POTENTIAL OF VEGETABLE OIL AS A TRANSPORTATION FUEL

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Abstract

The esters of vegetable oils (Biodiesel) have potential as direct replacements for diesel fuel in compression ignition engines. This paper discusses fuel properties, short and long term engine tests, production, processing and economics of these renewable, alternative fuels. Most tractor manufacturers in Europe now extend their warranties to cover Biodiesel. Biodiesel is produced through a simple process that can be carried out in large industrial plants, in small rural cooperative size plants, or on the farm. University of Idaho scientists have developed improved rape varieties, processing systems and have experimented with the fuel in many engine tests. Additional work is needed before the fuel can be commercially acceptable. Major limitations are total production (which, in the U. S., is limited to about 10 percent of diesel fuel use or about the amount of diesel we use in agriculture) and the increased cost compared to petroleum based fuels.

Introduction

During the past decade the U.S. has become increasingly dependent upon imported oil to meet our energy demands. Nearly 50 percent of our U.S. consumption of petroleum is imported. Research has shown that agricultural crops can be used to reduce this dependence. Vegetable oil as an alternative fuel has been under study at the University of Idaho since 1979. Since then the Idaho research team has pioneered the use of transesterified rapeseed oil (RME) as a diesel fuel substitute.

Many studies have shown that vegetable oils such as soybean oil, sunflower oil, safflower oil, cottonseed oil, peanut oil and rape oil have potential as alternative fuels for diesel engines. However, this is not an entirely new concept; history records that Rudolph Diesel, the inventor of the engine that bears his name, used vegetable oil fuel in his engines as early as 1900. In the intervening years, readily available, inexpensive and abundant supplies of petroleum based fuels have provided little incentive for experimenting with alternative, renewable fuels.

The energy crisis of the 1970's sparked a renewed interest in the use of vegetable oils as fuels (Peterson, 1986). The most promising form of vegetable oil for use in CI engines is that of an ester (methyl, ethyl or butyl).

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It is reported that over 60 million gallons of RME per year is being produced in Europe. Plants are planned or are operating in European countries such as Germany, Czechoslovakia, Hungary, Italy, Belgium and France. Most engine manufacturers have extended their engine warranties to cover operation on this fuel. In the U.S., Interchem, Inc., a company in Leawood, Kansas, plans to market over 30 million gallons of methyl soyate. They purchase this product from Procter and Gamble. Development of the technology for vegetable oil fuels makes it possible to provide energy for agriculture from renewable sources located close to the area where it can be used. The National Soybean Development Board is encouraging and/or sponsoring studies which will lead to commercialization of Biodiesel in the United States.

This paper will discuss the technical issues surrounding the use of vegetable oils for diesel fuel substitutes.

A. Properties of vegetable oils relative to diesel fuel.

Over 350 oil bearing crops have been identified, the most predominantly considered of these as fuel substitutes are sunflower, safflower, soybean, cotton, winter rape, canola and peanut. In 1981, 19 percent of the U. S. cropland was planted to vegetable oil crops: 14.7 percent was devoted to soybeans, 3.1 percent to cottonseed, 0.8 percent to sunflower and 0.3 percent to peanuts. Each of the other species were produced in very small quantities. The U. S. is the largest oilseed producing nation (35% of the world production). The U.S exports about 365 million gallons of vegetable oil annually, equivalent to 11 percent of the diesel fuel used in agriculture.

All of the vegetable oils have energy contents similar to diesel (94 percent of the energy content on a volume basis), but vegetable oils are many times more viscous. This high viscosity causes injector pattern problems and is thought to be at least in part responsible for difficulties experienced with engine life.

Several researchers have reported on properties of vegetable oil in comparison to diesel fuel. Goering et al. (1982) presented data on eleven alternate fuels. Vinyard et al. (1982) reported many of the relevant properties of five types of vegetable oils. Needham and Doyle (1985) compared sunflower oil with other alternate fuels. Vander Griend et al. (1989) focused on properties of rape oil and its esters relevant to modeling combustion in a diesel engine.

