This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 26, No. 2, pp. 322–327 & 332, 1983)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

Vegetable Oil Substitutes for Diesel Fuel

C. L. Peterson, G. L. Wagner, D. L. Auld
MEMBER
ASAE

THE possibility of using vegetable oils as a direct substitute for diesel fuel is one of several concepts for on-farm production of fuel. Vegetable oils, however, show promise of providing all of the liquid fuel needed on a typical farm by diverting 10 % or less of the total acreage to fuel production. The meal remaining from the fuel extraction can be a source of high protein livestock feed which could replace the soybean meal currently imported into the Pacific Northwest. Further, the extraction and processing of vegetable oil is a simple low-energy process that makes use of equipment not unlike that with which farmers are already familiar.

There are some negative aspects to vegetable-oil based fuels. Engine life, in certain cases, has been shown to be drastically reduced. Crop yields are inconsistent. The meal from some of the crops contain compounds which are toxic to livestock. The total cost of the vegetable-oil based fuels still exceeds that of commercially available diesel fuel.

Research at the University of Idaho on use of vegetable oil fuel is interdisciplinary in that plant scientist are involved in variety and breeding studies; agricultural and chemical engineers are studying fuel properties, fuel formulations, fuel storage, engine testing, and oil processing; animal scientists are involved in feeding studies; and agricultural economists are involved with economic evaluation, economics of scale and farm budgets.

Data from a regional crop introduction project (Auld et al., 1981) indicates that sunflowers, safflower, and winter rape produce the highest yields of vegetable oil in the Pacific Northwest. Based on this prior research, five types of oil have been considered by the Idaho researchers: oleic safflower, linoleic safflower, high erucic acid rapeseed (winter rape), low erucic acid rapeseed (spring rape), and sunflower. The objectives of this work were to determine the chemical and physical properties of these oils and to conduct short- and long-term tests of engines which use vegetable oils as fuel.

REVIEW OF LITERATURE

It has been reported that Rudolph Diesel, the inventor of the compression ignition engine, used peanut oil for fuel in a 1900 demonstration. Reference to vegetable oil as a potential fuel has occasionally appeared in the literature since that time with many different types of oils being mentioned. However, not until the energy crisis of 1974 was there serious interest into non-petroleum based alternative fuels such as vegetable oils.

Engelman et al. (1978) present data on waste soybean-diesel oil blends compared with the diesel fuel alone in short-term engine tests. They conclude that use of the blends is feasible, but long-term test data are lacking.

Bruwer et al. (1980) in South Africa, reported on sunflower seed oil as a fuel and concluded that in short-term tests it was comparable to diesel fuel. In long term tests lubricating oil problems, sticking piston rings, and injector atomization patterns all contributed to engine mechanical difficulties. A more recent news release from South Africa (duPlessis, 1981) indicates that they have successfully operated an air-cooled, precombustion chamber engine for 2300 h at a constant 70 % load on 100 % sunflower oil. They suggest that this result is a major breakthrough in the quest for using vegetable oil as a fuel.

Quick (1980), Hofman et al. (1981), and Peterson et al. (1981) report on various tests each using sunflower, safflower, and/or winter rape as fuels. Their results are similar to those of Bruwer. Quick suggests that blends of 20 percent sunflower oil—80 percent diesel could probably be used now. All express caution as premature use before testing is complete could result in severe engine damage and a voiding of manufacturer warranties.

Deere and Company (Barsic and Humke, 1981) has reported tests with sunflower and peanut oil and blends with No. 2 diesel fuel. Injector deposits, and filter plugging were problems. A trend to slightly higher HC, CO, and particulate emissions were considered to be a result of using a fuel system optimized for diesel fuel. NOX emission were not significantly changed.

Catepiller (Bartholomew, 1981) has initiated extensive tests using vegetables oil fuels as well as other alternative fuels. When using vegetable oil as a fuel, they have found a distinct advantage for precombustion chamber engines compared to direct injection engines and to full load operation avoiding light loads. Caterpiller has extended their warranty on some engines operating on up to 10 % vegetable oil, but only in Brazil. Warranty for partial vegetable oil use demonstrates acceptance by a major manufacturer of the general concept of vegetable oil based blends.

Volkswagen do Brazil (Pishinger et al., 1981) has tested vegetable oil in the Volkswagen Passat, which has a prechamber diesel engine, with a 30 % salad oil blend with diesel, 100 % salad oil, and processes methyl esters of the begetable oils. Their tests strongly support the choice of monoesters, in place of straight vegetable oils, as the best diesel fuel altervative. Quick (1981), however, points out that the extra cost and high crystalization temperature (0 °C) are problems with esters. Hugo (1981) also reports that incomplete removal of the catalyst used in the transesterification process will result in severe fuel system corrosion when the ester is used in the engine.

