LACK OF REGULATORY UNIFORMITY UNDERMINES COMPLIANCE

As already noted, there are several discrepancies between hazardous product and hazardous waste transportation regulations. This is exacerbated by the involvement of individual state governments in the United States which each have their own hazardous waste programs, with few of them being the same as the federal program or that of any other state. The most evident discrepancy is in the manifest, with many states insisting on use of their own form (which differs from other states' forms) for wastes generated, discarded or moving through that state. Lack of a uniform manifest system, where many borders will be crossed, is destructive to compliance. Lack of uniformity generally destroys compliance, especially for companies having plant sites in multiple jurisdictions and shipping to disposal sites in many more jurisdictions.

REGULATORY ACTION AGAINST DUMP SITES HAS BEEN INEFFECTIVE

Under CERCLA (Superfund) which is aimed at historic disposal sites and the companies involved in those sites, any one company can be held liable for the entire cost of clean-up of the site, regardless of the volume of waste sent there or the level of hazard of that waste or when it was generated. This is true whether the actions of the generator were legal at the time, whether the generator had knowledge of the disposal, or whether the site operator mismanaged the wastes.

This legal concept, where any one company pays for all, is called "joint and several liability," and it is having an enormous impact on all companies under the law. The target company must initiate its own lawsuits against all other parties, who in turn may countersue or bring in other companies as joint defendants. This causes an expanding ripple of lawsuits, all designed to spread the liability to as many other parties as possible so the target company's share is reduced.

These suits often are initiated before the total cost of clean-up or even the full dimension of the problem is known. The litigation takes years. During this time, the matter stands as a cloud over the assets of the company, impairing relations with stockholders, customers, lending institutions, and potential merger or acquisition partners.

As you can imagine, only the lawyers prosper under this system. To date, it has not resulted in major clean-up of a significant number of the thousands of sites which have been identified.

The difficulties encountered to date under this new liability system are enormous. They are small, however, compared with those anticipated under legislation now being considered in the US Congress, which would give *private* parties the right to sue for damages for personal injuries and damage to private property. These so-called "Toxic Victim Compensation Acts" are expected to enhance the cost of doing business dramatically.

Companies are finding that with the new liabilities created by the legislature, and the dimension of costs involved, their current and past insurance coverage is totally inadequate. In some instances, policies clearly do not provide coverage. In others, there is coverage, but not enough, while in still others the insurance companies are simply refusing to honor the claims, resulting in yet further lawsuits by the company against its insurance carrier.

Bankruptcy of waste generators, disposal sites, transporters and insurance companies is becoming a common occurrence. With each company that goes bankrupt, the monetary obligations of surviving companies increase.

Within the United States, the only solution to this problem is political and legislative. To other countries or international bodies which are considering regulatory recommendations or liability schemes, I offer this message as guidance on mistakes to avoid.

Oleochemicals as a Fuel: Mechanical and Economic Feasibility

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ABSTRACT

The status of vegetable oils as diesel fuel substitutes is currently dubious. Although it is fair to consider them as short-term emergency fuels (or, more desirably, low proportion supplements to diesel fuels), they present mechanical problems in long-term use that have not yet been solved. It is preferable to use these oils blended in small proportions with diesel fuels. Indirect-injection diesel engines have had fewer problems than direct-injection engines, whether the tests were performed with pure vegetable oil fuel or with vegetable oil/diesel fuel blends. The economic prospect for these fuels is not promising. In general, they are not and have not been economical alternatives to diesel fuel. Exceptions appear to have occurred recently in Brazil and the Philippines where low local prices for vegetable oils combined with high petroleum prices encouraged officials to use low proportion vegetable oil/diesel fuel blends. Nonetheless, current and long-term trends in petroleum and oilseed prices indicate that these fuels will probably not be price competitive within the near future. Emergency disruption of petroleum supplies completely changes the economic situation. Vegetable oils would be worth much more as a fuel during disruptions than otherwise; thus incentives could be strong to include these oils in the fuel supply, diverting them from the food supply.

INTRODUCTION

Oleochemical products have been used with mixed success as diesel engine fuels. Government researchers, diesel engine manufacturers and farmers have all performed tests that demonstrate the potential and the problems of this fuel source. There is a very real potential for using vegetable oils in some form as a diesel fuel. There are, however, very real problems that will restrict the introduction of this resource into the energy pool.

This discussion considers the mechanical feasibility of this fuel source, the economics of the situation and the supply of vegetable oils compared to the current demand for liquid fuels.

VEGETABLE OIL FUELS: MECHANICAL FEASIBILITY

The mechanical feasibility of using vegetable oils as a diesel fuel has been clearly established in short-run tests. Numerous experiments have yielded consistent results.

Rudolf Diesel, the inventor of the compression combustion engine, recognized at the turn of this century that vegetable-based fuels would work in his engines. Since then, vegetable fuels have been used when petroleum supplies were scarce, expensive, or difficult to obtain. This early work and experience has been documented (1-3). It is believed that Duetz (engine manufacturers) of Germany warranted its engines for use with vegetable oils in the early part of this century. The technology for using vegetable oils was evolving in parallel with the technology for using petroleum-based oils. The research on vegetable oils decreased with the increased availability of petroleum-based fuels in the 1950s.

New interest in vegetable oils as a diesel fuel appeared in the middle and late 1970s after the sudden increase in the prices of petroleum products around the world.

Three different approaches to using vegetable oils as diesel fuels have been identified and tested: pure vegetable oils, esterified vegetable oils, and blends of oils or esters with diesel fuel.

Preliminary studies indicate that, over short periods of time, 100% vegetable oil fuels perform satisfactorily in unmodified diesel engines. This is true for several major indicators of performance, including power output, torque, brake thermal efficiency and fuel consumption for a number of different vegetable oils in a number of different makes and models of diesel engines.

Tests with 100% vegetable oil have found slight decreases (several percent) in maximum engine power and increased fuel consumption (ca. 10%) relative to performance with diesel fuel (4-7). Esterified vegetable oils have produced slightly better short-run performance results.

Blends of oils or their esters with diesel fuel have given results more similar to pure diesel fuel, with smaller proportions of oils performing somewhat better than blends with high proportions. The following discussion of problems relates primarily to the use of unblended vegetable oils. This is useful because the mechanical problems encountered with the other two methods are of a similar nature.

The short-term success in using unblended vegetable oils as a diesel fuel has been accompanied by problems. These problems may be divided into two broad classes. The first includes those involved with daily short-term use, and the second involves those resulting from long-term continuous use of vegetable oils. It is important that diesel operators understand and anticipate these problems before they attempt to use vegetable oils.

Several short-term problems include some difficulty with cold starts; plugging and gumming of filters, lines and injectors; and engine knocking. Although these problems are not universal, they have been noted by various researchers in different situations.