An American Society of Agricultural Engineers (ASAE) Engineering Practice is being proposed which provides for reporting of appropriate data when experiments are conducted related to using vegetable oil as a diesel fuel.. In addition, a vegetable oil as a diesel fuel standard is being developed for consideration by the American Society of Testing Materials (ASTM).

B. Extracting and processing.

Transesterification of vegetable oils involves reacting an alcohol with the oil in the presence of an alkaline or acidic catalyst. In this work, the transesterification being studied is an alcoholysis where the glycerine component of a vegetable oil is replaced by an alcohol.

All of the oil used in the University of Idaho studies has been extracted with a small oil plant consisting of a mechanical screwpress manufactured by CeCoCo of Japan. The plant has a capacity of 45 kg per hour (100 lb per hour) and generates about 19 liters (5 gallons) of oil per hour. For a complete description of the process see Peterson et al. (1983) and Peterson et al. (1989). The esterification plant was designed for a 756 L (200 gallon) capacity. Typically 605 L (160 gallon) batches have been produced.

The described plant has been used successfully to produce approximately 4000 liters (1000 gallons) of the RME oil. Conversion has been 98 percent and above. Handling large quantities of methanol constitutes an explosion and fire hazard and is the biggest major element of concern in implementing the process. The relatively large quantities of water used constitute a disposal problem. No attempt has been made to define the process for any other purpose than for fuel use. Transesterification is used only as a method to lower the viscosity of the vegetable oil to a more suitable level for use as a fuel.

C. Fuel evaluation in short term performance tests.

In a summary of 22 short term engine tests conducted at 12 locations worldwide in which vegetable oil was compared to diesel as a fuel, peak engine power on the vegetable oil fuels ranged from 91 to 109 percent of that produced when the same engine was operated with diesel fuel. In these tests, 16 of the 22 reported peak power equal to or exceeding that when the engines were operated on diesel. Fuel consumption is generally slightly higher reflecting the reduced energy content of the vegetable oil. Thermal efficiencies are also generally reported to be slightly higher than for diesel fuel.

Peterson et al. (1987) ran a series of short term engine tests to evaluate the effects of RME on injector coking. The results showed the transesterification treatment to decrease the injector coking to a level significantly lower than that observed with No. 2 diesel.

D. Fuel evaluation in long term test cycles: neat vegetable oils.

While short term test results are almost always positive, longer term tests with the neat vegetable oils lead to severe engine deposits, ring sticking, injector coking and thickening of the lubricating oil. Polymerization of the vegetable oil in the ring belt area causes the rings to seize, associated with an increase in blow-by, and increase in the viscosity of the lubricating oil and resulting catastrophic failure of the engine.

A North Dakota study (German et al., 1985) concluded that use of a 25% sunflower oil/75% No. 2 diesel fuel blend or a 50% sunflower oil/50% diesel fuel blend as a substitute diesel fuel cannot be recommended. However, under emergency conditions, a 25/75% blend of alkali-refined, winterized sunflower oil/diesel fuel could be used as a diesel engine fuel. The operator must be aware that reduced engine life would occur.

E. Fuel evaluation in long term test cycles: Direct injection vs. indirect injection engines.

Problems associated with using vegetable oils have been observed to be much less severe in indirect injection engines; i.e., those with pintle type injectors and precombustion chambers, than in their direct injection counterparts. One test in South Africa reported that after 1800 hours no problems were observed and no injector coking was evident. The general condition of the engine components at the completion of the test was such that the manufacturer issued a warranty on their indirect injection engines for operation on sunflower oil. (Fuls et al., 1984). This and other tests have shown that vegetable oil can be used successfully in unmodified, indirect injection engines. Most tractors and trucks made in the U.S. are of the direct injection type while most of the small import tractors and high speed engines are of the pre-combustion chamber type.

F. Fuel evaluation in long term test cycles: Transesterified vegetable oil fuels.

A number of researchers have evaluated RME in engine tests. They conclude that the performance of the esters of vegetable oil did not differ greatly from diesel (Mora, 1985). The brake power was nearly the same as with diesel fuel while the specific fuel consumption was higher than diesel. Based upon crankcase oil analysis, engine wear rates were low but some oil dilution did occur. Carbon deposits inside the engine were normal with the exception of intake valve deposits.

