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# Fuel Characteristics of Vegetable Oil from Oilseed Crops in the Pacific Northwest[1]

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## ABSTRACT

The purpose of this research was to evaluate vegetable oil from various oilseed crops adapted to the Pacific Northwest as a potential source of liquid fuel for diesel engines. Sunflower (*Helianthus annuus* L.), oleic and linoleic safflower (*Carthamus tinctorius* L.), and low and high erucic acid rapeseed (*Brassica napus* L.) oils were evaluated for fatty acid composition, energy content, viscosity, and engine performance in short term tests. During 20 minute engine tests power output, fuel economy and thermal efficiency were compared to diesel fuel. The long term effect of using linoleic safflower oil as a fuel was evaluated in a single cylinder diesel engine operated for 830 hours.

Vegetable oils contained 94-95% of the energy content (KJ/L) of diesel fuel, but were 11.1-17.6 times more viscous. Viscosity of the vegetable oils was related to fatty acid chain length and number of unsaturated bonds ($R^2$ =.99). During short term engine tests, all vegetable oils produced power outputs equivalent to diesel, and had thermal efficiencies 1.8-2.8% higher than diesel. After 830 hours of operation, linoleic safflower oil formed extensive carbon deposits in the combustion chamber and exhaust port and heavy gum deposits on the injector and compression rings. The development of an additive package to inhibit carbon and gum formation is essential before pure vegetable oils can be used for long term operation of diesel engines.

Additional index words: Vegetable oil, Fatty acid composition, Fuel performance, Thermal efficiency, Energy content, Viscosity, Long term

engine performance, Oilseed crops, Helianthus annuus L., Carthamus tinctorius L., Brassica napus L.

Agricultural production on the 5.1 million cultivated hectares in the Pacific Northwest currently requires 840 million liters of liquid fuel annually (10). In recent years, the agricultural industry has been threatened by the increased costs and limited supplies of conventional petroleum fuels. The production of liquid fuels from agricultural products could insure a continuous supply of fuel for this industry.

Recent research on agriculturally produced fuels (biofuels) has concentrated on alcohol. Using existing technology, alcohol production from corn nets less that one cal for each cal of input (2, 9, 10). Major engine modifications are required in order to use alcohol as a substitute for diesel fuel (10). Because most energy intensive operations in crop production involve the use of diesel engines, it is becoming increasingly imperative that the technology to produce a substitute for diesel fuel be developed.

Researchers at the University of Idaho and North Dakota State University estimate that dryland production regions could produce the liquid fuel necessary for crop production by diverting 10% of the total crop acreage to an oilseed crop (7, 10). The extraction and processing of vegetable oil to a fuel grade product requires relatively simple technology. Small expeller presses and simple filtering systems would allow individual farms or cooperatives to process their own fuel.

In short term engine tests the performance of vegetable oil is essentially identical to that of diesel fuel (2, 6, 7, 10). In long term engine tests, where sunflower (<u>Helianthus</u> <u>annuus</u> L.) oil was the principle component in fuel mixtures, carbon residues gradually decreased engine power and shortened injector life (2). Economic analyses indicate that refined vegetable oils currently cost more than diesel fuel (7, 9, 10). However, if the price of petroleum-derived fuels continues to rise more rapidly than the price of oilseed crops, it may become economically feasible to use vegetable oil as an agricultural fuel. During periods of diesel fuel shortages, vegetable oil could be a valuable substitute to insure continuous crop production.

Data from a regional project indicates that sunflower, safflower (Carthamus tinctorius L.) and winter rape (Brassica napus L.) produce the highest yields of vegetable oil in the Pacific Northwest (10). The objective of this study was to evaluate the vegetable oils from these crops to determine the effect of fatty acid composition on viscosity, energy content, and fuel performance in short-term diesel engine tests. Linoleic safflower oil was also evaluated to determine its performance in a long-term engine test.

## MATERIALS AND METHODS

The five vegetable oils were obtained from commercial processors. High erucic acid rapeseed (HEAR) oil from Coast Trading Company, Great Falls, Montana; low erucic acid rapeseed (LEAR) oil from C.S.P. Foods, Ltd., Saskatoon, Saskatchewan, Canada; sunflower oil from Cargill, Inc., Minneapolis, Minnesota; and oleic and linoleic safflower oils from Pacific Vegetable Oils International, Richmond, California, were filtered and alkali refined by the respective processors. Each oil was evaluated to determine 1) fatty acid composition; 2) the physical characteristics of specific gravity, viscosity, and heat of combustion; and 3) the fuel performance characteristics of power, fuel consumption, specific energy and thermal efficiency.