Accompanying these short-term problems are a number of quite serious potential long-term problems which may lead to reduced performance or even to complete failure of the engine. These include coking of injector nozzles; carbon deposits on the piston and cylinder head; dilution of the crankcase lubricating oil; excess wear on the rings, pistons and cylinders; and failure of the engine lubricating oil due to oxidation and polymerization.

Researchers have correlated these with several basic properties of vegetable oils, such as naturally occurring gums; high viscosity; acid composition; free fatty acid content; and low cetane rating.

Crude vegetable oils contain gumming materials called phosphatides. The trash and gums may collect and clog the fuel filter, lines and injectors. Most engine tests have used crude degummed or more highly refined vegetable oils (4-7). A notable exception is described (8) in which crude vegetable oil was used in short engine tests with satisfactory results.

Virtually all experts recommend degumming vegetable oil for fuel use. The other recommended practice is to prefilter the oil through a 4-micron screen (4,5).

The free fatty acid component of vegetable oils can be harmful to engines. These acids can cause corrosion in the fuel system, fuel injectors, piston and cylinders and the crankcase.

Vegetable oils are naturally more viscous than diesel fuel (see Table I). This has been mentioned by virtually all researchers as a major factor in using vegetable oils in diesels (4,5,9,10). The higher viscosity of vegetable oil means that when it is injected into the cylinder it does not atomize properly for combustion. This can result in incomplete combustion of the fuel, with build-ups of carbon deposits on the injectors, head and piston (4). Some of this unburned fuel will blow by the piston rings and into the crankcase. Accumulation of the blow-by may result in dilution of the lubricating oil, causing increased engine wear. More seriously, accumulation of vegetable oil in the crankcase combined with the high heat and pressure of operation may cause the lubricating oil to solidify due to oxidation and polymerization of the vegetable oil (4,9,10). This causes complete failure of the lubricating oil, and may ruin the engine.

TABLE I

Viscosity of Various Vegetable Oils Compared to Diesel Fuel (7)

Oil	Viscosity (centipoise) @ 21 C (70 F)
Diesel fuel (#2)	3.8
Soybean	57.2
Sunflower	60.0
Coconut	51.9
Peanut	67.1
Palm	88.6

The chemical composition of the vegetable oil is directly related to problems with failure of engine lubrication. Some oils are more likely to polymerize/oxidize in the crankcase than others, notably those high in unsaturated acids. This problem was discussed extensively at the USDA Peoria seminar (9). Personal communications with many of the leading researchers in this field affirm this as a crucial problem.

The problem arises due to the triglyceride composition of the oils. All unsaturated triglycerides have a tendency to polymerize, depending on the degree of unsaturation.

Typical oil compositions for several oils are shown in Table II. The most highly unsaturated oil in the table is linseed oil, which is called a "drying oil." This "drying" action is due to polymerizing of the unsaturated triglycerides. The same action occurs, although to a lesser extent, with the less highly unsaturated oils. Polymerization is accelerated by high temperature, pressure and the presence of certain metals—conditions often found in the crankcase of an internal combustion engine. The problem has been reported by Bruwer (4) and has been experienced by some, but not all, users of vegetable oil fuels.

TABLE II

Typical Composition of Vegetable Oil Triglycerides (11)

	Acid composition (% by weight)			
		Unsaturates		
Oil	Saturates	Mono	Di	Other
Corn	14	34	42	0
Cottonseed	25	25	50	0
Linseed	10	23	20	47
Palm	47	45	8	trace
Peanut	20	60	20	trace
Soybean	15	24	51	10
Sunflower	12	28	60	trace

This same problem of polymerization of crankcase oil in diesel engines occurred with petroleum-based fuels in the 1950s. The solution was to put additives into motor oils. This same prescription, plus changing motor oils at shorter regular intervals, may apply to vegetable oil fuels. Further research and experience is needed. Currently, this problem, combined with the viscosity of vegetable oils, presents the greatest difficulty in using vegetable oils in diesel engines.

The problems with using straight vegetable oils in diesel engines, probable causes and potential solutions are outlined in Table III.

These properties can be modified or improved on by either modifying the oil to an ester, or mixing the oil with diesel fuel.

Esterification shows promise and problems. The esters are less viscous than vegetable oils, which should improve engine performance through better atomization and combustion in the cylinder. This should reduce blow-by of unburnt fuel into the crankcase and dilution of the lubricating oil. Engine wear should be better than with straight vegetable oils. However, laboratory bench tests by a US diesel engine manufacturer indicate that esterified oils may have a greater tendency to polymerize than crude or refined vegetable oils. Polymerization occurs more rapidly and at smaller concentrations of the ester in the lubrication oil. This is a major problem that must be verified and solved before ester fuels can be used outside an experimental environment.

The other approach to using vegetable oil fuels is to blend them with diesel fuel. This gives better engine performance than with 100% vegetable oil fuels, and reduces the problems encountered because smaller proportions are blended.

Blending of oils with diesel fuel has been used with reasonable success in field trials and is being tried on a larger scale in Brazil and the Philippines. In Brazil, soybean oil has been mixed with ratios as high as 30% with diesel fuel for use in diesel equipment. At least one equipment manufacturer has extended its warrantee to cover engines using up to 30% vegetable oil (for soybean, sun, groundnut and rapeseed oils). The Philippines government reportedly has used fuels with 5% coconut oil in diesel equipment.

Another approach with promise is the use of vegetable oils with alcohol and diesel fuel. Because oils and alcohol do not mix readily, these fuels must be blended into microemulsions which can then be used in engines. Several of these blends have been tested with favorable short-term results; however, this work is in the early stages.

A final finding is that some diesel engines are more susceptible to vegetable oil problems than others. There are two major types of diesel engine: direct-injection and indirect-injection or precombustion chamber engines. The direct-injection engines are reported to be more susceptible to long-term problems of incomplete combustion of fuel, coking of injectors, formation of carbon deposits in the engine, dilution of lubricating oil and ultimately polymerization of the lubricating oil. These engines are less tolerant of different fuel properties than indirect-injection engines.

The indirect-injection or precombustion chamber engines have fewer long-term problems because the injection technology promotes mixture of the fuel with the air and more of the fuel burns. Emissions from these engines are cleaner, but at a cost of ca. 10% lower engine efficiency.

Tests and field trials using indirect-injection engines have been generally more successful when judged on the criteria of engine durability and performance. The engines warranteed for use with 30% vegetable oil blends in Brazil were indirect-injection.