Article was submitted for publication in February, 1982; reviewed and approved for publication by the Power and Machinery Div. of ASAE in October, 1982. Presented as ASAE Paper No. 81-3578.

Approved as Paper No. 8232 of the Idaho Agricultural Experiment Station.

The authors are: C. L. PETERSON, Professor, G. L. WAGNER, Scientific Aid, Agricultural Engineering Dept.; and D. L. AULD, Professor, Plant and Soil Sciences Dept., University of Idaho, Moscow.

The literature verifies that vegetable oil can be used as direct replecement for diesel fuel in existing engines with no modifications if used only for short periods. However, modifications to both engines and fuels such as precombustion chambers, improved lubricating oils, and identification of acceptable blends or modifications of each vegetable oil type and appropriate additives may be needed before vegetable oils can be safely recommended for general use.

PROCEDURE

The vegetable oils were obtained from commercial processors in all cases except for the winter rape oil used in the endurance tests. This oil was processed with a CeCoCo expeller operated by the University of Idaho. Filtering the sediment was the only additional processing. The commercial oils were alkali refined and degummed. Each oil was evaluated to determine (a) fatty acid composition, (b) specific gravity, (c) viscosity, (d) heat of combustion, and (e) ash content. The oils were then evaluated in short term engine tests to determine their effect on engine performance. Four cycles of long-term (830 h) tests were conducted to evaluate potential effects on engine life.

Fatty acid content was determined on a Packard-Becker model 419 gas chromatograph with a flame ionization detector. Physical characteristics were evaluated in accordance with ASTM procedures for petroleum products. Viscosity was measured in Cannon-Fenske viscosimeters and heat of combustion in a Parr model 1241 bomb calorimeter with an adiabatic jacket.

Short term engine tests were conducted on a Ford 4-cylinder, 2.8 L, direct injection diesel engine and multi-hole type injectors. The engine was connected to a General Electric cradled dynamometer. The engine fuel system was modified by adding an additional spin-on fuel filter and a 3-way, hand-operated, two-position directional control valve which allowed rapid switching between the No. 2 diesel used as a standard and the test fuel. Each vegetable oil fuel was used to power the engine for 20 min. An identical diesel fuel test was conducted both before and after each vegetable oil test. Switching between tests was done under load in all cases. The fuel filter on the test oil line was changed for each new vegetable oil blend. Data collected included dynamometer load and rpm, fuel consumption at 5-min intervals, and temperature of the incoming air, oil, engine coolant, fuel, and exhaust. Each oil was tested three times and the data were analyzed using a completely randomized design. Similar procedures were used for varying power and torque performance tests.

Two Yanmar model TS70C, 376-cc, single-cylinder, water-cooled, diesel engines with precombustion chambers and pintle type injectors were used for long-term tests. Four cycles on each engine; two each on diesel fuel, linoleic safflower oil and 70 % winter rape—30 % No. 1 diesel fuel blend with and without a dispersant additive were conducted.

The safflower oil was chosen for the first tests because of its low viscosity. The winter rape blend was chosen because the erucic acid has only one double bond which reduces the oxidation and polymerization rates. The diesel fuel was added to the winter rape to reduce the viscosity to acceptable levels.

Test cycle number one used 100 % safflower in one engine and No. 2 diesel in the second engine. Test cycle number two used the same fuels only the engines were reversed. Test cycles numbers three and four used 70 % winter rape—30 % diesel in one engine and 70 % winter rape—30 % diesel with a DuPont FOA-2 (DuPont, 1980) additive in the second engine. Before and after each test, the engines were completely disassembled to measure clearances and weight critical components such as bearings and rings.

The engines were connected to electric generators with resistor banks for load units. The engines were operated at wide open governor control with the load cycle on and off at 15-min intervals. Once each day the engines were stopped for general maintenance and were stopped for longer periods at irregular intervals for convenience of running the tests. For example, when the Mount St. Helens volcano erupted, the engines were shut down to avoid possible damage due to ash fallout. The total time of the tests was determined from the first test and was simply the time at which the safflower fueled engine would no longer start (830 h). This time was repeated for the other tests.

Oil analyses were conducted by a laboratory which performs oil analysis as a part of their regular commercial business.

A three-cylinder Ford model 4600 tractor was also operated on 100 % linoleic safflower oil for 150 h over a 15-mo period. The tractor was first operated on a 50-50 mixture of sunflower oil and diesel beginning December 27, 1979. Beginning on June 6, 1980 the tractor was run on 100 percent safflower oil from the main fuel tank. The test was terminated in August 1981 when the engine was disassembled for inspection. The tractor was used for approximately 120 h for general farm work and the remainder on short term demonstrations in many areas of Idaho. Engine inspection included an evaluation of the diesel injector pump by a commercial pump repair firm.