In order to determine fatty acid contents, each oil was converted to its respective fatty acid esters by the transesterification technique of Mason and Waller (8). Additional water washing and drying over anhydrous sodium sulfate was conducted to prepare samples pure enough for gas liquid chromatography (GLC) analysis. Chromatographic analyses were performed on a Packard-Becker Model 419 gas chromatograph with a flame ionization detector. Glass columns 1829 x 6 mm O. D. were packed with 10% SP-2330 on 100-120 mesh Chromasorb WAW (Supelco, Inc., Belefonts, PA). The injection port, column, and detector were maintained at 220, 195 and 235 C respectively. Nitrogen at 20 ml/min, was used as a carrier gas.

Physical characteristics of the five vegetable oils and No. 2 diesel fuel were evaluated in accordance with the American Society for

Testing and Materials (ASTM) guidelines for petroleum products. Specific gravity was determined using hydrometers as per ASTM D28-67 (1). The kinematic viscosity of the oils was measured at 37.78 C using Cannon-Fenske viscometers as per ASTM D445-79 (1). Heat of combustion was determined in a Parr Model 1241 bomb calorimeter with an adiabatic jacket. For this purpose samples were enclosed in gelatin capsules to prevent volatilization during handling. ASTM D240-76 (1) was used as a procedural guide.

Each oil was evaluated as a fuel in short-term engine tests on a Ford, 4-cylinder, 2818 cc, diesel engine equipped with separate fuel filters for diesel and vegetable oils. This engine has hole-type, direct fuel injection nozzles. Each vegetable oil was used to power the engine for 20 minutes during which (i) power and (ii) fuel consumption were measured at 5 minute intervals, and (iii) the temperature of the incoming air, oil, engine coolant, fuel and exhaust gases were monitored with thermocouples and automatically recorded at 1 minute intervals. Diesel fuel was used to power the engine for 20 minutes before and after each vegetable oil test and the same data was recorded to detect any changes in engine performance during the testing procedure. Specific energy, a measure of power output per volume of fuel, and thermal efficiency were derived from these data. After each oil test, the vegetable oil fuel filter housing was cleaned and the spin-on type element was replaced. Filters were located immediately ahead of the fuel pump to minimize mixing of the oil types between tests. Each oil was tested three times and the data were analyzed using a completely randomized design.

Two new Yanmar Model TS70C, single-cylinder, water-cooled, diesel engines equipped with pre-combustion chambers and pintle type injectors were used for an unreplicated long-term test. Linoleic safflower oil was chosen for the test because of its low viscosity. Prior to the test, the engines were disassembled to measure clearances and weigh components subject to wear. After re-assembly, the engines were connected to 3KVA Yanmar Model YNG35 generators which were connected to 2.75 KW load units. One engine was fueled with linoleic safflower oil and the other with diesel fuel. Both were allowed to run continuously at 3500 rpm except when shut down for daily oil checks and for oil changes which occurred every 100 hours. During the test the engines were automatically cycled on and off the load unit every 15 min. The test was concluded after 830 hours when the safflower oil-powered engine would no longer start. The engines were then disassembled to measure and weigh components and to inspect for corrosion and deposits.

An unmodifed three-cylinder diesel Ford Model 4600 tractor was also operated on 100% linoleic safflower oil for 150 hours. The tractor was primarily a demonstration unit, but was also used to show the practicality of vegetable oil substitutes in actual farming operations. The tractor was used for 120 hours at the University of Idaho Plant Science Farm for plowing, discing and hay harvest.

# RESULTS

Physical Properties:

Vegetable oils consist primarily of triglycerides with fatty acid chains 16 to 22 carbons in length (12). Classification of the vegetable oils by their predominant fatty acid resulted in three groupings (Table 1). Both sunflower and linoleic safflower oil had high concentrations of linoleic acid. Oleic safflower and LEAR oils were high in oleic acid and HEAR oil was high in erucic acid. The HEAR oil contained significant amounts of fatty acids longer than 18 carbons, with 64% of the fatty acids being either erucic acid or its biosynthetic precursor eicosenoic acid. Only sunflower and LEAR oils contained linolenic acid. All oils contained significant amounts of oleic and linoleic acids.