TABLE III

Known Problems, Probable Causes and Potential Solutions for Using Straight Vegetable Oils in Diesels

Problem	Probable cause	Potential solution
Short-term		
1. Cold weather starting.	High viscosity, low cetane, and low flash point of vegetable oils.	Preheat fuel prior to injection. Chemically alter fuel to an ester.
2. Plugging and gumming of filters, lines and injectors.	Natural gums (phosphatides) in vegetable oil. Other ash.	Partially refine the oil to remove gums. Filter oil to 4 microns.
3. Engine knocking.	Very low cetane of some oils. Improper injection timing.	Adjust injection timing. Use higher compression engines. Same as (1).
Long-term		
4. Coking of injector nozzles.	High viscosity of vegetable oil, incomplete combustion of fuel. Poor combustion at part load with vegetable oils.	Heat fuel prior to injection. Switch engine to diesel fuel when operating at part load. Chemically alter the vegetable oil to an ester.
5. Carbon deposits on piston and head of engine.	Same as (4).	Same as (4).
6. Excessive engine wear.	Same as (4). Possibly free fatty acids in vegetable oil. Dilution of engine lubricating oil due to blow-by of vegetable oil.	Same as (4). Increase motor oil changes. Motor oil additives to inhibit oxidation.
7. Failure of engine lubricating oil due to polymerization.	Collection of polyunsaturated vegetable oil blow-by in crankcase to the point where polymerization occurs.	Same as (4) and (6). Use vegetable oils low in polyunsaturates.

ECONOMIC ANALYSIS

Whether vegetable oil fuels are used in diesels will depend in the end on the price and availability of petroleum-based fuels. The fact that vegetable oil fuels can be used in diesel engines is not sufficient reason to do so. The decision will finally come down to the economics which, to date, have not been favorable.

Costs of soybean, palm and coconut oils as fuels were examined. These oils were selected because:

- they are all major oilseed crops;
- they are relatively inexpensive compared to other vegetable oils;
- palm and coconut are primarily produced in tropical developing nations, many of which have balance-of-trade problems related to petroleum imports; and
- some nations are seriously considering use of these oils as fuels.

This analysis compares the cost of diesel fuel to the cost of an energy equivalent amount of vegetable oil fuel. Prices are wholesale market values of bulk quantities and vegetable oil prices are for crude or once-refined oils. These are the least expensive products that might be used as a diesel fuel substitute or supplement. More refined grades of oils and esterified oils sell at substantial premiums to the crude oils, and do not improve the engine efficiency or specific fuel consumption in proportion to their increased cost. Therefore, the short-run cost of using these modified vegetable oil fuels is greater than that for the crude oils. Only if crude oils become price competitive with diesel fuel will a closer look at refined and esterified oils be useful.

LONG-TERM TRENDS

The two recent surges in petroleum product prices are the primary cause of interest in vegetable oil fuels (see Figs. 1-3). The price of diesel fuel was ca. 8 ¢/gallon between 1950 and 1972 (in the USA or FOB Persian Gulf). It was 28.2 ¢/gallon in 1974! By 1978 the price was 38 ¢/gallon and it leapt to $1.08/gallon in 1981 before falling to the current level of 87 ¢/gallon. A wholesale price series for diesel fuel in the United States is used for 1950-72 because world market diesel fuel prices were not readily available prior to 1972. Prior to the oil embargo of 1973-74 and subsequent price controls, petroleum prices were generally higher in the USA than on the world market. Note the stability of diesel prices between 1950 and 1972. Vegetable oil prices had more variation than fuel prices. Prices of agricultural commodities tend to run in cycles, with peaks and troughs. Palm and coconut prices have exhibited similar variability.

The price series displayed for each oil is for bulk shipments CIF Rotterdam. It would be desirable to use prices at a major production point (such as: Decatur, Illinois, for crude soybean oil; the FOB value in Malaysia for palm oil and the FOB value in the Philippines for crude coconut oil). The FOB values are lower than delivered values due to shipping and insurance costs. Reported market prices may also omit lower prices in long-term contracts. The values at the point of production represent the value to a producer of goods in exchange. This price is also lower than prices at world markets, and is more likely to demonstrate economic feasibility of vegetable oil fuels. These data are extremely difficult to obtain, however. Fortunately, indications are that transportation expenses only add a small proportion to the delivered price, and the conclusions of this analysis are not sensitive to small price variations.

The diesel fuel equivalent price of the vegetable oil is found by multiplying the price per metric ton by 0.00385 or the price per pound by 8.47. This factor reflects that there are ca. 7.7 lb of a vegetable oil in a gallon, and diesel engines require in the range of 10% more fuel when run on straight vegetable oil (7.7 × 1.1 = 8.47). Note that vegetable oils have ca. 14% less energy than diesel fuel per unit volume; however, they burn slightly more efficiently. This ratio also roughly applies for vegetable oil blended with

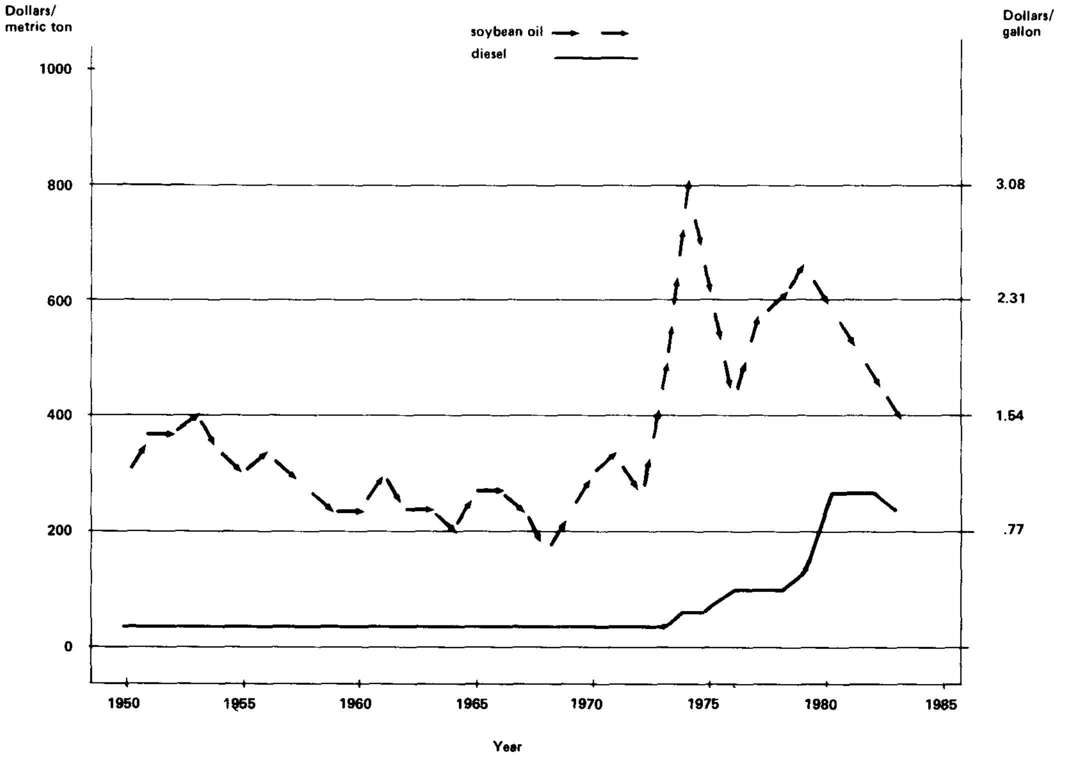

FIG. 1. Prices of soybean oil and diesel fuel, 1950-83.

diesel fuel in any proportion, so the cost analysis is representative of both methods of using these fuels.

