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POTENTIAL OF HIGH ERUCIC ACID RAPESEED (*BRASSICA NAPUS*, VAR. DWARF ESSEX) OIL AS A HYDRAULIC FLUID

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Potential of High Erucic Acid Rapeseed (*Brassica napus*, var. Dwarf Essex) Oil as a Hydraulic Fluid

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Abstract. *Rapeseed oil has been found to be a potentially useful substitute for petroleum-based hydraulic fluid. This article compares the hydraulic fluid properties of raw rapeseed oil with three commercially available hydraulic fluids: Mobil EAL 224H, PlantoHyd 40, and Hy-TransPlus.*

Experimental results showed that rapeseed oil has hydraulic fluid properties comparable to the three commercial hydraulic fluids. Some of the hydraulic fluid properties, like flash point, viscosity index, and mist spray flammability, were better for rapeseed oil. ***Keywords.** Rapeseed oil, Hydraulic fluid, Environment.*

A steady increase in the use of off-road machines in the agricultural and forest industries has increased the demand for petroleum products. In 1991, seven hundred and sixty-five million liters (202 million gal) of hydraulic oil were sold (National Petroleum Refineries Association, 1991). The depletion of petroleum reserves, combined with increasing demand for petroleum products, has stimulated the search for alternative sources of hydrocarbons. Petroleum continues to be the main source for hydraulic and lubricating oil. Crude oil obtained from U.S. oil fields is not suitable for the production of high quality lube oil base stocks, therefore these requirements are met by importing suitable crudes. There is a great need to identify alternative sources for hydraulic and lubricating oil base stocks (Bisht et al., 1989).

Most used lubricating oils can be recycled; however, less than 5% of the used lubricating oil is re-refined. Over 95% is dumped into sewers or waterways, spread on roads, or burned as fuel. The present methods of disposing of used oil can create major environmental hazards, as well as waste about 42,000 barrels of lubricating oil every day (Domenici, 1981.)

A 1983 Federal Environmental Protection Agency study reported that American industry, automobiles, trucks, and construction equipment use at least 8.8 billion L (2.3 billion gal) of lubricating oil annually. Of that, more than half returns to the nation's waste stream as waste oil. The sheer volume of these fluids implies a potentially dramatic effect of improperly managed waste oil on the environment. State and federal environmental legislation has increased significantly over the past few decades, and the potential impact of waste oil, particularly used waste oil, has been noted (Shipley and Boyd, 1991). The use of environmentally acceptable hydraulic fluids in mobile machines is gaining acceptance worldwide as a way to reduce environmental pollution.

The oil in an hydraulic system serves as the power transmission medium, lubricant, and coolant. Selection of the proper oil is important. Hydraulic fluids are rated on their viscosity and anti-wear properties. The International Standards Organization (ISO) Standard 3448 consists of a numbering system designating the nominal viscosity of industrial fluid lubricants at 40°C (104°F). This standard is essentially the same as ASTM Standard D 2422-75, Viscosity System for Industrial Fluid Lubricants. For example, ISO VG46 has a Mid-Point Viscosity of 46 mm^2/s (cSt) at 40°C (104°F). The second important factor in selecting a hydraulic fluid is the antiwear properties. Anti-wear additives are a group of chemical compounds with lower chemical activity when temperature and pressure are increased. These fluids are generally referred to in hydraulic oil applications as AW oils. A biodegradable and nontoxic antiwear hydraulic fluid has been developed based on a selected vegetable oil and additive system. This oil is designated "Environmental Awareness" (EA).

Objective

The goal of this project was to compare the hydraulic fluid properties of raw rapeseed oil with three commercially available hydraulic fluids: mineral oil based Hy-TransPlus; PlantoHyd 40N, which is rapeseed oil based; and Mobil EAL 224H, also a vegetable oil based product.

The fluids were evaluated by measuring the following properties: Kinematic Viscosity, Viscosity Index, Total Acid Number, Pour Point, Flash Point, Volume Change of Elastomeric Material under Static Condition, and Mist Spray Flammability of Hydraulic Fluids. Spectrographic analysis of each oil was also done. Wear characteristics were determined using a vane pump test.

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Approved as paper no. 95306 of the Idaho Agricultural Experiment Station. Use of trade names is for simplification in identification and does not constitute an endorsement of the product nor discrimination against similar products which are not mentioned.

