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High Performance 4-Cycle Lubricants from Canola

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IDENTIFICATION OF A MARKET

Developing a new market for an established international crop like canola (*Brassica napus* L., *Brassica rapa* L., Brassicaceae) requires significant care and study. Canola has been identified by several authors as a highly desirable food oil. Canola oils are relatively rich in monounsaturated fatty acids and with small percentages of both saturated and polyunsaturated fats. Canola can be differentiated from rapeseed by Canadian standards of low erucic acid and low glucosinalate content. Canola's relatively high percentage of monounsaturated fats, natural antioxidants, and lubricity make it ideal for lubricant applications

To develop a canola oil industry which does not compete with existing canola markets requires identification of new applications. Three objectives for a canola-based lubricant were identified: first, an oil functionality equal to or better than comparable petroleum oils; second, a cost which is acceptable to the general consumer; and third a product which is environmentally benign, allowing for some premium in cost and market.

Currently, numerous vegetable oils are used in lubricant applications. Current lubricant applications include additives in synthetic oils, transmission fluids, two-cycle motor oils, chain oils, hydraulic oils, greases and biodiesels. US consumption of these oils requires about 8 million kilograms of vegetable oil annually. This represents about 9% of all industrial applications for vegetable oils (USDA-ERS, 1995). To identify a market not currently served by a vegetable oil, a product was selected which is not typically vegetable oil based: four-cycle motor oils. This market consumes 9.66 billion liters of refined petroleum oil annually within the United States for lubrication purposes. Approximately 3.9 billion liters are consumed solely for four cycle engine oil (Fig. 1).

DEVELOPMENT OF A FOUR CYCLE MOTOR OIL

The internal combustion engine is an extreme environment for vegetable oil. The combination of extreme pressure and heat frequently cause a polymerization of the oil, changing the oil into a plastic within a short period of time. This polymerization has been observed since the development of the internal combustion engine. Prior attempts after the turn of the 20th century found the lifespan of vegetable oils to be unacceptable for modern engine applications. As engine compression increased with increasing requirements of power and performance, vegetable oils were found to be severely lacking in performance. Vegetable oils frequently would polymerize within hours of engine startup. Attempts to use fatty acid esters derived from vegetable oils were successful but production costs made them unacceptable to consumers.

The blending of any of several common base oils with hydroxy oils and wax esters, however, provided the initial functional motor oil. Modifications and variations of these oils have been made to adjust for various applications ranging from small, air cooled engine applications to water cooled, gasoline and diesel engines. Using a base oil derived from essentially any vegetable oil, initially being canola, with a relatively high concentration of monounsaturated fatty acids, was key to providing for an oil that met the objectives of the project.

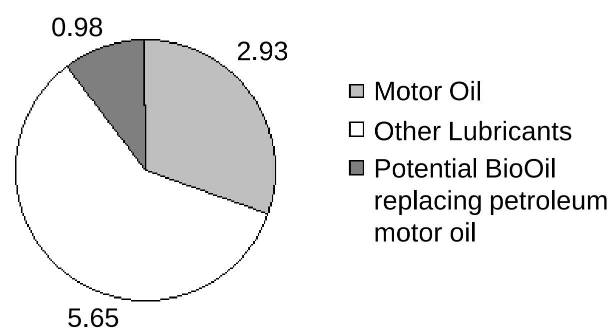

Fig. 1. Lubricant consumption in the United States (Billion liters). (US Petroleum Institute, 1990 modified.)

Evaluation of Vegetable Oil Functionality

A canola-based 4-cycle motor oil was constructed for use in a multitude of engine applications. Production cost-estimates were considered in formulations used to simulate actual production and performance expectations.