RESULTS AND DISCUSSION

Chemical Properties

Vegetable oils consist primarily of triglycerides with fatty acid chains 16 to 22 carbons in length. Classification of the vegetable oils by their predominant fatty acid is shown in Table 1. Three groups result:

Group 1. Sunflower and linoleic safflower have high concentrations of linoleic acid.

Group 2. Oleic safflower and spring rape are high in oleic acid.

Group 3. Winter rape is high in erucic acid.

The fatty acids with one double bond in their structure, such as erucic, have oxidation rates about 10 times slower than those with two double bonds and about 15 times slower than those with three double bonds at temperatures in the range of 20 °C to 100 °C (Considine, 1974). The oxidation rate is an important factor for estimating gum formation in storage. Thermal polymerization causes gumming of the piston rings and tends to increase the viscosity of the lubricating oil. Thermal polymerization rates were determined in the laboratory at 200 °C. Winter rape developed less gum in these tests than did the other oils. The rates of thermal polymerization and oxidation were deciding factors in selecting winter rape as the test fuel for the third and fourth endurance tests.

TABLE 1. FATTY ACID COMPOSITION OF FIVE VEGETABLE OILS LISTED AS PERCENT BY WEIGHT METHYL ESTER FOR EACH

	Fatty acid						
Oil Type	Palmitic 16:0‡	Stearic 18:0	Oleic 18:1	Linoleic 18:2	Linolenic 18:3	Eicosenoic 20:1	Erucic 22:1
	---% by weight methyl esters§---						
Sunflower	6.4	4.2	23.9	61.4	3.0	—	—
Linoleic safflower	7.1	2.5	13.3	76.6	—	—	—
Oleic safflower	5.4	2.1	75.3	16.1	—	—	—
Winter rape*	4.4	1.8	59.8	20.6	11.1	—	0.9
Spring rape†	3.2	1.1	14.8	12.7	—	17.7	46.7

*High erucic acid variety winter rape.
†Low erucic acid wariety spring rape (Canola).
‡Number of carbons and unsaturated bond, respectively, for each fatty acid.
§May not sum to 100% due to the presence of other minor fatty acids.

TABLE 2. PHYSICAL CHARACTERISTICS OF FIVE VEGETABLE OILS AND NO. 2 DIESEL.

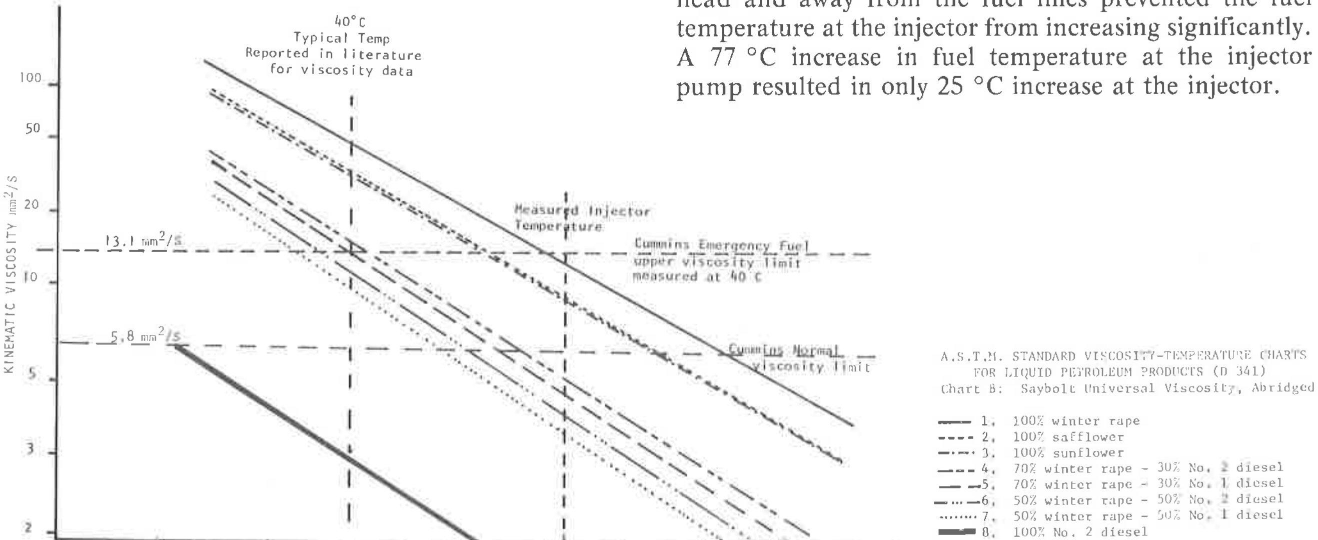
	Higher heat of combustion		Kinematic viscosity		Specific gravity		Ash	
Oil	KJ/L	Ratio‡	mm^2/S (37.8°C)	Ratio‡		Ratio‡	(%)	Ratio‡
Sunflower	36327.0	0.94	34.9	12.0	0.92	1.08	0.0046	0.37
Linoleic safflower	36379.0	0.94	32.3	11.1	0.93	1.09	0.0074	0.60
Oleic safflower	36032.0	0.94	42.1	14.5	0.92	1.08	—	—
Winter Rape*	36330.0	0.95	51.0	17.6	0.91	1.07	0.0043	0.35
Spring Rape†	36543.0	0.95	39.0	13.4	0.92	1.08	0.00984	7.9
No. 2 Diesel	38498.0	1.00	2.9	1.00	0.85	1.00	0.0124	1.0