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Literature Review

Eichenberger (1991) made a very detailed study of the properties of rapeseed oil. He reported that rapeseed oil offers good corrosion protection for hydraulic systems and does not attack sealing materials, varnish, or paint. It does not affect the oil performance when mixed with conventional mineral oil. Rapeseed oil is not water soluble. Since rapeseed oil is lighter than water, escaped oil on a water surface can be skimmed off. High temperature stability of rapeseed oil is very critical. High temperature operation causes oxidation, oil deterioration, and viscosity increase.

A test for determining the biodegradability of two stroke cycle outboard engine oils in water (CEC-L-33-T-82) was developed by the Coordinating European Council (CEC). Eichenberger (1991) conducted the test on rapeseed oil and other selected products. A biodegradability of 99% for rapeseed oil, 70 to 99% for polyethylene, 10 to 90% for synthetic ester, and 20% for mineral oil, was reported.

Lubrizol Corporation (1990) described the basic chemistry of rapeseed oil as containing three major types of fatty acids: Erucic acid (C22:1), Oleic acid (C18:1), and Linoleic acid (C18:2). The percentages of the acids varies in different types of rapeseed oil. Two types of rapeseed oil are currently being marketed, Low Erucic Acid Rape (LEAR), and High Erucic Acid Rape (HEAR) oils. LEAR oil typically contains 0 to 5% Erucic acid, while HEAR contains 50 to 60% Erucic acid. HEAR type oils provide good lubricity and oxidation stability (due to the higher mass percentage of the longer C22:1 chain). LEAR oils provide good biodegradability and are more liquid at lower temperatures (due to the higher mass percentage of the shorter C18:1 chain) but have poorer lubricity.

Cheng et al. (1992) of Mobil Oil Corporation has assessed the biodegradability of hydraulic fluids by the shake flask test and the Coordinating European Council (CEC) test. Vegetable oils and a number of synthetic esters met the "ready biodegradability" criterion developed by Mobil Oil Corporation. Products are considered acceptable if their aquatic toxicity is greater than 1000 ppm, and "ready biodegradability" is greater than 60% (as measured by conversion to CO_2). None of the formulations tested containing mineral oil base stocks were able to meet the "ready biodegradability" criterion, even though 40 to 49% of these materials were converted to CO_2 in 28 days. A range of mineral oil formulations was assessed by the CEC test and biodegradability values for a typical white oil ranged from 49 to 60%. The polyglycol-based materials also failed to meet the ready biodegradability criterion. Typically only 6 to 38% of the test materials were converted to CO_2 in 28 days.

In his U.S. patent applications, Jokinen et al.(1988) has claimed that vegetable oils with iodine values between 50 and 130 are ideal for hydraulic fluids. Below 50, fluids have high pour points due to lack of unsaturated fatty acids; above 130, oils tend to be oxidatively unstable. He pointed out that the fatty acids contained in some vegetable oils are polar in nature and tend to cling to metal surfaces more effectively than mineral oils, thus providing improved lubricity. Using these criteria as a guide, a biodegradable and nontoxic hydraulic fluid was formulated by Cheng et al. (1992), based on a selected vegetable oil and additive system. This oil was designated as "Environmental Acceptable oil A" (hereafter, EA oil A.) Two characteristics presented special formulation challenges. First, a vegetable-based antiwear fluid had a high foaming tendency, and second, the water tolerance property, which indicates additive stability in the presence of water contamination, was a difficult target to meet. Seal swelling tests on EA oil A showed acceptable compatibility with Buna N and Viton elastomers; and an extended stability study at several temperatures demonstrated satisfactory fluid stability during long-term storage.

Since EA oil A gave satisfactory results based on an ASTM D2882 wear test. Cheng et al. (1992) repeated the test and extended the time from 100 h to 200 h. Water equal to 1% by weight was added at 0 h and 100 h of test operation in the second test. The results indicated low cumulative wear. There was a small viscosity and total acid number increase over the test duration. EA oil A was also evaluated in the Hagglands-Denison HF-O piston test rig. This is a 100 h test based on the high pressure/output series 46 piston pump at two temperatures. Wear (shoe thickness) measurements and thorough surface examination showed the critical parts to be in exceptionally good condition. In addition to the axial piston pump evaluation, a vane pump test, based on a new A.SK-30320 procedure recently developed by Hagglunds-Dension for environmentally acceptable hydraulic fluids was conducted. This is a 600 h cyclical test (300 h dry and 300 h with the addition of 1% water). EA oil A, received a good passing result. To further assess fluid useful life in critical applications, EA oil A was evaluated in a proprietary hydraulic fluid durability test. An increase in viscosity and total acid number were observed for EA oil A. Despite these increases, the pump operated satisfactorily over 2000 test hours. Turbine Oil Stability Test (TOST) values of less than 75 h for vegetable oil and less than 500 h for the ester and polyglycol fluids were measured. The TOST test measures the time for a fluid to incur a total acid value (TAN) increase of 2 NN. Passing is 1000 h. However they are also careful to note that even though the TOST test has historically been used to characterize the oxidation stability of hydraulic fluids the relevance to EA oils has not been established.