The prices of vegetable oils and diesel fuel are graphed in Figures 1-3 to permit a preliminary cost comparison. The vertical axes on the left of the figures show the price per metric ton in current dollars, and the vertical axes on the right show the fuel equivalent cost per gallon in current dollars. At no time in the period examined has it been economical to use vegetable oil fuels. Currently, vegetable oil prices are on the rise, while diesel prices are falling. Diesel fuel costs less than $0.90 from the Persian Gulf, and ca. $0.80 in the USA. Spot market prices for soybean, palm

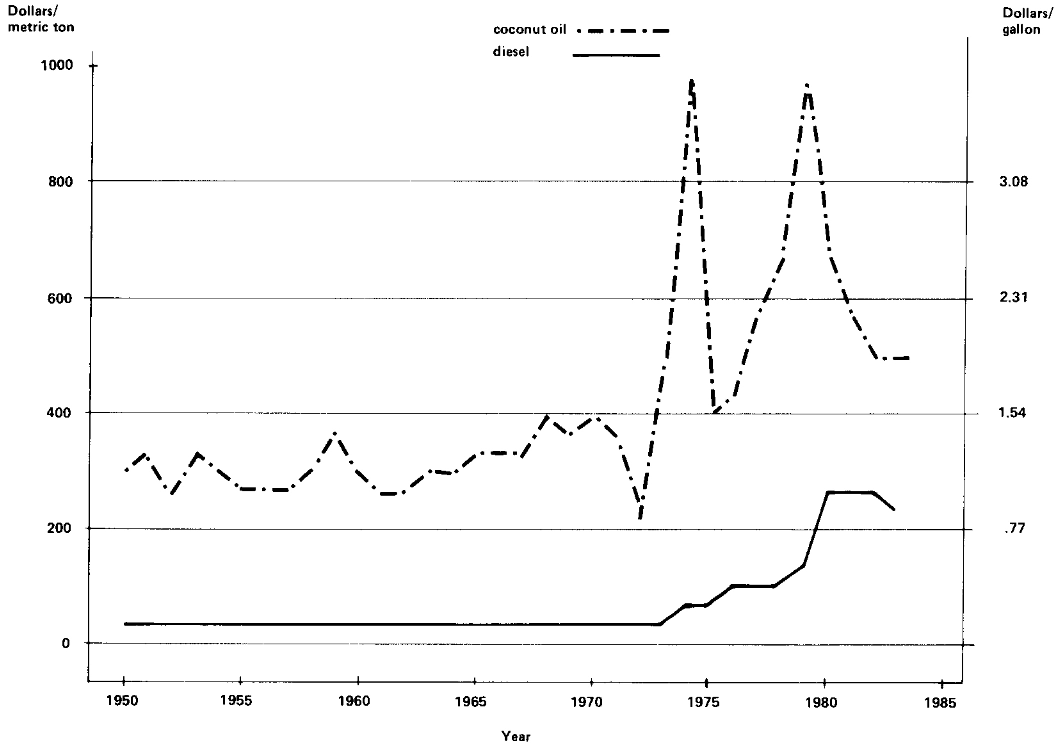

FIG. 2. Prices of coconut oil and diesel fuel, 1950-83.

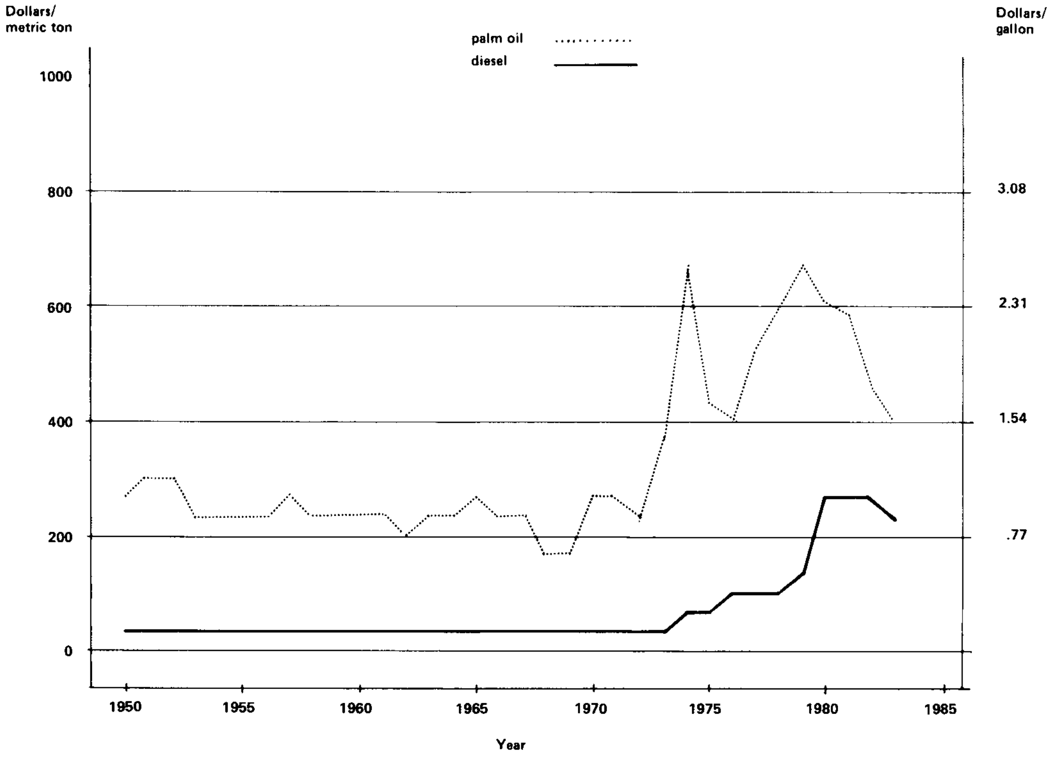

FIG. 3. Prices of palm oil and diesel fuel, 1950-83.

and coconut oils in August were ca. \$2.30, \$2.10 and \$3.80/gallon equivalent (\$600, \$550 and \$990/ton), respectively.