Although most researchers agree that vegetable oil ester fuels are suitable for use in CI engines, a few contrary results have also been obtained. Vinyard et al. (1982) reported an extensive coking problem while using degummed sunflower ethyl ester. The ester produced unacceptable coking levels after only 50 hours of operation under part load even when diluted with up to 30% diesel fuel.

The results of these studies point out that most vegetable oil methyl esters are suitable as diesel substitutes but that more long term studies are necessary for commercial utilization to become practical.

G. University of Idaho 1000 Hour Tests

Tests at the University of Idaho have shown that use of RME is equivalent to diesel fuel in direct injection, diesel engines.

Three, Yanmar 3TN75E-S, 3-cylinder, 4-stroke, naturally aspirated, direct injection diesel engines were used. One was fueled with 100% RME, one with a 50% number 2 diesel - 50% RME blend, and one with a reference fuel of 100% No. 2 diesel, were investigated in both 200 hour EMA test Cycles (Zhang et al., 1988) and in 1000 hour test cycles using the EMA test procedure for alternate fuels (Perkins et al., 1991). It was found that RME was equivalent to No. 2 diesel when compared on the basis of long term performance and engine wear. The primary factors which were evaluated included engine brake power and torque, injector tip coking, and engine component wear (based on oil analysis). The only noticeable adverse effect of the ester fuel was a slight decrease in engine oil viscosity.

H. On-Road vehicle tests.

A Biodiesel demonstration project was launched this past summer in cooperation with the Energy Division, Idaho Department of Water Resources to show the use of Biodiesel for on-the-road vehicles. Two diesel powered pickups are being tested on 20 percent vegetable oil fuels mixed with 80 percent diesel. One pickup is powered by a 5.9 liter turbocharged and intercooled, direct injection engine. It is fueled with 20 percent RME and 80 percent diesel. The second engine is a 7.3 liter, naturally aspirated, precombustion chamber engine which is being tested on 20 percent raw rapeseed oil and 80 percent diesel. The precombustion chamber permits satisfactory operation with much less suitable fuels. The engines are unmodified, but modifications have been made to the vehicles for convenience of running the test.

The fuel delivery systems have been modified to provide for onboard mixing of the fuel. A 50-gallon fuel tank has been placed in the bed of each vehicle which holds the vegetable oil fuel. A small mixing tank has been mounted to the frame of each vehicle into which the two fuel components are pumped. The return line from the diesel injection system also comes into this small tank. Since vegetable oil have a pour point only slightly below freezing, the fuel tanks have also been provided with a heating system. Providing for onboard mixing greatly extends the range of the vehicles compared to carrying premixed fuels in the existing tanks. The vehicles as outfitted can travel over 4000 miles between fills with vegetable oil.

The pickups are regularly tested on a dynamometer at the Western States Caterpillar truck shop in Spokane, Washington. Oil samples are analyzed for wear metals, antifreeze, fuel dilution, water and viscosity.

To date the Dodge pickup has accumulated 19,300 miles and the Ford 16,300 miles. Both are operating normally, wear metals are well within limits as shown by the oil analysis. Dynamometer tests (at 2350 rpm) show the 20 percent RME fuel developed 4.5 percent less horsepower and had a 36 percent decrease in exhaust opacity compared to 100D2 and 100 percent RME had 9 percent less horsepower and 63.6 percent less opacity.

The 20 percent neat vegetable oil blend developed 3 percent less horsepower and 22 percent less opacity in the Ford truck at rated load.

I. Environmental impact of using vegetable oils as fuel.

Fatty acid esters have surprisingly good emissions characteristics. Mittelbach et al. (1985) found that emissions of two different RME fuels gave significantly lower total particulates and lower polynuclear aromatic hydrocarbons than No. 2 diesel fuel. However, combustion of RME fuels produced higher levels of NOx emissions and aldehyde emissions than did No. 2 diesel fuel. Similar results have been reported by others. Particulate production has been shown to be reduced by from 50 to 66 percent. Both engine modification and fuel modification have potential for enhancing engine heat release rates and further reducing exhaust emissions.