The vegetable oil used in the development of the EA oil had a pour point of –20°C (–4°F). In a cold-storage study, a sample of the neat vegetable oil showed onset of solidification in just a few hours at –18°C (–0.4°F). EA oil A, formulated with an optimum blend of an effective pour depressant, was found to stay fluid over three months in storage at –18°C (–0.4°F). At 4°C (7.2°F) lower (i.e., at –22°C or –7.6°F), the first signs of solidification were observed after 14 days.

Cheng et al. (1992) conducted two tests to assess the affect of diesel engine oil (DEO) contamination on EA oil A. A storage stability study that involved contaminating the EA fluids by several dosages of a typical DEO, ranging from 5% to 40% under both dry and wet (0.5% water) conditions, was conducted. Observations were made after the samples were stored at several temperatures for a two-week period. Up to 20% contamination under dry conditions resulted in the mixture being free from deposits. However, under wet conditions, even 5% contamination brought heavy deposits. Several other commercial, environmental acceptable (EA) fluids were also evaluated and gave similar results. A secondary study, based on a dynamic filterability test which was developed to simulate in-service filtration problems relating to water contamination and extended shutdown for machinery equipped with fine-porosity filters, was also conducted. While an uncontaminated EA fluid clearly passed this test requirement, it was found that a fluid contaminated with 5% of DEO was a definite failure. In comparison, no problems were observed when a typical mineral AW hydraulic fluid was used in place of the DEO in both of the tests cited above. This compatibility study underscored the need for a very thorough flushing procedure, particularly in systems where a DEO had been used.

Eichenberger (1991) reported a Caterpillar field test using bio-oils. This test was conducted because of the new regulations being placed on equipment owners. Equipment owners wanted to know if their equipment could operate with bio-oils. Their first step was to select several different machines with the simple objective of gaining practical experience under field conditions. A one-year test program was started in cooperation with Caterpillar dealers in Austria, Germany, and Switzerland; the oil suppliers; and the machine owners. In addition to regular maintenance procedures, oil sample analysis was done. The test program was successfully completed without any indication of equipment operating deficiencies because of the fluid used.

Eichenberger (1991) also reported a field test program, using a medium size wheel loader. After 4045 operating hours, the hydraulic pump (vane type) was removed and inspected. Samples of new and used rapeseed oil were analyzed in the laboratory. The analysis showed that the used oil was still in acceptable condition. Only a minor viscosity change was measured. Pump performance was lower than expected for 4045 h of operation, but not enough that the operator had noticed any difference. This case showed that extension of the regular hydraulic fluid change period (2000 h) was possible. Caterpillar's recommendations, however, remain the same. Equipment owners were advised to follow the guidelines published for specified mineral oils.

An example of a future trend in hydraulic systems was reported by Eichenberger (1991). Gravel pit and quarry operations are particularly vulnerable to pollution. A company operating several pits throughout Switzerland took the initiative to convert all hydraulic systems from mineral oil to biodegradable oil. Their equipment fleet involved 101 machines. Some difficulties were expected and in fact some systems behaved differently than others. Equipment maintenance personnel faced some seal problems and reduced pump bearing life. Other unusual measures taken by the company was the reduction of onsite bulk storage of oil and diesel fuel. This example may not be typical or representative, but it may indicate a trend into the future. Other companies are taking similar actions to reduce the risk of environmental pollution.

Materials and Methods

This study was undertaken to demonstrate the potential of rapeseed oil as a hydraulic fluid. The primary elements and procedures used in this research are in accordance with the American Society for Testing and Materials (ASTM) standards, except where noted.