Between 1950 and 1974, vegetable oil fuel would have cost 10-15 times more than diesel fuel, based on prevailing world prices. This ratio steadily decreased from 1975 on, until in 1981 vegetable oil fuel cost about twice as much as diesel fuel and in 1982 it cost only 75% more. This was an impressive rate of decrease; however, it would be incorrect to conclude that the relative price difference would continue to narrow. In 1983, the ratio increased again as world petroleum prices sagged under excess supplies. Vegetable oil prices have also increased recently.

Despite the great proportional change in prices of vegetable oil fuels and diesel fuel, the actual cost difference has changed much less. Between 1950 and 1972, soybean oil fuel would have usually cost in the range of 90¢ to \$1.10/gallon, \$225-\$300/metric ton) compared to diesel fuel at 9 ¢/gallon, a difference in cost of 80¢ to \$1.00/gallon. This difference increased to nearly \$3.00/gallon in 1975 (when soybean oil reached \$795/metric ton). In 1979, soybean oil still cost \$2.55/gallon, compared to 56¢ for diesel, a difference of \$1.99/gallon. During the 1982-83 crop year, the difference fell to 70 ¢/gallon when oil prices were \$400/metric ton. The current spot market prices for soybean oil and diesel fuel have widened the difference to ca. \$1.50/gallon once again.

These same patterns have been repeated for palm and coconut oil: price differentials with diesel were relatively large during the 1970s; however, they fell in 1981-83. Present market prices have pushed the margin per gallon to \$1.25 for palm and almost \$3.00 for coconut oil.

Regression analysis of the relative and absolute price differentials between 1950 and 1983 for the three vegetable oils and diesel fuel corroborate the graphic analysis. Although it was found that the relative differential is strongly related to both an annual trend and the price of crude oil, the absolute cost difference per gallon shows no distinct pattern.

Only over the last 10 years can a clear relationship be observed. Both the relative and absolute differences between vegetable oil fuels and diesel fuel have decreased over this period. The strength of this 10-year trend and its potential continuation must be questioned for several reasons. First, the market for oilseed products was at an all-time high in 1973-75 due to shortages in key protein meal commodities. This was followed by several years of a more stable market. Then, in 1981-83, prices declined to levels quite low by historical standards when inflation is accounted for.

The past 10 years have brought unusual conditions in both the petroleum and oilseed markets. Even in these circumstances, vegetable oil fuels have not been economical. Apparently, only in two situations—Brazil and the Philippines—have prices been depressed enough locally to justify considering vegetable oil fuels. These situations have presumably ended with the recent price recovery.

Even though vegetable oil fuels are not now and have not been economically viable alternatives to diesel fuel, there is good reason to ask whether they might become viable in the future. Petroleum price increases have twice shocked the world economy. Vegetable oil prices have also increased—however, not nearly as rapidly.

Future economic prospects can be assessed by examining the real price trends for vegetable oils and diesel fuel. The nominal price series are adjusted for inflation and reported in 1982 dollars. Figure 4 depicts an analysis of price projections for soybean oil. Units on the axes are as in Figures 1-3. Price relationships for coconut and palm oils show similar trends.

The graph starts with data on the real price of diesel fuel (in 1982 dollars). This price fluctuated minimally until 1973, then proceeded to increase in two steps. The 1980 and 1981 prices were the highest in history; however, there were substantial declines of 9 and 17% in 1982 and 1983, actually recapturing ca. 44% of the increase between 1978 and 1981 after adjustment for inflation.

There are also projections of diesel fuel prices to 1990. These are based on estimates published by the International Bank for Reconstruction and Development (12) and the US Department of Energy. The World Bank predicted that crude petroleum would cost \$30/barrel in 1985 and \$39/

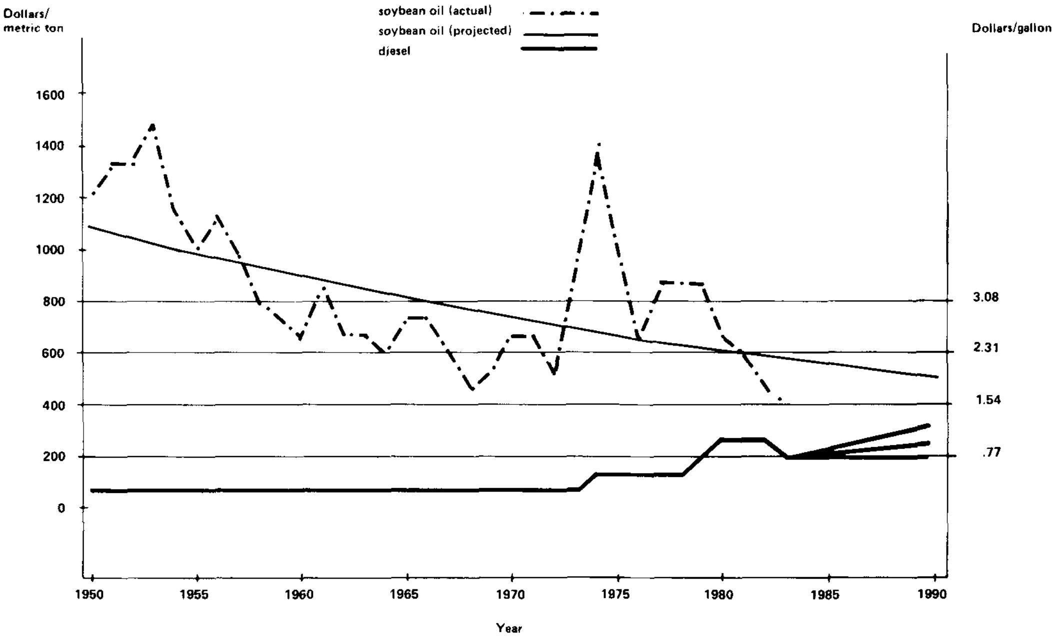

FIG. 4. Actual and projected prices of soybean oil fuel and diesel fuel (in 1982 dollars), 1950-90.

barrel in 1990. The US Department of Energy projections are for $25/barrel in 1985 and $37/barrel in 1990, with a high estimate of $48 and a low estimate of $28 in 1990. The values graphed for 1990 are the diesel prices corresponding to the middle, high and low crude oil price estimates published by the US Department of Energy. The World Bank report did not include high and low estimates.

The graph for soybean oil shows the annual average real prices delivered CIF in Rotterdam, and a semilogarithmic trend line of these prices extrapolated to 1990.

The graph for soybean oil shows two distinct periods: 1950-72 and 1973-83. The first period was characterized by steadily and rapidly decreasing real prices, reaching a low of $450/ton ($1.70/gallon) in 1968. The world oilseed markets were very strong in 1973-75, and trended to a trough in 1983 of $400/metric ton ($1.50/gallon). Taken over the entire 34-year period there is a discernible downward trend that is statistically significant. The relationship with petroleum prices was also tested, but was statistically insignificant. This trend line represents an historical average that abstracts from the cycles and extraordinary conditions. It may be considered as a reference, to compare with diesel fuel prices.