*High erucic acid variety winter rape.
†Low erucic acid variety spring rape (Canola).
‡Relative to No. 2 Diesel.

Physical Properties

The physical properties determined at the University of Idaho are shown in Table 2. The vegetable oils are 7 to 9 % heavier than diesel fuel; contain only 94 to 95 % as much energy per liter; have viscosities 11 to 17 times higher than that of diesel fuel; and the ash content was found to be less than diesel in all cases except for the spring rape.

Viscosity-temperature relationships for the vegetable oil diesel blends have been developed (Fig. 1). Actual measurement of the fuel temperature at the injector on two engines, one air-cooled and one water-cooled, has shown temperatures of 85 °C to be typical. In selecting a blend of oil for the long-term engine tests, temperatures of the fuel at the injector were used to compare the viscosity of the blend with diesel fuel recommended viscosities. Diesel fuel was added to bring the viscosity of the blend close to the upper limit (13.2 mm^2/s) set as the emergency fuel specification published by the Cummins Engine Company (1980). Referring to Fig. 1, note that a temperature of 140 °C would need to be reached by 100 % winter rape to equal the viscosity of the 70 % winter rape—30 % diesel mixture at 85 °C (actual injector temperature); whereas, comparing the fuels at 40 °C would indicate a fuel temperature of the 100 % winter rape of only 82 °C to obtain equal viscosities. heating to raise the temperature of the fuel at the injector pump did not result in a corresponding increase in injector fuel temperature. It was found that the rapid transfer of heat away from the injectors to the engine head and away from the fuel lines prevented the fuel temperature at the injector from increasing significantly. A 77 °C increase in fuel temperature at the injector pump resulted in only 25 °C increase at the injector.



Data for this chart was developed by M. Slusser and D. Diezieger, Mechanical Engineering students at the University of Idaho.

Fig. 1—Viscosity vs. temperature for vegetable oil blends.

TABLE 3. DIESEL ENGINE* PERFORMANCE USING VEGETABLE OIL AND VEGETABLE OIL-DIESEL MIXTURES AS A FUEL.

Fuel type	KW	Fuel kg/h	Fuel L/h	BSFC†, kg/kwh	BSVC, kW·h/L	Exhaust Temp., °C	Energy kJ, kJ/kg	Thermal efficiency, %	Fuel weight, kg/L
100% Sunflower	29.5	10.1	11.0	0.34	2.70	660	39486	26.6	0.92
75% Sunflower	29.8	10.3	11.4	0.34	2.64	667	40854	25.5	0.91
50% Sunflower	30.2	10.2	11.4	0.33	2.64	671	42273	25.2	0.89
25% Sunflower	29.6	9.5	11.0	0.32	2.70	659	43752	25.6	0.87
100% Diesel	29.4	9.4	11.0	0.32	2.66	663	45292	24.9	0.85
100% Linoleic Saffl.	29.4	9.8	11.0	0.34	2.70	659	39542	27.3	0.92
75% Linoleic Saffl.	29.8	10.1	11.4	0.34	2.68	666	40893	26.0	0.91
50% Linoleic Saffl.	29.8	9.8	11.0	0.33	2.70	659	42301	25.9	0.89
25% Linoleic Saffl.	29.7	9.6	11.0	0.32	2.68	667	43766	25.4	0.87
100% Diesel	29.1	9.4	11.0	0.32	2.64	661	45292	24.6	0.85
100% Winter Rape	28.9	9.7	10.6	0.33	2.72	692	39923	26.8	0.91
75% Winter Rape	29.4	10.4	11.7	0.35	2.54	704	41170	24.7	0.90
50% Winter Rape	29.6	10.3	11.7	0.35	2.56	715	42517	24.3	0.89
25% Winter Rape	29.2	9.9	11.4	0.34	2.56	710	43850	24.2	0.86
100% Diesel	28.2	9.3	11.0	0.33	2.58	690	45292	24.1	0.85
100% Spring Rape	29.9	10.3	11.2	0.34	2.67	700	39721	26.3	0.92
75% Spring Rape	30.1	10.4	11.2	0.34	2.68	701	41031	25.4	0.91
50% Spring Rape	30.5	10.3	11.1	0.34	2.74	707	42394	25.1	0.89
25% Spring Rape	30.1	10.2	11.1	0.34	2.72	698	43813	24.2	0.87
100% Diesel	29.4	9.7	11.4	0.33	2.58	698	45292	24.1	0.85
100% Oleic Safflower	29.8	10.1	11.0	0.34	2.71	695	39165	27.1	0.92
75% Oleic Safflower	30.0	10.4	11.3	0.35	2.65	703	40612	25.6	0.90
50% Oleic Safflower	30.3	10.0	10.9	0.33	2.78	707	42112	25.9	0.88
25% Oleic Safflower	30.2	10.1	11.0	0.33	2.74	709	43671	24.6	0.87
100% Diesel	29.0	9.7	11.4	0.33	2.55	693	45292	23.7	0.85