Selection of Oils

The rapeseed (*Brassica napus*) oil used was extracted from Dwarf Essex variety winter rapeseed grown in Nez Perce and Latah counties in northern Idaho. Dwarf Essex is an industrial rapeseed high in erucic acid. The oil was extracted and filtered in a laboratory at the University of Idaho Department of Agricultural Engineering. Hy-TransPlus (MS 1207) is a Hydraulic/Transmission fluid, manufactured for Case Corporation of Racine, Wisconsin. Mobil EAL 224H hydraulic oil is a nontoxic biodegradable antiwear hydraulic oil having an ISO VG of 32/46. Its trademark is registered to Mobil Oil Corporation of Fairfax, Virginia. PlantoHyd 40N (viscosity of 40 mm^2/s or cSt) is also a nontoxic biodegradable hydraulic oil. The product was supplied by Metal Lubricants Co. of Harvey Illinois.

Spectrographic Analysis and Pour Point Test

The spectrographic analysis and pour point tests were conducted at the Oil Analysis Lab Inc. of Spokane, Washington. The spectrographic analysis gives the concentration of 19 trace elements which relate to component wear, airborne dirt, and oil additive concentrations.

Test Methods for Determining Kinematic Viscosity and Viscosity Index

ASTM standard test procedure D445 was followed for determining the viscosity (ASTM, 1991b). A Cannon-Fenske routine viscometer was used to determine the viscosity at both 40°C (104°F) and 100°C (212°F). The viscometer was suspended in a water bath; a temperature controller was used to maintain the bath at a constant temperature. After determining the kinematic viscosity of the oil at both 40°C (104°F) and 100°C (212°F), ASTM test procedure D2270 was followed for calculating the viscosity index (ASTM, 1991c).

Test Method for Flash Point

The ASTM standard test procedure D93 was followed for determining the flash point (ASTM, 1991d). The apparatus used was a Pensky-Martens closed flash tester. In this test, the sample is heated at a slow, constant rate with continual stirring. At regular intervals the stirring is interrupted and a small flame is directed into the cup. The flash point is the lowest temperature at which application of the test flame causes the vapor above the sample to ignite.

Test Method for Acid and Base Number

The ASTM standard test procedure D974 was followed for determining the total Acid Number (ASTM, 1991e). The apparatus used was a 50 mL buret graduated in 0.1 mL subdivisions. Reagents used were hydrochloric acid solution, methyl orange indicator solution, p-Naphthol benzein indicator solution, potassium hydroxide solution, and titration solvent (a mixture of 500 mL toluene, 5 mL water, and 495 mL anhydrous isopropyl alcohol).

In this test, the sample is dissolved in titration solvent and the resulting single-phase solution is titrated at room temperature with standard alcoholic base or alcoholic acid solution, respectively, to the end point indicated by the color change of the added p-Naphtholbenzein solution.

gun used was not recommended by ASTM, but it met the ASTM specifications.

Test Method for Volume Change of Elastomeric Materials in Hydraulic Fluids Under Static Conditions

The test was conducted according to the ASTM standard test procedure D3604 (ASTM, 1983a). The specimen selected was a Buna N rubber o-ring from a Vickers vane pump. An electric oven, at 70°C (158°F), was used to maintain the specimen temperature. An electronic balance accurate to 0.0001 g was used to weigh the specimen. The specimen was wiped with cheese cloth that has been saturated with anhydrous methanol. Then, the specimen was air-dried for one hour and weighed both in air and distilled water at room temperature. The specimen was immersed in the test fluid and placed in an oven at 70°C (158°F) for one week. The specimen was weighed again to calculate the volume change.

Test Method for Mist Spray Flammability of Hydraulic Fluids

This test was conducted according to the ASTM standard test procedure D3119 (ASTM, 1983b) (fig. 1). A pneumatic spray gun was used to generate a mist of the test fluid. The ignition source was a natural gas laboratory Bunsen burner capable of being adjusted to give a steady yellow flame. A metal sheet was used to intercept the excess fluid spray that did not burn or vaporize. The intercepted fluid was collected in a metal pan. The test sample was heated by a hot plate and the temperature of the heated fluid was measured by a thermometer. The spray gun used was not recommended by ASTM, but it met the ASTM specifications.

Test Method for Indicating the Wear Characteristics of Petroleum and Non-Petroleum Hydraulic Fluids in a Constant Volume Vane Pump

The ASTM standard test procedure D2882 was followed for conducting the test (ASTM, 1991f). Perez and Brenner (1992) have developed a new constant volume vane pump test for measuring wear characteristics of fluids which uses a Vickers 20VQ5 vane pump. This new test method was compared with various alternate pump tests to evaluate fluids. The results showed that the new method ranked the fluids the same as the existing pump tests, which uses a Vickers 104C vane pump. Because the Vickers 104C pump is no longer available from the manufacturer, the Vickers 20VQ5 pump was used in this test.