If the trend line is accepted as a crude projection of soybean oil prices, then the prediction for 1990 is for ca. $500/metric ton ($1.94/gallon). This compares to the middle estimate for diesel fuel of $1.10/gallon (based on crude oil at $39/gallon). The low estimate is for 85 ¢/gallon, and the high estimate is $1.40/gallon. For soybean oil fuel to be economical it would have to drop to $285/metric ton compared to the middle petroleum estimate, $365/metric ton for the high estimate, or $220/ton for the low estimate.

Data for coconut and palm oils were interpreted in the same way. Coconut oil has sold at a premium to soybean or palm oil in the past, and its trend line is higher and flatter. Consequently, the general outlook for this oil as a fuel source is not even as promising as soybean oil. The trend line projection for 1990 is $680 ($2.63/gallon). This oil might be considered at times because its price is more volatile than that of soybean oil and the low prices during cycles have dropped below those of other oils.

Palm oil has sold at a discount to soybean oil, and it would therefore be more attractive on economic grounds than the other oils examined here.

A further consideration is offered for coconut and palm oil. They are both primarily produced in tropical countries quite distant from major export markets. To the extent that local prices are substantially below world market prices as represented by these data, the economic viability of these oils as fuels is improved. This was apparently the case in Brazil and the Philippines, where programs were initiated to use low proportion vegetable oil/diesel fuel blends because the local price of the oils was badly depressed. This situation has changed with the recent price increases for vegetable oils and continuing price decreases for petroleum products.

However, it serves to bring up an important point. In many nations, the retail price of motor vehicle fuel (both gasoline and diesel) is substantially greater than the world price for bulk quantities of vegetable oils. The difference is due to large import tariffs and taxes on these fuels.

A survey of world petroleum prices reported by the United States Department of Energy (13) clearly shows the large differences in retail prices between different nations (see Table IV). In January 1982, diesel fuel cost as little as 8 ¢/gallon in Saudi Arabia and as much as $2.50/gallon in Ghana and the United Kingdom. World market bulk prices were ca. $1.00/gallon.

TABLE IV

Retail Price of Petroleum Products in Selected Nations—January 1982 (13, 14)

Nation	Auto diesel fuel ($/gal)	Regular gasoline ($/gal)
Ghana	2.57	3.42
United Kingdom	2.50	2.46
Switzerland	2.34[a]	2.47[a]
South Africa	2.30	2.27
COCONUT OIL	2.06[b]	–
El Salvador	1.98	2.90
PALM OIL	1.93[b]	–
SOYBEAN OIL	1.75[b]	–
Australia	1.90[a]	1.83[a]
South Korea	1.53	4.06
Philippines	1.45	2.36
Jamaica	1.35	2.12
United States	1.05	1.22
DIESEL—Persian Gulf	1.05[c]	–
DIESEL—USA	0.98[d]	–
Argentina	0.60	1.29
Indonesia	0.32	0.91
Saudi Arabia	0.08[a]	0.18

[a] July 1, 1981.

[b] CIF Rotterdam, January 1982.

[c] Posted price, Saudi Arabia, 1982.

[d] Wholesale price from refiners and large distributors, January 1982.

Vegetable oils may have appeared attractive compared to retail diesel fuel at that time with soybean oil (CIF Rotterdam) priced at $1.75/gallon equivalent (20.7 ¢/lb), or $455/metric ton). Palm and coconut oil were slightly more expensive.

Vegetable oils appeared attractive primarily because of the heavy duties and taxes imposed on diesel fuel. The more correct comparison is between the net bulk prices for diesel and vegetable oils on the world market. By this criterion, the vegetable oil fuels still cost appreciably more than diesel fuel, even at a time when vegetable oils were depressed and petroleum prices were near their highest levels in history.

At this point, the question becomes one of whether vegetable oil fuels should be subsidized or taxed for use as a fuel. If vegetable oil fuels are taxed at a low rate, then 1982 was clearly a year where these fuels were economically competitive in some high tax/high duty nations. However, these nations would bankrupt themselves and/or ruin their balance of trade by burning soybean oil worth $1.75/gallon (20.7 ¢/lb of $455/metric ton) on the world market instead of diesel that cost ca. $1.00/gallon on the world market. The nations' balance of trade would worsen by 75¢ for every gallon equivalent of vegetable oil used as fuel.

Emergency Short-Term Situations

The major interest in vegetable oil fuels has arisen in the agricultural area. Farmers were concerned about the availability of diesel fuels during energy crises. It is absolutely essential to have fuel during crucial field operations, and the fact that vegetable oil fuels may cost farmers more than normal diesel prices would be insufficient reason not to use vegetable oil fuels when an entire crop hangs in the balance. Farmers in that situation would pay a great deal more than average to obtain fuel, whether it is for diesel or vegetable oil.

The same argument has been applied to the entire economy (15-17). Fuel shortages affect every sector of the economy, not just agriculture. Over longer periods of time, petroleum will be replaced by coal, synthetics, solar and biomass (such as vegetable oils). However, during short periods the conversion is difficult, if not impossible.

Vegetable oils provide a marked contrast with the other alternative energy sources because they can be added immediately to the energy pool as a diesel fuel substitute or supplement by blending with diesel fuel. Of course, the availability is limited by current world stocks and potential oilseed production during the course of the year. Nonetheless, vegetable oils could be used immediately in an emergency.

Rough estimates of the short-term cost to the US economy of a reduction in petroleum supplies have been made (15-17). This allows an estimate of the value of an additional barrel (or gallon) of petroleum. The volume edited by Plummer (17) presented projections from 4 different analysts that a major interruption reducing US supplies by 2.5 million barrels of petroleum daily (14% of total consumption) would reduce gross national product by between 5 and 12%. The value of additional petroleum to the economy would be between $150 and $340/barrel ($4-9/gallon for diesel fuel).

According to our analysis, the value of vegetable oil as a diesel fuel would be $4-9/gallon ($1,000-2,300/metric ton). These values are clearly large enough relative to historical vegetable oil prices to divert some of the vegetable oil supply into the supply of fuel, whether it is used on farms, industry or transportation. The value of vegetable oils as emergency fuels could be even greater in nations that depend completely on imports for petroleum. Incentives would be very strong to supplement stocks of diesel fuel with indigenous oilseed crops. This would be possible in some of those nations producing coconut and palm oil, as demonstrated next.

THE SUPPLY OF VEGETABLE OIL

Despite the fact that vegetable oils show promise as a fuel, they are unlikely to make an impact on the world diesel fuel market in the near future simply because of limited production. Although vegetable oils have already been used as commercial fuels in several particular instances, these have been exceptional cases, limited to markets with large supplies of particular oils during periods of unusually low prices.