*Information in this table was obtained on a 2.8 L Ford 4-cylinder, 2,200 rated rpm diesel engine.
†BSFC is Brake Specific Fuel Consumption and is a measure of work output per unit of fuel used.

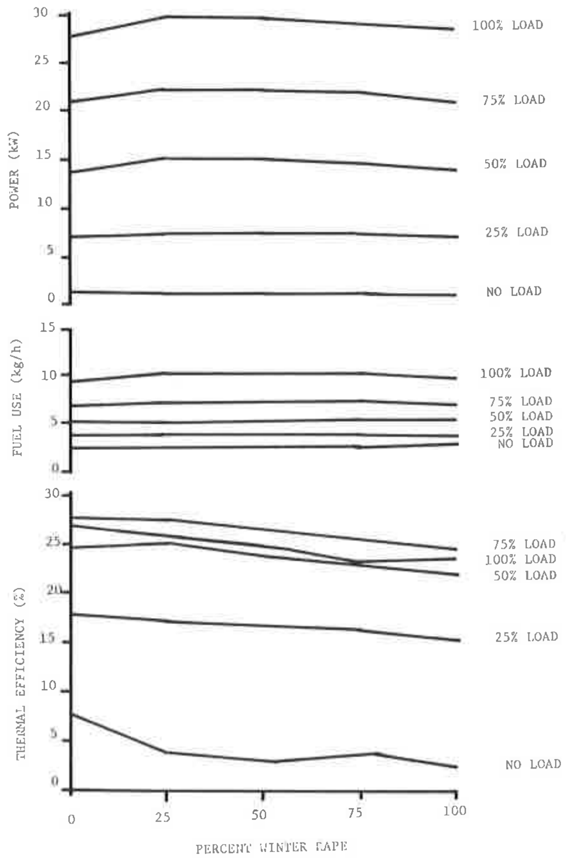


Fig. 2—Power, fuel consumption, and thermal efficiency measured in a varying load test with winter rape-diesel blends as fuel. Engine used was a 2.8 L direct injection 4-cylinder diesel with hole-type injectors manufactured by Ford (the data is typical of the other vegetable oils tested).

SHORT TERM PERFORMANCE TESTS

Three sets of performance data were developed. Maximum power and fuel consumption at rated engined rpm (Table 3), varying power and fuel consumption at rated engine rpm (Fig. 2) and maximum torque and varying engine rpm (Fig. 3) are reported for the 4-cylinder, direct injection engine connected to the laboratory dynamometer.

During the maximum power and fuel consumption tests, the power output of the engines did not vary significantly for the different fuel types although there was a general tendency for power to increase 2 to 3 % with the 50-50 blends. Fuel consumption by volume was the same as for diesel fuel and thus was higher for the vegetable oils on a weight basis. Thermal efficiency was also higher for the vegetable oil fuels.

Only the data for winter rape blends are shown for the varying power and fuel consumption tests (Fig. 2). The data for the other fuels is very similar. Both the maximum power and varying power tests show slight differences in engine performance, but they are so small that in actual operation of an engine an operator would not detect which of the different fuels was in use. Only the 100 % vegetable oil torque test is shown, Fig. 3. Tests were conducted with sunflower, linoleic safflower, and winter rape. Various blends of the oils with diesel were included in the tests but the data were deleted as explained below. Torque, power, and BSFC were measured in 200 rpm steps from 2200 to 1000 rpm.