A Kubota diesel engine was used to run the Vickers 20VQ5 vane pump. A 19 L (5 gal) reservoir with a 60-mesh screen in its outlet was used as the test fluid reservoir. System pressure was controlled at 13 790 kPa (2,000 psi) with a relief valve (Vickers pressure relief valve CT-06 F50 3,000 psi). A constant fluid temperature of 65.5°C (150°F) was maintained with a heat exchanger (Young Heat Exchanger, RFF-314-H05-2P-N), temperature control valve (Johnson Penn), fan, radiator, and a water pump. A digital thermocouple was used to measure temperature. A 25 micron return line filter was used for filtering the oil and a flow meter was used to record the flow rate. Low oil level, high temperature, and high pressure safety systems were used. Figure 2 shows a schematic of the test stand.

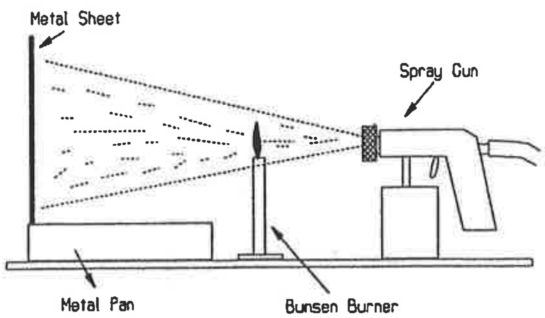

Figure 1–Flammability test setup.

Results and Discussion

In the presentation of results the term "New" oil refers to the oil before the wear test, and "Used" refers to the oil after the wear test. All tests were conducted in the laboratory at the Department of Agricultural Engineering, University of Idaho, except for the spectrographic analysis and pour point test.

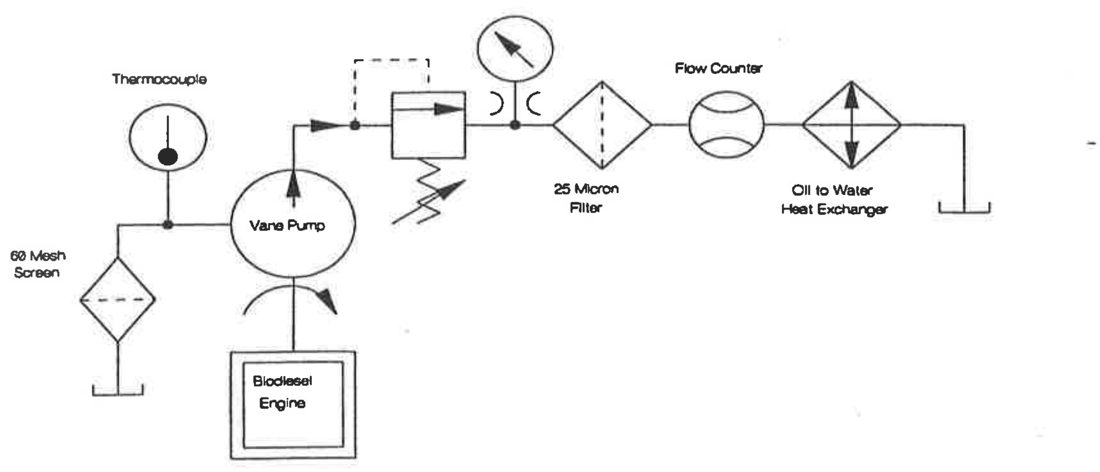

Figure 2–Schematic diagram of wear test setup.

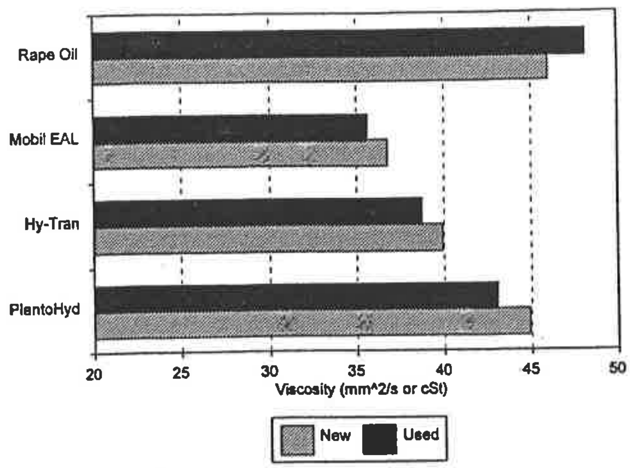

Figure 3–Kinematic viscosity at 40°C (104°F) for the three commercial fluids and rape oil before and after the wear test.