The vegetable oils did not differ in specific gravity, but all were 7 - 9% heavier than diesel fuel (Table 2). The heat of combustion did not differ between vegetable oils, but vegetable oil contained only 94 - 95% as many KJ per liter as diesel. Viscosity of the five vegetable oils was from 11 to 17 times higher than that of diesel fuel. Multiple regression analysis indicated that 99% of the variation in viscosity of the vegetable oils was due to the fatty acid chain length, the number of unsaturated bonds and the interaction between these two components (Fig. 1).

$$\text{Chain} = \sum \frac{(\text{Chain Length})\ \ (\%\ \text{Fatty Acid}).}{100}$$

$$\text{Unsat} = \sum \frac{(\text{Unsaturated bonds})\ (\%\ \text{Fatty Acid}).}{100}$$

$$\text{Viscosity} = 120.05 + 10.07\ \text{Chain} + 77.8\ \text{Unsat} - 5.22\ \text{Chain} * \text{Unsat}$$

Short Term Engine Performance:

During short term engine tests, the average power output of the engine did not vary significantly for different fuel types (Table 3). Fuel consumption did not differ between fuels, but No. 2 diesel had the lowest rate of fuel consumption by weight and the highest rate of consumption by volume (Table 3). The lower rate of consumption of diesel fuel by weight was expected due to its lower specific gravity but it is not clear why a greater volume of diesel fuel was consumed since diesel fuel contains more energy per unit volume than do vegetable oils. The vegetable oils did not differ in their power produced per unit of fuel (specific energy). All vegetable oils except linoleic safflower oil produced more power per liter than did diesel fuel. Thermal efficiency of all vegetable oils was significantly higher than that of diesel, indicating that the chemical energy of vegetable oil was more efficiently converted to mechanical power than that of diesel fuel. This could be why both vegetable oil and diesel produced equivalent power outputs even though the vegetable oils contained 5% less energy per volume than diesel fuel. Oleic safflower oil had a higher thermal efficiency than linoleic safflower oil even though they were produced by varieties from the same genus and species.

Endurance Test:

Both Yanmar engines started equally well at the beginning of the test, but as the experiment progressed the linoleic safflower oil-powered engine became progressively more difficult to start and after 665 hours gasoline was required to start the engine. At 700 hours the fan belt on the safflower oil-powered engine broke, causing the engine to overheat and subsequently stop. At this time the cylinder heads of both engines were removed to evaluate damage caused by the overheating event. The exhaust port of the safflower oil-powered engine had heavy carbon deposits, excessive valve train wear and piston scoring. The valve train wear was caused by a defect in the lubrication system which analysis of engine oil indicated had occurred at about 50 hours. These problems were probably not related to the use of safflower oil as a fuel. Both engines were reassembled after the evaluation at 700 hours and the test continued until 830 hours when the safflower oil powered engine would no longer start.

Analysis of clearances and component weights showed a slight increase in wear of some components in the safflower oil-powered engine but the wear was within acceptable limits for both engines. Compared to the diesel fuel-powered engine, heavy carbon deposits were found in the combustion chamber and exhaust port of the safflower oil-powered engine. Gum and varnish deposits were found on the piston rings and injector of the safflower oil-powered engine. The deposits on the injector had caused it to seize, and prevented the safflower engine from starting at 830 hours. Gum and varnish deposits were not found elsewhere in the fuel system.

Demonstration Tractor:

After 150 hours of operation on linoleic safflower oil the Ford 4600 tractor was still operating normally but total power had declined approximately 5%. The injectors were covered with deposits, but both the spray pattern and injector pressure were normal. The decline in power may be related to a reduction in the amount of fuel delivered by the injector pump. The engine had compression pressures about 12% below specifications, but the power of diesel engines does not necessarily decline because of lower compression pressures if the diesel pump is properly adjusted.

## DISCUSSION

The energy content of vegetable oils is very similar to diesel, but vegetable oils are 11-17 times more viscous. The high viscosity of vegetable oils may be overcome in several ways. Shorter chain lengths and increased unsaturation of fatty acids would reduce viscosity. Fatty acid unsaturation and chain length of safflower and rapeseed oils have been altered by genetic manipulation (3, 5). Sunflowers grown at higher latitudes produce a higher concentration of poly-unsaturated fatty acids (11). The minimum viscosity obtainable through genetic manipulation would still result in vegetable oils that were several times more viscous than diesel fuel. This viscosity would probably cause fuel flow problems under cold operating conditions. Chemical modification of the vegetable oils to form methyl or ethyl esters of the fatty acids could decrease the viscosity still further (2), but this process may be too energy intensive and complex to be practical in farm size operations.

