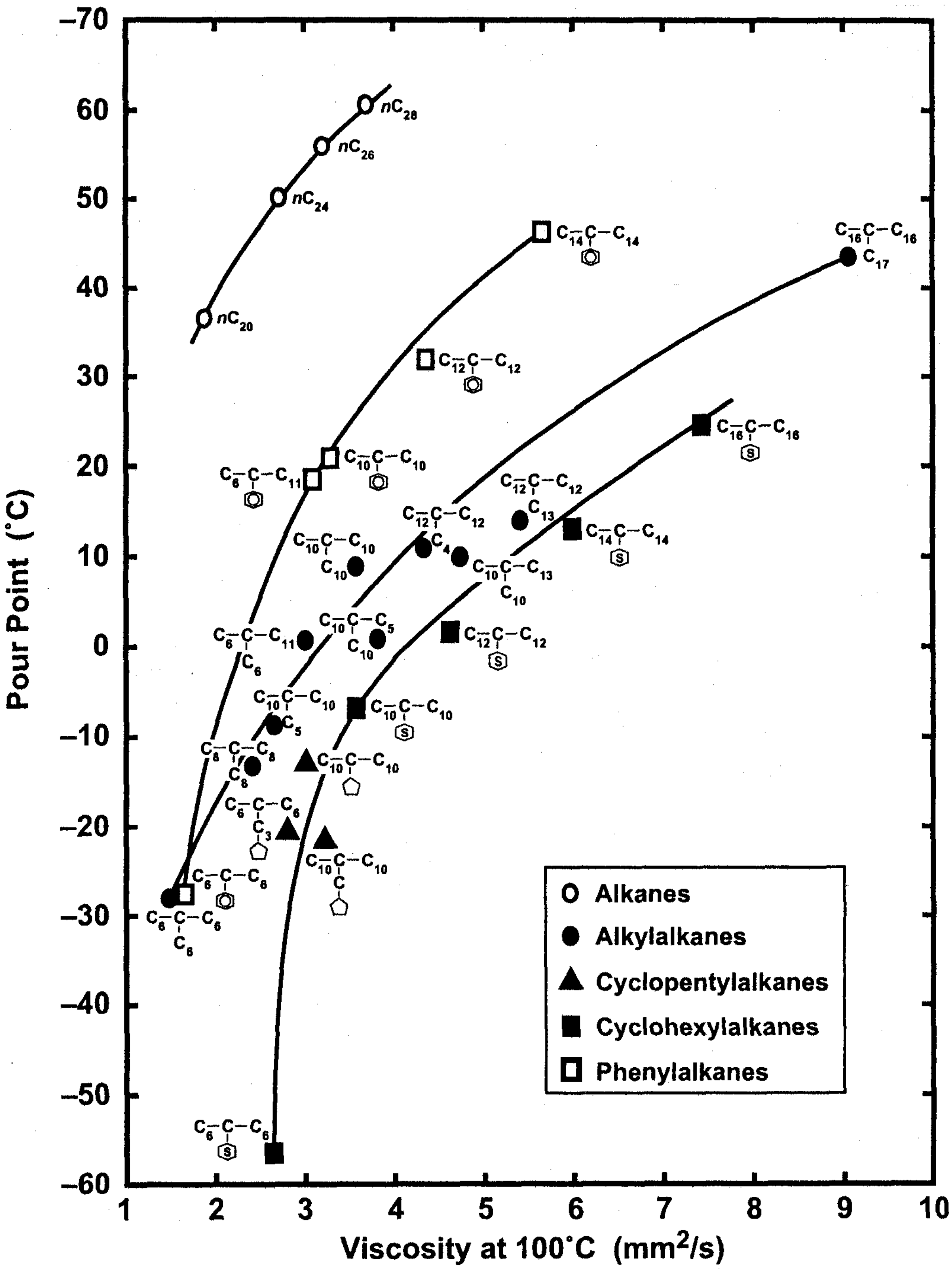


Figure 4 Pour Point of a Number of Hydrocarbons

ability to furnish products in accordance with the terms and conditions of the contract specifications. The user 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.