The test engine was severely damaged during the conducting of the torque tests. Operating the engine with 100 % sunflower oil under load at reduced engine rpm severely gummed the piston rings causing an almost immediate loss of power, and an increase in engine blow-by. This experience causes the authors to believe that maximum torque tests are an essential part of endurance

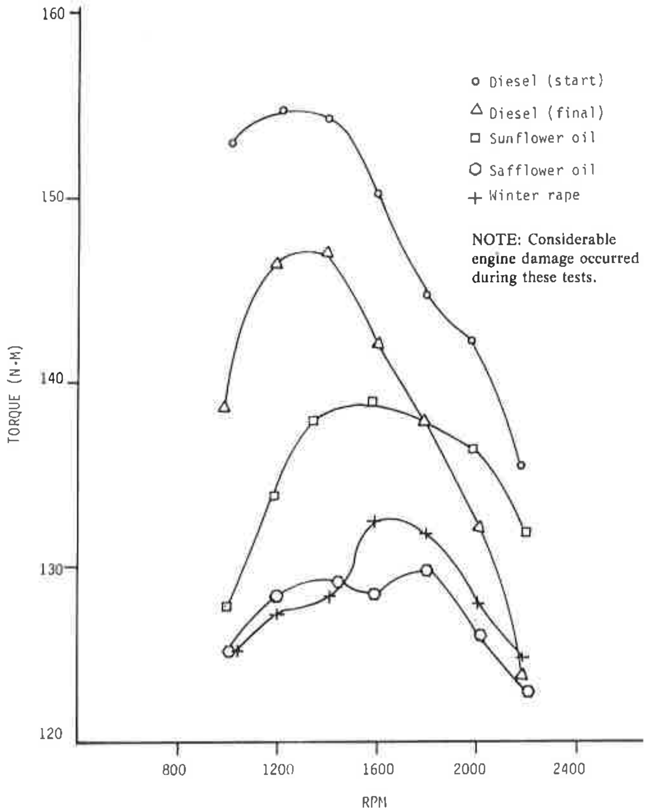


Fig. 3—Torque curves for diesel fuel and 100 percent vegetable oil fuels. Engine used was a 2.8 L direct injection, four cylinder engine manufactured by Ford.

test cycles and should be included in test procedures. Since engine damage occurred early in the torque tests, a considerable difference in engine power between the beginning and ending test cycles on diesel can be observed in the test data of Fig. 3. Because of the engine damage, reliability of the data is in question and the remaining data were deleted.

LONG TERM ENGINE SCREENING TESTS

Long-term testing thus far has included 1660 hours (two 830-h tests) on each of the following fuels: 100 percent linoleic safflower oil, 70 % winter rape—30 % No. 1 diesel with and without DuPont FOA-2 dispersant additive added at the rate of 150 ppm, and 100 % diesel. Power, fuel consumption, and wear data for the four long-term test cycles are shown in Table 4.

Measurements and weights showed about twice the wear rate for the safflower-fueled engine compared to the diesel engine. The safflower-fueled engine also showed more carbon in the combustion chambers and additional varnish and carbon build-up on the injector nozzle. At the conclusion of the first test, the injector in the safflower engine had seized and the engine would no longer start. A broken fan belt at about 700 h allowing the engine to overheat and insufficient oiling of the valve train caused by a blocked oil line undoubtedly affected the results of the first test. The second test, without those problems, still resulted in the piston ring gumming problems, a loss of compression, and increased blow-by.

For the test durations indicated and for the particular engine used, the winter rape blend is clearly superior to the linoleic safflower as a fuel. In all cases where the safflower oil has been used, the engines have suffered severe degradation primarily as a result of ring gumming, lubrication oil thickening, and some injector gumming. None of these problems were found in the engines fueled with winter rape oil. Some gumming was noted on the upper piston land although it had not progressed to a point where it had any effect on engine performance.

Oil analysis data confirmed the results of engine measurements, Table 5. A tendency for the oil to thicken was noted in the 100 % safflower tests. A ratio of beginning to final lubricating oil viscosity of 2.6 was noted for the safflower engine, 1.6 for the diesel engines, had an increase of 1.6 for the winter rape blend and winter rape blend with additive, respectively.

The oil analysis also indicated excessive oxidation, high iron, aluminum, chromium, silver, molybdenum, tin, and lead for the engine operated on linoleic safflower. The engine fueled with the winter rape blend was equivalent to diesel in nearly all of these factors. No engine maintenance problems would have been detected by the oil analysis data during the long term endurance cycle using winter rape as a fuel.

It would appear from the oil analysis, wear measurements, and engine performance data that the fuel additive was detrimental to the engine. The additive did appear to drastically decrease fuel filter plugging by a factor of 5:1.

While the test data show that use of a winter rape blend may be feasible, additional testing will be required with many types of engines before it can be recommended for general use. Anyone contemplating

TABLE 4. POWER, FUEL CONSUMPTION, AND WEAR DATA FROM LONG TERM SCREENING TESTS USING SINGLE CYLINDER, 376 cc, PRE-COMBUSTION CHAMBER YANMAR TS70C TEST ENGINES.