To test the oil formulation, a series of bench tests and small engine tests were used to confirm the functionality of the oil. Completion of these tests led to evaluations of the oil in everyday automotive applications. Bench tests included boundary friction analysis using a Timpken bearing test to measure pressure, time to seizure and scar size at seizure. Oxidative stability was measured using a modified AOCS CD-12B-92 hydraulic stability test (72 hrs @177°C). The oxidative stability of the oil was measured with a viscometer (cSt). An oil functionality index (b) was developed from the summed data of a commercial 10W-30 petroleum-based oil and various canola- and canola-soy oil formulations. Conventional and high oleic base oils were used in addition to various added oils based on commercial sources of hydroxy and wax ester sources. Base vegetable oils from either commercial canola, high oleic canola or soybean oils were combined with hydroxy oils from castor and wax esters from jojoba. Functionality indexes are given in Table 1. It became obvious that that the oleic content of the oil increases, index values increase. The addition of a hydroxy fatty acid source provides a motor oil superior to conventional petroleum. The further addition of a vegetable liquid wax ester more than doubles the functionality index (Table 1). The general conclusion was that a low cost base oil, combined with a source of hydroxy fatty acids and wax esters would provide adequate quality for use in engine applications. For all engine tests conducted a modified commercial canola-based motor oil formulation [commercial canola oil (can) + hydroxy fatty acid oil (hy) + liquid wax ester enriched oil (wx)] was used. Modification was done with commercially available vegetable-based oil additive packages.

Small Engines

Small engine trials were conducted on 5 and 6 hp air-cooled engines which were run under full load for 300 to 500 hours at regular oil changes at 35 hours. Consistent observations showed a 20% reduction in wear at friction points and a reduction of oil consumption of 63% over the petroleum lubricated check engine. Engine operating temperatures were also reduced by 15%–23% over the check in replicated trials. Observational data also show reductions of exhaust emissions from hydrocarbons and carbon monoxide (D. Peiper pers. commun. Univ. of Wisconsin, 1997).

Automotive Applications

Initially, three pre-1975 automobiles not equipped with catalytic converters or engine computers were selected. More recently, six newer automobiles manufactured from 1990 to 1998 have been included in the field trials. The field trials include daily commuting within municipalities as well as long distance, highway kilometers. A total of 10,000 hours in small engine trials and an additional 20,200 hours (173,000 kilometers) in automotive trials. Automotive trials were conducted in Colorado environments ranging from altitudes of 1,525 meters (5,000 feet) to 3,660 meters (12,000 feet). Ambient air temperatures ranged from –28.9°C (–20°F) to 43.3°C (110°F) and at humidities ranging from 8% to 95%.

Automotive engine trials were conducted using replicated samples nested within engines. This was done to minimize variation effects from engines and was considered a better test than a randomized block test. Prior small engine trials have indicated biasing of emissions data following use of the vegetable motor oil (reducing emissions

Table 1. Functionality indexes for vegetable oils.

Oil	Functionality index
10W-30	12.3
Commercial soybean oil	6.7
Commercial canola oil	8.7
Commercial high oleic canola oil	10.9
Commercial canola oil + hydroxy fatty acid rich oil	11.5
Commercial high oleic canola oil + hydroxy fatty acid rich oil	19.8
Commercial canola oil + hydroxy fatty acid rich oil + liquid wax ester enriched oil	24.6
Commercial high oleic canola oil + hydroxy fatty acid rich oil + liquid wax ester enriched oil	31.2

in the petroleum cycle) and so petroleum cycles required additional run time (10 to 20 hours) and purging with mineral-based oils. Petroleum-based 10W-30 motor oil was then used in the petroleum cycle. A similar purge system was used with the vegetable cycle with each replication.

Pre-1975 automotive applications included an air-cooled 1600 cc 1971 Volkswagen, a 1970 5 liter Ford Mustang, and a 1966 6.4 liter Ford Thunderbird. These older vehicles were selected since they lacked emission control devices such as onboard computers and catalytic converters. More recent additions include: a 1990 2.2 liter Chrysler Cirrus, a 1996 8 liter Dodge Ram truck, a 1998 5.2 liter Dodge Ram truck, a 1998 Jeep Wrangler, and a 1990 4.2 liter Chevrolet APV.

Observations in Automotive Applications

Results of the automotive applications were similar to observations in the small engine tests. All vehicles tested to date show consistent reductions in automotive emissions of hydrocarbons, carbon monoxide and carbon dioxide. Fuel economy has likewise shown consistent increases from 3–6% in all vehicles tested. Across vehicles monitored, a 4.67% increase in fuel economy has been noted (Table 2).