Vegetable oils are also more environmentally friendly in case of a spill. The fuel is not water soluble and is not carried into the soil and will biodegrade. Tests comparing the effect of spills on the environment are in the planning stage.

Vegetable oil contains no sulphur which decreases the acid rain problem and CO_2 production in the exhaust emissions can be balanced against CO_2 utilization by the vegetable oil producing plant resulting in little or even a net loss in CO_2 with implications for global warming.

J. Economics

Two University of Idaho graduate students, Melville (1987) and Caringal (1989) have made zero profit analysis of the cost of RME. Melville (1987) estimated the production cost of RME at $0.31 per L ($1.18 per gallon) and $0.425 per L ($1.61 per gallon) for a COOP sized unit and farm sized unit respectively. The farm size unit processed 78.6 t (86.7 tons) of seed per year producing nearly 34,000 L (9000 gallons) of RME per year (enough to meet the diesel demand of an average sized farm.) The COOP sized unit processed 1480 t (1,632 tons) of seed per year producing 655,000 L (173,000 gallons) of RME per year (enough to supply approximately 20 average sized farms.)

Alcohol has been made successful as an additive to gasoline by certain tax breaks. In some cases, these breaks amount to approximately $0.0264 per L ($0.10 for each gallon) of fuel produced containing at least 10 percent alcohol or the subsidy is essentially $0.264 per L ($1.00 per gallon.) A subsidy of this magnitude would make the RME an economically attractive fuel.

K. Potential production.

As of 1982, the active crop land in the United States consisted of 382.8 million acres; an additional 21.5 million acres of crop land was idle. Assume that 1 acre of vegetable oil is capable of producing 100 gallons of oil. (rapeseed at 1 ton per acre is equivalent to 100 gallons of oil and approximately 1200 pounds of meal.) On this basis, if every acre of available crop land were to be put into rape production approximately 40,425 million gallons of fuel per year could be produced. This is equivalent to 1.6 times the annual consumption of diesel use in transportation.

Computations of the land actually available for vegetable oil production are complicated. Certainly land must be available for domestic production of food. It is also logical to assume that some production of food for export will continue to be needed. In 1990, 35 million acres were in the conservation reserve program and 24.8 million acres were in the set-aside programs (USDA. 1990). These two sources of idle crop land could produce 5.98 billion gallons of vegetable oil per year or 24 percent of the diesel used in transportation. An estimate of additional crop land potentially available for vegetable oil production was made by comparing crop production for several of the major crops with domestic use. Any production over domestic use was termed excess and using the national average production for that crop an estimate of excess crop production land of 65 million acres was calculated (Peterson et al., 1990).

Conclusions

Based upon evaluation of engine performance, wear (oil analysis), and injector deposits as indicators of engine durability, RME appears to be at least equivalent to number 2 diesel. A major disadvantage for the RME at this time is its relatively high cloud and pour points.

The major limiting factors for use of vegetable oil are economics (cost) and potential production. Cost is largely driven by the value of the by-products (meal and glycerol). Production is limited by available agricultural acreage. Environmental impacts for vegetable oil fuels are potentially less than for using diesel fuel. Future research will concentrate on identifying those uses for vegetable oil fuels where the environmental attractions are enough to overcome the economic restraints. Diversion of 10 percent of cropland to the production of Biodiesel could provide the diesel fuel used in agriculture. However because it is an environmentally friendly fuel, there may be places where it is more valuable than for agriculture. In order for this fuel to be used, we need legislation which would encourage production, make it possible to develop production facilities, to assist cooperatives in startup, and to continue the research. While ethanol has received an enormous amount of government and industry support, we have yet to see a similar amount of support for Biodiesel.

Disclaimer Statement

This report contains a summary of research results. This is not to be construed as a recommendation for the use of any alternative fuel mixture mentioned. The engine operator is responsible for all decisions concerning use of alternate fuels. Production of RME involves the use of certain hazardous materials, the competence of the personnel involved and suitability of available equipment must be considered before attempting to reproduce this work in any form.

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