	Test #1		Test #2		Test #3		Test #4	
Engine no.	11	22	11	22	11	22	11	22
Fuel	100% Saff.	100% Diesel	100% Diesel	100% Saff.	70% W. Rape 30% Diesel	70% W. Rape 30% Diesel	70% W. Rape 30% Diesel	70% W. Rape 30% Diesel
Additive	None	None	None	None	None	DuPont FOA-2	DuPont FOA-2	None
Hours of test	830	830	883.4	837.8	853.8	851.0	807.9	819.5
Comp. change (%)	N.A.	N.A.	-6	-10	-6.2	-3.1	-3.1	+1.5
Power drop (%)	N.A.	N.A.	+5*	+2*	-4.5	-2.7	-14.5	-12.4
Fuel cons. L/h	0.83	0.79	0.79	1.36	0.87	1.06	0.89	1.15
Stuck rings	2	0	0	2	0	0	0	0
Ring #1, g†	0.173	0.124	0.123	0.150	0.169	0.260	0.1987	0.1324
Ring #2, g	0.078	0.039	0.054	0.262	0.086	0.188	0.1161	0.0914
Ring #3, g	0.037	0.029	0.042	0.380	0.047	0.098	0.0797	0.0412
Oil ring, g	0.022	0.034	0.038	0.107	0.048	0.121	0.1096	0.0582
Rod bearing, g	0.088	0.026	0.059	0.138	0.014	0.019	0.0300	0.0217
Piston, g	0.00	0.09	0.32	0.00	0.10	0.40	0.3900	0.2000
Upper cyl. wear, mm	0.025	0.025	0.010	0.028	0.013	0.025	0.013	0.00

*These data are not directly comparable because of changes in the fuel setting.
†Numbers are change in weight of component between start and finish of test in grams.

TABLE 5. OIL ANALYSIS DATA FOR LONG TERM ENDURANCE TESTS (850 HOURS) WITH 376 CC DISPLACEMENT SINGLE CYLINDER PRECOMBUSTION CHAMBER, YANMAR DIESEL ENGINES (DATA BY MONTECH, INC., SPOKANE, WASHINGTON). FIGURES REPORTED ARE THE AVERAGE OF DATA COLLECTED AT THE END OF EACH OIL CHANGE OR APPROXIMATELY 100 HOURS.

Fuel used	Ave. hours on oil	Viscosity (mm^2 /s @ 38° C)	Ratio	Fuel Dilution §	Oxidation §	Silicon §	Iron §	Copper §	Aluminum §	Chromium §	Magnesium §	Silver §	Moly §	Tin §	Lead §
100% Safflower	104.7	291.5*	2.6	N	M-E	21.6	131.5	5.25	34.0	5.49	19.75	0.75	4.25	19.1	18.3
70% Winter rape 30% Diesel	105.4	149.6†	1.5	N	N	16.3	46.8	6.0	11.0	2.7	24.7	1.0	1.6	6.1	8.5
70% Winter rape 30% Diesel with FOA-2 Additive	104.2	157.8†	1.6	N	M	17.5	52.6	7.6	12.7	3.2	27.0	0.8	1.7	6.7	8.0
100% Diesel	110.4	182.8*	1.6	N	N	8.0	37.9	3.2	7.9	2.5	18.5	0.03	0.5	4.0	10.1

*Oil used was Delo 400 SAE30 with initial viscosity of 113.0 mm^2 /s @ 40° C.
†Oil used was Delo 300 SAE15w-40 with initial viscosity of 10 mm^2 /s @ 40 °C.
‡N = Normal; M = Marginal; E = Extreme.
§ Values given are in parts per million.

the use of vegetable oil in a diesel engine should be aware of the possible consequences and be prepared to assume the risks.

Tractor Demonstration

A Ford 4600 3-cylinder tractor fueled by 100 % alkali refined safflower oil has been used for demonstration purposes. The engine was operated on a 50-50 sunflower oil-diesel fuel mixture for less than 5 h and then was switched to 100 % safflower oil. The engine continued on 100 % safflower oil for 15 mo and accumulated 154 engine hours; about 120 h doing field work and 35 h in demonstration work. At the end of that period the power had declined by 30 % and the tractor was quite hard to start. Engine inspection showed severe piston ring seizing, sluffing of the piston onto the cylinder walls, and pitting of the rod bearings.