The world's supply of edible vegetable oils was 41 million metric tons in the 1979-80 crop year (14). Translated into energy equivalents, this was nearly 700,000 barrels/day of diesel fuel (Table V). These quantities are insignificant compared to the 63 million barrels/day (13) of petroleum consumption in 1980.

A slightly less pessimistic picture is painted when the comparison is made with world consumption of petroleum distillates—the class of products that includes diesel fuel, but also includes liquid fuels used for residential heating and industrial process heat. World demand for these fuels was 14.5 million barrels/day (compared to gasoline consumption of 14.9 million barrels/day), ca. 21 times greater than world vegetable oil production. Assuming that roughly half of all petroleum distillates are used in transportation, it is noted that ca. 10% of world diesel fuel requirements could be met by diverting total annual production of edible vegetable oils into use as a fuel. Although this is a small proportion, it is not too small a figure to allow this potential fuel source to be ignored by policy makers.

More perspective is gained on this issue by comparing fuel demands and vegetable oil production for particular nations and oilseed crops. Soybeans are the largest source of vegetable oil, and the United States produces over 60% of the world total. The 1979-80 harvest of 62 million metric tons of soybeans in the USA was roughly equivalent to 9.5 million metric tons of oil, or 160,000 barrels/day of diesel fuel equivalent. This compares to United States consumption of 1,347,000 barrels/day of diesel fuel (18,19). The total soybean crop in 1979-80 was roughly equivalent to 12.8% of annual diesel fuel requirements in the United States.

The situation in Brazil is also interesting. The harvest of 15.1 million metric tons of soybeans in 1979-80 potentially yielding 2.3 million metric tons of soybean oil, was roughly equivalent to 39,000 barrels of diesel fuel daily. Brazilian consumption of petroleum distillates in 1980 was 326,000 barrels daily, of which ca. 160,000 barrels daily might be

TABLE V

Vegetable Oil Production and Petroleum Consumption in Major Oilseed Producing Nations—1980 (13, 14)

	Vegetable oil production		Petroleum consumption		Ratio of oil to petroleum distillate (%)
	Volume^a (thousand metric tons)	Fuel equivalent (thousand barrels/day)	Total (thousand barrels/day)	Distillate (thousand barrels/day)	
World—all edible vegetable oils	41,263	699.1	63,033	14,545	4.8
Soybean					
United States	9,472	160.5	17,056	2,855	5.6
Brazil	2,325	39.4	1,164	326	12.1
People's Republic of China	1,145	19.4	1,834	511	3.8
Argentina	560	9.5	499	150	6.3
Coconut					
Philippines	1,274	21.6	225	83	26.0
Indonesia	892	15.1	408	131	11.5
India	213	3.6	643	231	1.6
Malaysia	134	2.3	134	53	4.3
Palm					
Malaysia	2,597	44.0	134	53	83.0
Indonesia	691	11.7	408	131	8.9
Nigeria	520	8.8	148	37	23.8

^{a}Actual production of palm oil; potential production of soybean and coconut oils based on 1979-80 harvest of soybeans and copra and yields of 15.3 and 64%, respectively.

diesel fuel. The annual soybean harvest could have replaced nearly 12% of distillates or 25% of diesel fuel requirements.

The People's Republic of China and Argentina are two other major soybean producers. Their domestic production of soybeans were equivalent to 4% and 6%, respectively, of their annual consumption of distillates.

The two leading producers of copra—the Philippines and Indonesia—annually grow enough to make up 26 and 11.5%, respectively, of their requirements for distillate fuels (and 52 and 23% of diesel fuel requirements).

The leading producers of palm oil have significant levels of production relative to consumption of petroleum distillates. In 1980, Malaysia produced 2.6 million metric tons of palm oil, equivalent to 44,000 barrels/day of diesel equivalent. This compared to consumption of 53,000 barrels/day of distillate, so that palm oil might have replaced 83% of Malaysian requirements. This replacement ratio was 8.9% in Indonesia and 23.8% in Nigeria. These nations might have replaced 166, 18 and 48%, respectively, of diesel requirements.

Note that Indonesia, Malaysia and Nigeria are net petroleum exporters presently.

Palm and coconut oil may also be studied more seriously by a number of small producing nations (see Table VI). These oils are primarily grown in developing countries which have low levels of petroleum consumption. In some of these nations, the indigenous production of vegetable oil could--in an emergency—potentially replace a large share of requirements for distillate fuel. In Africa, the nations of Benin, Cameroon, Guinea, Ivory Coast, Mozambique and Zaire could potentially supplement distillate supplies by 25% or more with their coconut or palm oil. This is also true for the South Pacific nations of Fiji, Papua-New Guinea, Vanuatu and Western Samoa. In some cases, current production of these oils could replace an even greater share of distillate fuel.

Although it is clear that in some places current vegetable oil production might supplement the diesel fuel supply a great deal, it is nonetheless apparent that on a global scale the present vegetable oil production is inconsequential compared to potential fuel demands.

TABLE VI

Vegetable Oil Production Compared to Petroleum Consumption in Selected Developing Nations—1979 (14, 20)

	Vegetable oil production[a]		Petroleum consumption[b]		Ratio of oil to petroleum distillate (%)
	Volume (thousand metric tons)	Fuel equivalent (barrels/day)	Total (thousand barrels/day)	Distillate (thousand barrels/day)	
Coconut					
Dominican Republic	13	220	27.9	6.3	3.5
Fiji	19	322	4.5	1.0	32.8
Jamaica	18	305	31.8	7.2	4.2
Mozambique	38	644	7.9	2.2	28.8
Sri Lanka	106	1,796	15.8	3.5	51.8
Vanuatu	43	72	0.34	0.07	985.4
Western Samoa	13	220	0.51	0.11	196.3
Palm					
Benin	28	474	2.0	0.56	85.1
Cameroon	80	1,355	9.2	2.6	52.2
Costa Rica	31	525	12.2	2.8	18.9
Ecuador	31	525	55.9	12.7	4.1
Guinea	40	678	4.8	1.4	50.2
Ivory Coast	150	2,541	13.3	3.8	67.6
Papua-New Guinea	36	610	10.0	2.2	27.7
Zaire	98	1,660	22.0	6.2	26.6

[a] Actual production of palm oil; potential production of coconut oil defined as 64% of annual copra production.

[b] Estimated as share of total petroleum consumption: 22.7% in South and Central America; 28.3% in Africa and 22.0% in Far East and Oceana.