Exhaust emissions have likewise been reduced by conversion to a vegetable-based motor oil. In the example of the 1966 Ford Thunderbird, not only did fuel economy increase but exhaust emissions were significantly reduced. In the case of the Ford, oil consumption was significantly reduced and this may be partially responsible for reductions in hydrocarbons and carbon monoxide (Table 3).

The Environmental Effects of a Canola-Based Motor Oil

Several physical and environmental concerns are addressed by the vegetable motor oil. These data are summarized in Table 4. Table 4 illustrates the "bench test" properties of the canola-based motor oil. The oil has superior properties for flash point, fire point, viscosity index, 4 ball wear, acute toxicity (trout toxicity test), biodegradability, and coefficient of friction. The vegetable oils were inferior to petroleum for pour point, oxidative stability, and low temperature cranking power. More recent studies have addressed these problems and preliminary data indicate they are solvable concerns.

The biodegradability test shows the oil will meet EPA standards for biodegradability. The oil when tested for marine toxicity was found to be over 210,000 times less toxic than its petroleum counterpart. Additional ICP analysis of used automotive oil show no significant metals in either the new or used canola-based motor oil. Heavy metals are an integral part of petroleum-based lubricants but are not added to the vegetable-based oil. No metal contaminants, with the exception of iron, were accumulated by the canola-based oil.

SUMMARY

A canola-based motor oil was found to be a feasible alternative to conventional and synthetic petroleum motor oils. Higher oleic fatty acid content was important to functional properties but due to current costs, a conventional fatty acid profile was used in the test.

Table 2. Sample fuel economy increases for replicated automotive trials using vegetable oil.

Automobile	Fuel economy increase (%)
'71 VW[z]	3.0
'70 Mustang	4.2
'66 Thunderbird	4.3
'90 Chevrolet	4.5
'98 Dodge	6.0

[z]Results of two replications using nested data

Table 3. Summary of emissions and oil consumption data for a 1966 Ford Thunderbird. Emission data from State of Colorado Emissions Testing Station, Ft. Collins, Colorado.

Variable	Canola-based oil	10W-30 petroleum
Hydrocarbons ppm (idle: 1230 rpm)	138	148
Hydrocarbons ppm (high speed: 2500 rpm)	75	89
Carbon monoxide ppm (idle: 1230 rpm)	3.14	4.94
Carbon monoxide ppm (high speed: 2500 rpm)	2.12	3.58
Carbon dioxide ppm (idle: 1230 rpm)	7.7	11.8
Carbon dioxide ppm (high speed: 2500 rpm)	10.7	12.9
Oil consumption (liters/1000 kilometers)	0.65	1.68

Table 4. Comparative functional and environmental properties of a canola-based motor oil. Data summary provided by US Naval Facilities Engineering Service Center.

Physical properties	ASTM method	Canola results	Petroleum 10W-30
Flash point (°C)	D 92	274	221
Fire point (°C)	D 92	320	243
Pour point (°C)	D 97	-30	-35
Viscosity index (cSt)	D 2270	193	93
Oxidative stability (min)	D 2272	164	225
4 ball wear (mm)	D 2266 (mod.)	0.61	0.69
Coeff. friction	D 2266 (mod.)	0.053	0.119
Cold cranking cSt@–20°C	D 5293	1,470	3,500
Biodegradability (%)	D 212	97.7	38.6
Acute toxicity, LC50 (ppm)	EPA/600/4-90/027F, 1993	7,320	0.03

Canola-based motor oils were evaluated in bench trials, small engine trials, and in automotive applications. In general, reductions in oil consumption, fuel consumption, engine operating temperatures and engine wear were universal in all engine trials.

Physically, the canola motor oil was superior to a comparable petroleum oil in five of seven categories. In terms of environmental concerns, the canola-based oil met EPA standards for biodegradability, marine safety, exhaust emissions, and fuel economy.

Additional improvements in the canola-based motor oil are possible and solutions are expected to improve deficiencies to make the oil more functionally superior to current petroleum products. Cost concerns may limit functional improvements but environmental concerns may overcome some cost constraints. Improvements in functionality and environmental safety appear viable within cost constraints.

REFERENCES

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