The injector pump from the Ford 4600 tractor was taken to Spokane Diesel Pump Repair in Spokane, Washington for inspection and testing. The pump is manufactured by CAV and is the rotary distributor type. During the disassembly and inspection of the pump, a gold colored sediment accumulation was discovered under the top cover. The sediment was the only abnormal condition found. The head, barrel, and charge pump condition are good indicators of the fuel's effects on the pump, and these items showed no wear or abnormal markings. Also, no oxidized fuel was found inside the pump. The injector pump was then placed on a pump test stand where high idle, low idle, fuel delivery, charge pump pressure, pump advance, and the high and low idle speed settings were all checked and found to be normal. A slight adjustment in the fuel cut-off setting was made.

CONCLUSIONS AND OBSERVATIONS

While vegetable oil cannot yet be recommended as a fuel for general use, considerable progress in utilization has been made. The following specific conclusions and observations result from the study:

1. High viscosity and a tendency to polymerize within the cylinder are major chemical and physical problems.
2. Attempts to reduce the viscosity of the vegetable oil by pre-heating the fuel were not successful.
3. Short-term engine performance with vegetable oils as a fuel in any proportion show power output and fuel consumption to be equivalent to that for the diesel-fueled engine.
4. Severe engine damage occurred in a very short time period in tests of maximum power with varying engine rpm. Additional torque tests with all blends need to be conducted.
5. A blend of 70 % winter rape—30 % No. 1 diesel has been successfully used to power a small single cylinder, swirl chamber, diesel engine for 850 h. No adverse wear, effect on lubricating oil or effect on power output were noted.
6. A diesel injector pump used for 15 mo and with 154 h of opertion with linoleic safflower had no abnormal wear, gumming, or corrosion.

References

1. Auld, D., B. Bettis, and N. Porter. 1981. Development of oilseeds as alternative crops for the Pacific Northwest. Yearly report of the University of Idaho, Washington State University, and Oregon State University Agricultural Experiment Stations submitted to the Pacific Northwest Regional Commission.
2. Barsic, N. J. and A. L. Humke. 1981. Vegetable oils: diesel fuel supplements? Automotive Engineering 89(4):37-41.
3. Bartholomew, D. 1981. Vegetable oil fuel. Journal of American

(continued on page 332)

Vegetable Oil Substitutes

(continued from page 327)

Oil Chemists Society, April, pp. 286-288.

4. Bruwer, J. J., B. D. Boshoff, F. J. C. Hugo, L. M. duPlessis, J. Fuls, C. Hawkins, A. N. VanderWalt, and A. Engelbrecht. 1980. Sunflower seed oil as an extender for diesel fuel in agricultural tractors. Presented at the 1980 symposium of the South African Institute of Agricultural Engineers on 11 June 1980.

5. Considine, D. M. 1974. Chemical and process technology encyclopedia. McGraw-Hill Book Co. p. 1132.

6. Cummins Engine Company. 1980. Fuel for Cummins engines. Service bulletin No. 3379001-03. Columbus, IN 47201.

7. duPlesses. P. T. C. 1981. Sunflower oil as tractor fuel: research report. News release, Department of Agriculture and Fisheries, Republic of South Africa. 15 June.

8. DuPont. 1981. Fuel oil additive No. 2. Specification sheet A040531. E. I. duPont, deNemours, and Company, Petroleum Chemicals Division, Wilmington, DE 19898.

9. Economic Research Service—USDA. 1976. Energy and U.S. agriculture: 1974 data base. U.S. Government Printing Office.

10. Engelman, H. W., D. A. Guenther, and T. W. Silvis. 1978. Vegetable oil as a diesel fuel. Diesel & Gas Engine Power Division of ASME. Paper 78-DG-P-19 presented November 5-9, 1978.

11. Hofman, V., D. Kaufman, D. Helgeson, and W. E. Dinusson. 1981. Sunflower for power. NDSU Cooperative extension Service Circular AE-735. Fargo, ND.

12. Hugo, F. 1981. Sunflower oil as a diesel fuel replacement: the South African research program. Proceedings of Vegetable Oil as Fuel Seminar II, NAEC-CRRC, Peoria, IL.

13. Peterson, C. L., D. L. Auld, V. M. Thomas, R. V. Withers, S. M. Smith, and B. L. Bettis. 1981. Vegetable Soil as an agricultural fuel for the Pacific Northwest. University of Idaho Agricultural Experiment Station Bulletin No. 598.

14. Pischinger, G., F. C. Clymans, and R. S. Sickman. 1981. Diesel Oil Substitution by Vegetable Oils—Fuels Requirements and Vehicle Experiments. Volkswagen do Brazil S/A, 04217. Sao Paulo, Brazil.

15. Quick, G. R. 1980. Developments in use of vegetable oils as a fuel for diesel engines. ASAE Paper No. 80-1525, ASAE, St. Joseph, MI 49085.

16. Quick, G. R. 1981. A summary of some current research on vegetable oils as candidate fuels for diesel engines. Proceedings of Vegetable Oil as a Fuel Seminar II, NAEC-NRRC, Peoria, IL.