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REFERENCES

1. Seddon, R.H., Gas Oil Power, August, p. 136 (1942).
2. Chowhury, D.H., S.N. Mukerji, J.S. Aggarwaw and L.C. Verman, DSIR Bulletin No. 19, Delhi, India, 1942.
3. Wiebe, R., and J. Nawakowska, USDA Bibliographical Bulletin No. 10, U.S. Government Printing Office, 1949.
4. Bruwer, J., B. van D. Boshoff, F.J.C. Hugo, L.M. du Plessis, J. Fuls, C. Hawkins, A.N. van der Walt and A. Engelbrecht, Presentation at the 1980 Symposium of the South African Institute of Agricultural Engineers, 1980.
5. Quick, G., Presentation at the 1980 Winter Meeting, Chicago, IL, Paper No. 80-1525.
6. Ryan, T.W., W. Likos and C.A. Moses, Second Annual Technical Progress report for the Period 1 June 1979 - 1 June 1980, Southwest Research Institute, 1980.
7. Cruz, J.M., A.S. Ogunlowo, W.J. Chancellor and J.R. Goss, Presentation at the Pacific Region Annual Meeting, American Society of Agricultural Engineers, Hawaii, 1980, Paper No. 80-027.
8. Hofman, V., W.E. Dinusson, D. Zimmerman, D.L. Helgeson and C. Fanning, Sunflower Oil as a Fuel Alternative, Cooperative Extension Service, North Dakota State University, Fargo, ND, 1980.
9. DeForest, S.S., Summary of a conference held at USDA Northern Agricultural Energy Center, Peoria, IL, 1980.
10. National Academy of Sciences, Vegetable Oils as Diesel Engine Fuels, Informal Report of a Discussion Seminar of the Advisory Committee on Technology Innovation, Board of Science and Technology for International Development, Commission on International Relations, 1980.
11. Swern, D., (ed), Bailey's Industrial Oil and Fat Products, 4th edn., Vols. 1 and 2, John Wiley and Sons, New York, 1979.
12. The World Bank, Commodity Trade and Price Trends, Johns Hopkins University Press, Baltimore, MD, and London, 1982.
13. US Department of Energy, Energy Information Administration, 1981 International Energy Annual, US GPO, Washington, DC, 1982.

14. US Department of Agriculture, Foreign Agriculture Service. Foreign Agriculture Circular: Oilseeds and Products, FOP 7-83 (and other issues), 1983.
15. Stobaugh, R., and D. Yergin, (eds.), Energy Future, Random House, Inc., Ballantine Books Division, New York, 1980.
16. Deese, D.A., and J.S. Nye, (eds.), Energy and Security, Ballinger Publishing Company, Cambridge, MA, 1981.
17. Plummer, J.L., (ed.), Energy Vulnerability, Ballinger Publishing Company, Cambridge, MA, 1982.
18. US Department of Energy, Energy Information Administration, 1982, Annual Energy Review, US GPO, Washington, DC, 1983.
19. US Department of Energy, Energy Information Administration, Energy Price and Expenditure Data Report, 1970-1980, US GPO, Washington, DC, 1983.
20. United Nations, Department of International Economics and Social Affairs. Yearbook of World Energy Statistics, 1979, United Nations, New York, 1981.

Properties and Uses of Some Unsaturated Fatty Alcohols and Their Derivatives

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ABSTRACT

A number of unsaturated fatty alcohols are known, but only those of the C_{16} and C_{18} chain lengths are of much importance. In particular, oleyl alcohol, 9,10-octadecenol-1, is by far the most important. A variety of grades of oleyl alcohols is produced and used in the USA ranging from high purity material having iodine values (IV) of 90-95 to those having IV of 45-55, with the other components being primarily cetyl (hexadecanol-1) and stearyl (octadecanol-1) alcohols. This paper takes a brief look at the various grades of unsaturated alcohols used in the USA, methods of preparation, and the change in physical and chemical properties as the octadecanol-1 content and IV decline. Uses of these alcohols industrially and in cosmetic and pharmaceutical preparations are also discussed. Unsaturated alcohols are useful chemical intermediates since they have two reactive sites, the hydroxyl group and the carbon-carbon double bond. Particular attention is paid to the properties, uses and potential uses of some of their sulfates, ether sulfates, ethylene oxide adducts and ethylene/propylene oxide adducts as detergents and emulsifiers for ultimate use in cosmetics and light-duty and heavy-duty systems. Current estimated consumption of unsaturated alcohols in the USA is discussed.

INTRODUCTION

The best known of the unsaturated fatty alcohols is oleyl alcohol (9-octadecenol-1), although palmitoleyl (9-hexadecenol-1) and myristoleyl (9-tetradecenol-1) are also well known. The latter two, however, are encountered in such small quantities that they are never isolated, and are usually viewed merely as other unsaturated alcohols in an alcohol mixture in which the major component is oleyl alcohol.

Reactions of the unsaturated fatty alcohols at the hydroxyl group are similar to those of the saturated alcohols. The double bond(s) in these alcohols, however, are other reactive sites. As a result, they are subject to side reactions which are frequently undesirable and difficult to control. Derivatives which are dark in color and have a bad odor may result when these compounds are subjected to ammonolysis or esterification. If attempts are made to sulfate these unsaturated alcohols, sulfation or sulfonation tends to occur at the double bond in addition to sulfation at the hydroxyl group unless special precautions are taken. In general, unsaturated alcohols are more expensive than saturated alcohols because of additional processing costs required to protect the double bond.

For these reasons, uses of unsaturated alcohols have been restricted to specialized applications. The influence of the double bond in these unsaturated alcohols, particularly on the physical and performance properties of some of their derivatives, has been largely overlooked or ignored, if recognized at all. Today, mainly because of changing consumer demand, environmental requirements, energy conservation needs and increasing petroleum and ethylene feedstock costs, this picture is beginning to change.

TYPES OF UNSATURATED ALCOHOLS

The major unsaturated alcohol is oleyl alcohol. The pure compound has the physical and chemical properties shown in Table I.

Pure octadecenol-1 is not available commercially. However, in the USA there are various grades of unsaturated fatty alcohols. They are generally called oleyl alcohols if they contain at least 55% oleyl alcohol and have an iodine value (IV) of 65 or higher. These are classified as refined, technical or industrial grade oleyl alcohols. They are characterized for specification purposes by hydroxyl number, iodine value, acid number, saponification number, cloud point, color and odor. Usually the hydroxyl value, iodine value and cloud point data are the main factors used to judge the quality of an oleyl alcohol.

Broadly, these classes of oleyl alcohols will compare as shown in Table II. Slight variations may occur depending on the producer.

In general, the higher the IV and the lower the cloud point (usually below 5 C), the higher the oleyl alcohol content. A rise in cloud point and decline in IV indicate increased saturated alcohol content. These saturated alcohols are usually stearyl and cetyl alcohols. The cloud point is also increased if the ester content is increased to above 1-2% or if C_{16}-C_{18} hydrocarbons are present in

TABLE I

Properties of Oleyl Alcohol

Structural formula	$CH_3(CH_2)_7CH{=}CH(CH_2)_7CH_2OH$
Molecular weight	268.47
Iodine value	94.5
Hydroxyl value	209.0
Melting point (C)	-7.5 (1)