Although small statistical differences were found between vegetable oils and diesel fuel for fuel consumption, specific energy and thermal efficiency, for practical purposes vegetable oils appear to be equivalent to diesel fuel in short term engine operation. However, long periods of using vegetable oil fuel may cause the formation of gum and carbon deposits which may cause mechanical problems in the engine. Further testing is necessary to determine the true reduction in engine life that occurs as a result of using vegetable oils as a fuel. The high viscosity of vegetable oil may be a major factor in carbon deposits in the combustion chamber and exhaust ports. A study in South Africa indicated that higher viscosities resulted in incomplete atomization of the fuel(2). Incomplete atomization of high viscosity fuels in turn prevents complete combustion of the larger droplets and results in carbon deposits. The utilization of additives that minimize viscosity and/or inhibit the formation and deposition of gum in the injectors and combustion chambers may be necessary to allow long term engine operation on vegetable oils.

## CONCLUSION

Despite these problems there is still potential for the use of vegetable oils as an alternative to diesel fuel. Compared to alcohol the production and processing of vegetable oils is far more energy efficient. Vegetable oils can be utilized in unmodified diesel engines and a small percentage of a farm's acreage could produce enough fuel to supply farm needs. Further research should concentrate on developing fuel additives or pre-treatments to reduce engine deposits, and to develop extraction and processing techniques to allow vegetable oil extraction and utilization at a local level.

Table 1 . Fatty acid composition of five vegetable oils.

| Oil Type | Fatty Acid | | | | | | |
|---|---|---|---|---|---|---|---|
| | 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 | -- | -- | -- |
| LEAR § | 4.4 | 1.8 | 59.8 | 20.6 | 11.1 | -- | 0.9 |
| HEAR § | 3.2 | 1.1 | 14.8 | 12.7 | -- | 17.7 | 46.7 |

†Number of carbons and unsaturated bonds, respectively, for each fatty acid.
‡May not sum to 100% due to the presence of other minor fatty acids.
§LEAR and HEAR refer to rapeseed oil with low and high erucic acid concentrations, respectively.

Table 2. Specific gravity, viscosity and heat of combustion of five vegetable oils and No. 2 diesel.

| Oil Type | Specific Gravity | | Kinematic Viscosity | | Heat of Combustion | |
|---|---|---|---|---|---|---|
| | g/ml | ratio‡ | $mm^2/s$ | ratio‡ | KJ/L | ratio‡ |
| Sunflower | 0.92 | 1.08 | 34.9 d* | 12.0 | 36473 ~~2081~~ b* | 0.95 |
| Linoleic Safflower | 0.93 | 1.09 | 32.3 e | 11.1 | 36481 ~~2082~~ b | 0.95 |
| Oleic Safflower | 0.92 | 1.08 | 42.1 b | 14.5 | 36162 ~~2064~~ b | 0.94 |
| LEAR† | 0.92 | 1.08 | 39.0 c | 13.4 | 36720 ~~2096~~ b | 0.95 |
| HEAR† | 0.91 | 1.07 | 51.0 a | 17.6 | 36552 ~~2086~~ b | 0.95 |
| No. 2 Diesel | 0.85 | 1.00 | 2.9 f | 1.00 | 38473 ~~2196~~ a | 1.00 |

* Means within a column not followed by the same letter differ at the 0.05 level of probability according to Duncan's new multiple range test.

‡ Relative to No. 2 diesel.

† LEAR and HEAR refer to rapeseed oils with low and high erucic acid concentrations, respectively.

Table 3. Power output, fuel consumption, specific energy and thermal efficiency of five vegetable oils and No. 2 diesel during short-term engine tests.

| Fuel Type | Power | Fuel Consumption | | Specific Energy | Thermal Efficiency |
|---|---|---|---|---|---|
| | -Kw- | -Kg/hr- | -L/hr- | -Kwhr/L- | - % - |
| Oleic safflower | 30.0 | 10.2 | 11.0 | 27.2 a* | 27.0 a* |
| Linoleic safflower | 29.5 | 10.4 | 11.2 | 26.4 ab | 26.0 b |
| HEAR† | 29.4 | 10.0 | 10.9 | 26.9 a | 26.6 ab |
| LEAR† | 29.7 | 10.2 | 11.1 | 26.9 a | 26.5 ab |
| Sunflower | 29.5 | 10.1 | 10.9 | 27.0 a | 26.7 ab |
| No. 2 diesel | 29.5 | 9.7 | 11.4 | 25.9 b | 24.2 c |

* Means within a column not followed by the same letter differ at the 0.05 level of probability according to Duncan's new multiple range test.