Including a requirement for compliance with Green Seal Standard GS–3, which relates primarily to ensuring the integrity of the environment, could also strengthen the quality control aspects of the end user's 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.

In summary, generally existing specifications for the purchase of oils and lubricants, when modified to insure that only reputable suppliers are certified, can be used for the procurement of re–refined lubricating fluids. It is noteworthy that there are several hundred suppliers of lubricating fluid 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.

CONCLUSIONS

1. Base stock oils recovered in the re–refining process are essentially equivalent to virgin crude oil base stock and meet all API standards for base oils. API modified their definition of *base stock* to include the use of re–refined oils. 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. 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.
2. When 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 regarding contaminants in purchased re–refined lubricating oil products are likely related to quality control problems associated with container processing rather than with the re–refined base oil or additive. This potentially serious problem should be addressed in one of the following ways:
   a. End users could qualify suppliers by requiring compliance with ISO 9000 or by Total Quality Management techniques.
   b. End users could require suppliers to furnish documentation demonstrating that oil furnished with the API service symbol label meets requirements for the designations thereon, including the API service category,

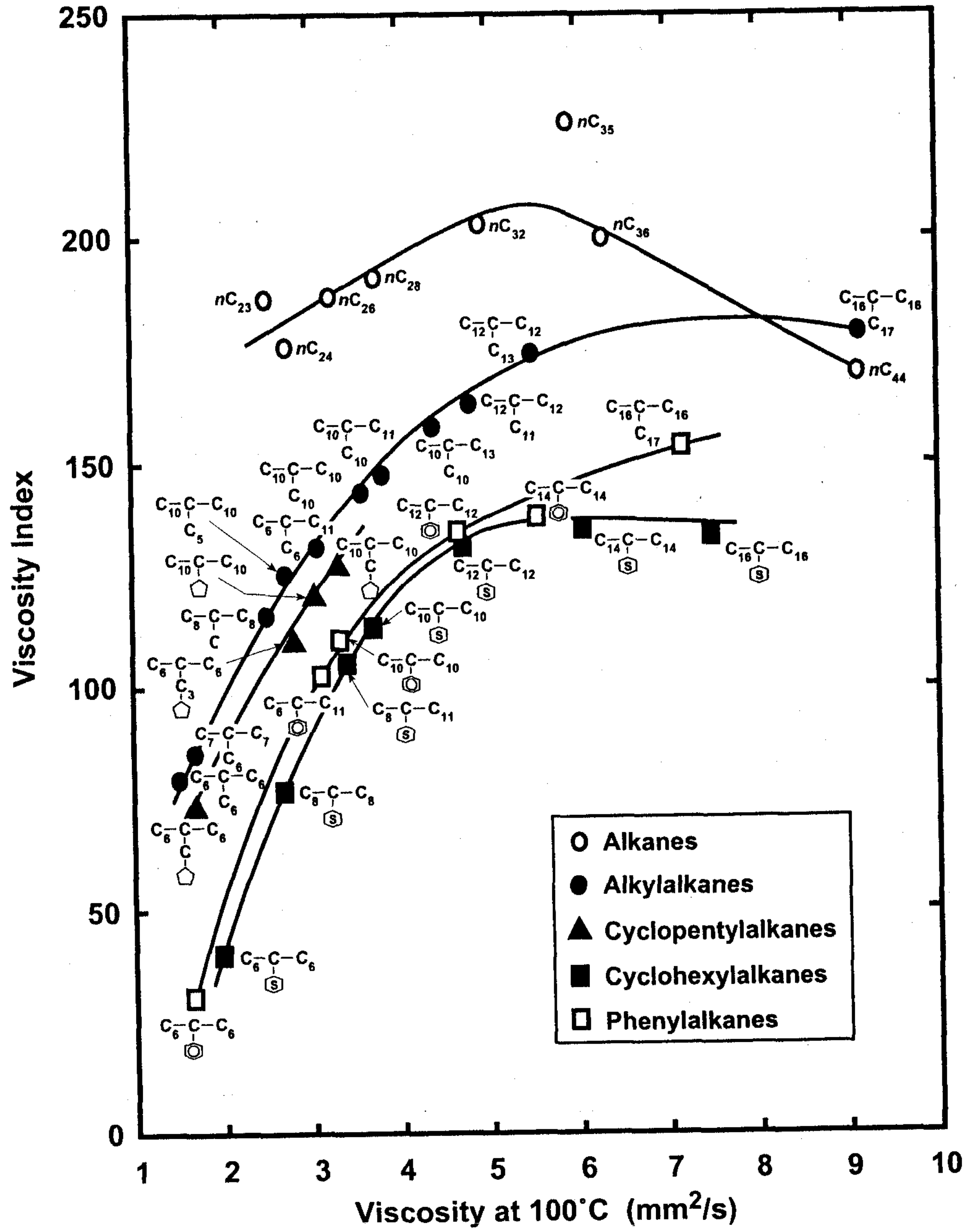


Figure 5 Viscosity Index of a Number of Hydrocarbons Branched at Mid–Chain [2]

the SAE viscosity grade, and *Energy Conserving* or *Energy Conserving II*. This is a requirement of SAE Standard J1423 dated February 1992.

c. End users could require suppliers to furnish documentation demonstrating that oil furnished meets manufacturer's recommendations, as stated in the equipment 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. End users could revert to 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.