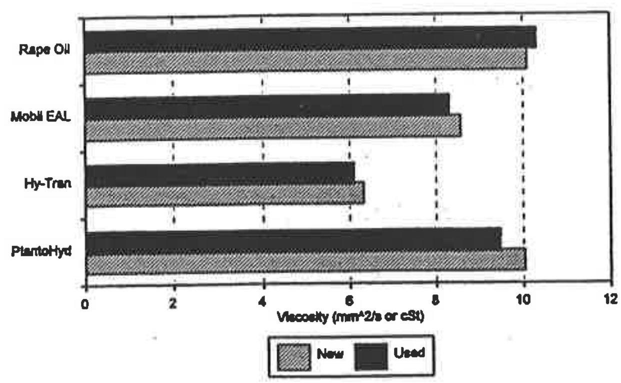

Figure 4–Kinematic viscosity at 100°C (212°F) for the three commercial fluids and rape oil before and after the wear test.

Kinematic Viscosity Test

Rapeseed oil has a higher viscosity than the other three oils, though not much higher than the PlantoHyd 40N (figs. 3 and 4). The viscosity of Hy-TransPlus, Mobil EAL, and PlantoHyd 40N decreased after the wear test, but it was opposite with the rapeseed oil. The viscosity of the rapeseed oil may have increased due to poor stability and polymerization.

Viscosity Index

The viscosity index of rapeseed oil was comparable to Mobil EAL and PlantoHyd 40N, and over twice that of Hy-TransPlus (fig. 5). The higher the viscosity index the smaller is the effect of temperature on kinematic viscosity. The result of this computation indicates that rapeseed oil has an acceptable viscosity over the normal temperature range for hydraulic systems.

Flash Point Test

Hy-TransPlus has lower flash point than rapeseed, Mobil EAL and PlantoHyd 40N hydraulic oils (fig. 6). This test only measures the response of the sample to heat and flame under controlled laboratory conditions, but does indicate that rapeseed oil is less hazardous than petroleum

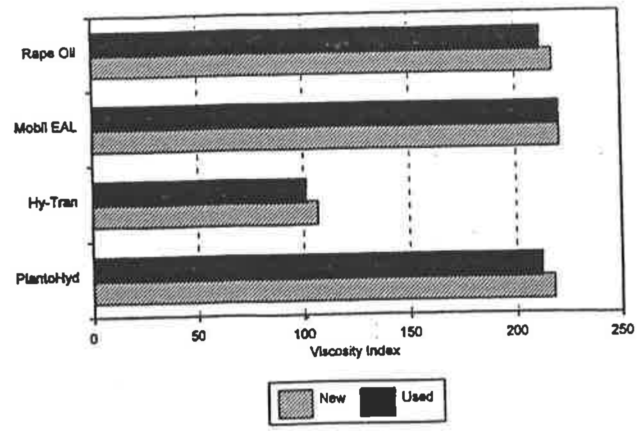

Figure 5–Viscosity index calculation from ASTM D445 for the three commercial fluids and rape oil before and after the wear test.

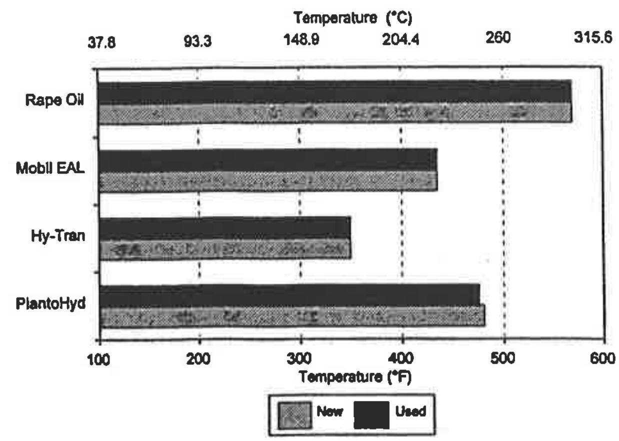

Figure 6–Flash point comparison for the three commercial fluids and rape oil before and after the wear test.