† LEAR and HEAR refer to rapeseed oils with low and high erucic acid concentrations, respectively.

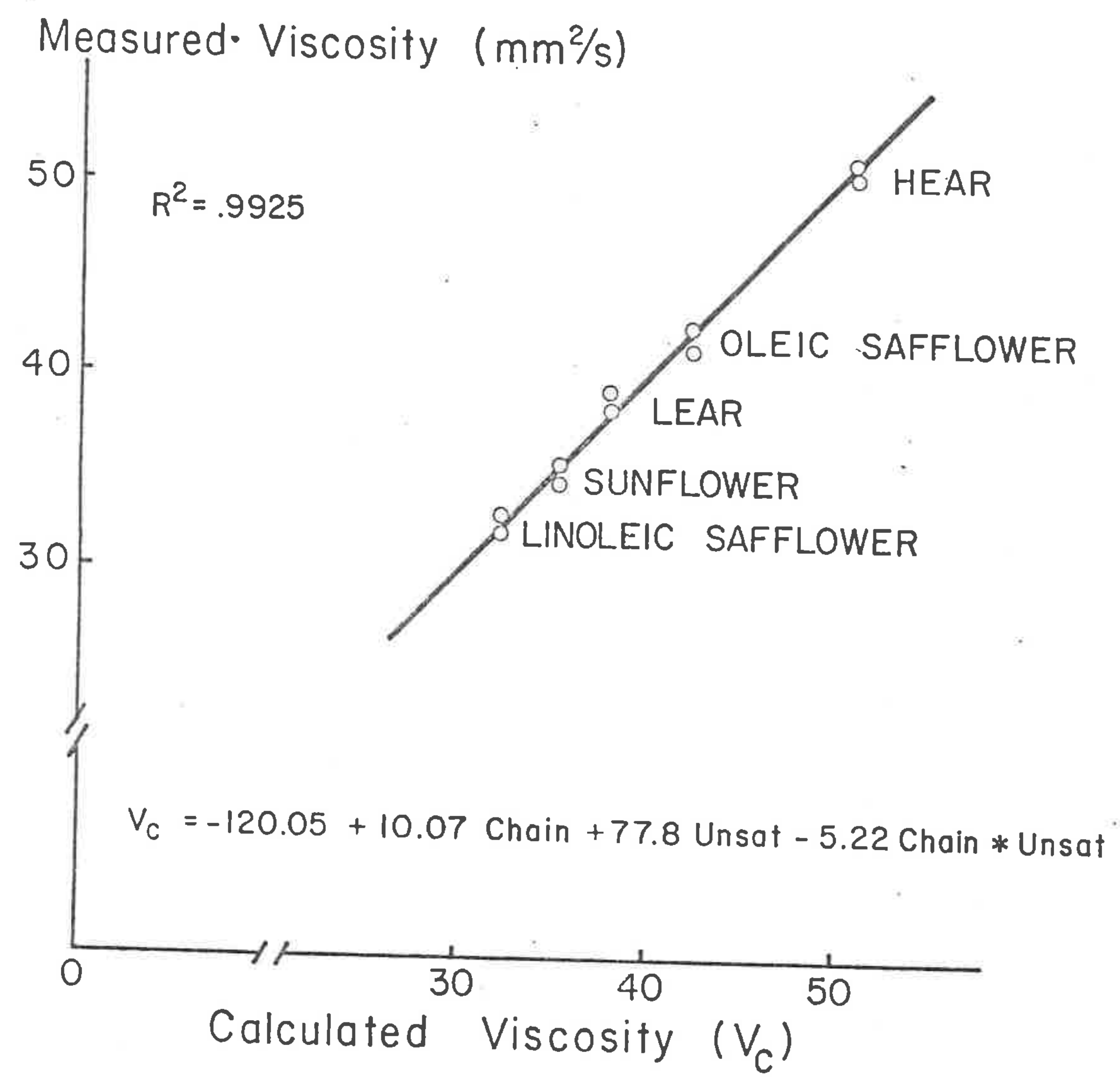


Fig. 1: Comparison of estimated viscosity with actual viscosity of five vegetable oils. HEAR and LEAR refer to winter rapeseed oil with high and low erucic acid concentrations, respectively.

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