e. End users could contract with lubricating fluid suppliers for *closed loop* (used oil collection and re–refined fluid supply) services only.

f. End users could include a requirement for compliance with Green Seal Standard GS–3 in lubricating fluid procurement specifications.

3. Based on a report published by Argonne National Laboratories [1], 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.
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.
5. The cost of disposing of used re–refined fluids is no different than that associated with virgin lubricating fluids.

ACKNOWLEDGMENTS

The authors would like to thank the Texas Department of Transportation for support of the research that led to this paper.

REFERENCES

1. Armstrong, J. and P. L. Strigner, (1982) *A Field and Laboratory Comparison of a Re–Refined and a Virgin Automotive Engine Oil*, Society of Automotive Engineers, Paper No. 821239, Presented at SAE Fuels and Lubricants Meeting, Ontario, Canada, October 1982
2. Brinkman, D. W., J. R. Dickson and D. Wilkinson, (1995) *Full–Scale Hydrotreatment of Polychlorinated Biphenyls in the Presence of Used Lubricating Oils*, ***Environmental Science Technology***, 29, 1995
3. *EPA Guideline for Purchasing Re–Refined Lubricating Oil*, (1991) Environmental Fact Sheet, US Environmental Protection Agency, 1991
4. *Facts About Used Motor Oil,* Used Oil Coalition, (undated circular)
5. Graziano, D. J. and E. J. Daniels, (1995) *Assessment of Opportunities to Increase the Recovery and Recycling Rates of Waste Oils*, ANL/ESD–29, Center for Industrial Technology, Energy Systems Division, Argonne National Laboratory, Argonne, Illinois, 1995
6. Hsu, S. M., C. S. Ku, and D. A. Becker, (1982) *Re–Refined Base Oil Characterization and Consistency Monitoring*, Society of Automotive Engineers, Paper No. 821240, Presented at Fuels and Lubricants Meeting, Ontario, Canada, October 1982
7. Mt Auburn Associates
8. Robbins, T. P., (1992) *Creating Local Jobs from Environmental Protection*
9. *The Next Step in Oil Evolution...Renewing Our Non–renewable Resources,* (1991) *T*, Advertising Brochure, Safety–Kleen