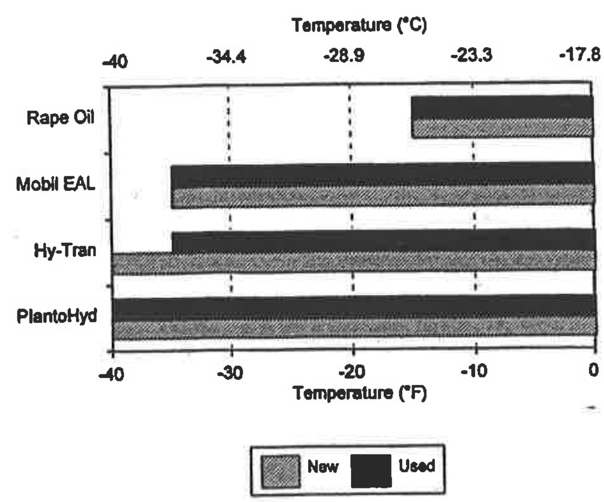

Figure 7–Pour point comparison for the three commercial fluids and rape oil before and after the wear test.

based products. Also, there is no change in the flash point of the oils following the wear test.

Pour Point Test

The pour point of rapeseed oil is much higher than Hy-TransPlus, Mobil EAL, and PlantoHyd 40N (fig. 7). The pour point of Hy-TransPlus increased slightly after the wear test but that of Mobil EAL, PlantoHyd 40N, and rapeseed oil did not change.

Neutralization Number Test (Total Acid Number)

Rapeseed oil is more acidic than Hy-TransPlus, Mobil EAL, and PlantoHyd 40N (fig. 8). This increase could cause a more rapid deterioration of the fluid, bearings, component parts, and seals.

Volume Change of Elastomeric Material Test

Both Hy-TransPlus and PlantoHyd 40N showed a decrease in volume of the elastomer after the wear test (fig. 9). Both Mobil EAL and rapeseed oil showed an increase in the volume after the wear test.

Mist Spray Flammability Test

Rapeseed oil offers better resistance to fire than the other three fluids. Violent fire was observed with Hy-TransPlus, i.e., the entire spray pattern ignited and burned vigorously. Mobil EAL and PlantoHyd 40N displayed fire at the torch, which means the fluid burned at the area of the ignition source only. Even though they are both vegetable oil based, fire at the torch was observed, where as there was no fire in case of rapeseed oil. The increased flammability over rapeseed oil might be due to the additives that are used in the formulation of Mobil EAL and PlantoHyd 40N.

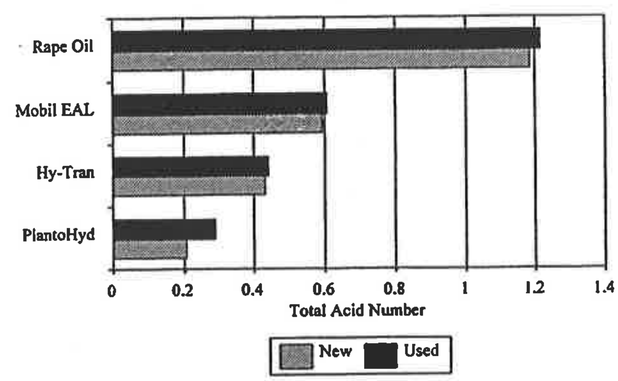

Figure 8–Total acid number comparison for the three commercial fluids and rape oil before and after the wear test.

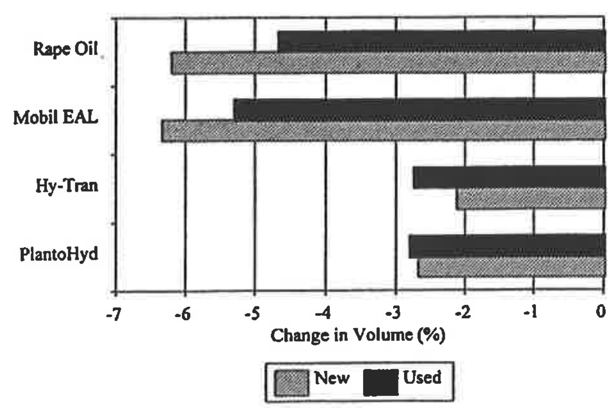

Figure 9–Volumetric expansion of an elastomer material compared for the three commercial fluids and rape oil before and after the wear test.

Wear Test

Rapeseed oil caused higher wear than the other three oils (fig. 10). Perez and Brenner (1992) conducted similar test on several commercial hydraulic fluids and have reported wear ranging from 7 mg (2.5×10^{-4} oz) to 329 mg (116×10^{-4} oz). The total weight loss of 18 mg (6.4×10^{-4} oz), observed for rapeseed oil was toward the low end of the range they reported.

Spectrographic Analysis

None of the oils were contaminated by water, and there was no trace of oxidation or nitration. More elements were found in rapeseed oil than than Mobil EAL, Hy-TransPlus or PlantoHyd 40N as shown in table 1. The lab report indicated the content of silicon in rapeseed oil as "impending failure". The high silicon content may be due to fine soil particles which contaminated the oil when it was pressed from the seed using the University of Idaho

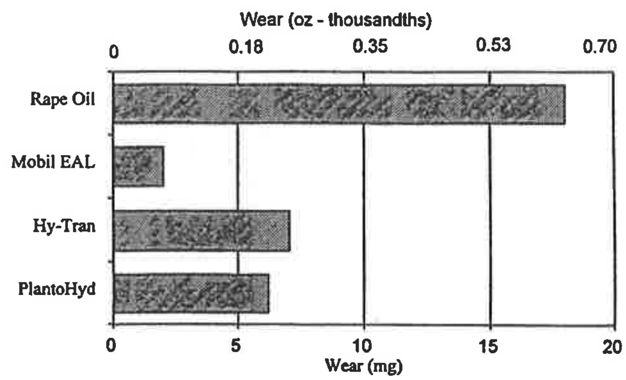

Figure 10–Wear test comparison for the three commercial fluids and rape oil.

Table 1. Results of spectrographic analysis (ppm)

Elements	New			Used		
	Hy-Tran	Mobil EAL	Rape Oil	Hy-Tran	Mobil EAL	Rape Oi
Silicon	5	5	53	4	5	49
Iron	0	0	12	0	0	4
Chromium	2	1	7	0	2	8
Aluminum	2	0	3	0	1	3
Zinc	19	0	13	2	5	35
Copper	0	0	1	1	0	3
Lead	0	0	4	0	0	12
Tin	0	0	5	2	0	8
Nickel	0	0	4	0	0	6
Barium	0	0	0	0	0	0
Silver	0	0	0	0	0	1
Molybdenum	0	0	5	0	0	9
Magnesium	0	2	12	6	3	16
Sodium	259	0	0	159	0	0
Phosphorus	3276	82	53	2401	84	60
Titanium	0	0	0	0	0	3
Boron	0	0	0	0	0	1
Vanadium	0	0	1	0	0	4
Calcium	4591	0	20	2066	1	15

small expellers. The silicon contents in Hy-TransPlus, Mobil EAL, and PlantoHyd 40N are all about the same and were about 10% that found in the rapeseed oil.

Conclusions

The test results documented in this report suggest that the potential of rapeseed oil as a hydraulic oil is very good. However, it is obvious that commercial fluids based on rapeseed oil have additional additives. The following conclusions are based on the data collected and presented in this article.

1. Rapeseed oil displays a slight increase in its viscosity after the wear test, where as the viscosity of Mobil EAL, PlantoHyd 40N, and Hy-TransPlus decreased.
2. Rapeseed oil displays a viscosity index almost equal to Mobil EAL and PlantoHyd 40N, and much higher than Hy-TransPlus.
3. Rapeseed oil has a relatively high pour point temperature when compared with Mobil EAL, PlantoHyd 40N, and Hy-TransPlus. Mobil EAL and PlantoHyd 40N evidently have an additive or some processing step has been done to reduce the pour point temperature.
4. Rapeseed oil was less flammable than the other oils tested.
5. Rapeseed oil displays high wear when compared with Mobil EAL, PlantoHyd 40N, and Hy-TransPlus. Considering that rapeseed oil did not contain any additives and that its silicon content is approximately 10 times higher that of the other oils, it was not surprising that the wear characteristics were higher.
6. Rapeseed oil has a higher acid number than its counterparts. The acid number is approximately twice of Mobil EAL, three times that of Hy-TransPlus, and almost six times that of PlantoHyd 40N.
7. Rapeseed oil was similar to Mobil EAL in the test for volume change of elastomeric material.
8. Rapeseed oil displays elements like, vanadium, boron, titanium, molybdenum, silver, nickel, lead, and iron, which are not present in Mobil EAL, PlantoHyd 40N or Hy-TransPlus, as measured by spectrographic analysis.

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