Using Unmodified Vegetable Oils as a Diesel Fuel Extender –

A Literature Review

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Abstract

This paper is a review of literature concerning using vegetable oils as a replacement for diesel fuel. The term vegetable oils as used in this paper refers to vegetable oils which have not been modified by transesterification or similar processes to form what is called biodiesel. The oils studied include virgin and used oils of various types including soy, rapeseed, canola, sunflower, cottonseed and similar oils. In general, raw vegetable oils can be used successfully in short term performance tests in nearly any percentage as a replacement for diesel fuel. When tested in long term tests blends above 20 percent nearly always result in engine damage or maintenance problems. Some authors report success in using vegetable oils as diesel fuel extenders in blends less than 20 percent even in long term durability studies. Degumming is suggested by one author as a way to improve use of raw oils in low level blends. It is apparent that few, if any, engine studies using low-level blends of unmodified vegetable oils, < 20%, have been conducted.

Introduction

Many studies have been done at the University of Idaho and elsewhere involving vegetable oils as a primary source of energy. Particularly, during the early 1980's, studies were completed that tested the possibility of using unmodified vegetable oils as a replacement for diesel fuel.

There is no question that vegetable oil can be placed in the tank of a diesel powered vehicle and the engine will continue to run and deliver acceptable performance. Some vegetable oils, such as rapeseed oil, have very high viscosity and thus may starve the engine for fuel when operated at 100 percent. Most studies show that power and fuel economy, when compared to operation on diesel, are proportional to the reduced heat of combustion of the vegetable oil fuel.

Despite the success when diesel engines are operated on vegetable oil for short term performance tests, the real measure of success when using vegetable oil as a diesel fuel extender or replacement depends primarily on the performance of vegetable oils in engines over a long period of time. Thus many researchers have been involved in testing programs designed to evaluate long term performance characteristics. Results of these studies indicated that potential hazards such as stuck piston rings, carbon buildup on injectors, fuel system failure, and lubricating oil contamination (Pratt, 1980) existed when vegetable oils were used as alternative fuels.   This effect diminishes as the blend of vegetable oil in diesel is decreased. The question of this literature review is to determine if there is a blend level at which vegetable oil in the unmodified form can be used as a diesel fuel extender. Throughout this paper when the term vegetable oil or the name of a particular vegetable oils is used, such as canola, it refers to the unmodified form.

100 Per Cent Vegetable Oil as Potential Fuel Sources

During World War II, Seddon (1942) experimented with using several different vegetable oils in a Perkins P 6 diesel engine with great success. The results of this experiment showed that vegetable oils could be used to power a vehicle under normal operating conditions. However, it was noted that much more work was needed before vegetable oils could be used as a reliable substitute for diesel fuel.

The Southwest Research Institute, Reid et al. (1982), evaluated the chemical and physical properties of 14 vegetable oils. These injection studies pointed out that the oils behave very differently from petroleum-based fuels. This change in behavior was attributed to the vegetable oils' high viscosity. Engine tests showed that carbon deposits in the engine were reduced if the oil was heated prior to combustion. It was also noted that carbon deposit levels differed for oils with similar viscosities, indicating that oil composition was also an important factor.

Goering et al. (1981) studied the characteristic properties of eleven vegetable oils to determine which oils would be best suited for use as an alternative fuel source. Of the eleven oils tested, corn, rapeseed, sesame, cottonseed, and soybean oils had the most favorable fuel properties.

Bruwer et al. (1980) studied the use of sunflower seed oil as a renewable energy source. When operating tractors with 100% sunflower oil instead of diesel fuel, an 8% power loss occurred after 1000 hours of operation. The power loss was corrected by replacing the fuel injectors and injector pump. After 1300 hours of operation, the carbon deposits in the engine were reported to be equivalent to an engine fueled with 100% diesel except for the injector tips, which exhibited excessive carbon build-up.

Tahir et al. (1982) tested sunflower oil as a replacement for diesel fuel in agricultural tractors. Sunflower oil viscosity was 14% higher than diesel fuel at 37°C. Engine performance using the sunflower oil was similar to that of diesel fuel, but with a slight decrease in fuel economy. Oxidation of the sunflower oil left heavy gum and wax deposits on test equipment, which could lead to engine failure.

Bacon et al. (1981) evaluated the use of several vegetable oils as potential fuel sources. Initial engine performance tests using vegetable oils were found to be acceptable, while noting that the use of these oils caused carbon build up in the combustion chamber. Continuous running of a diesel engine at part-load and mid-speeds was found to cause rapid carbon deposition rates on the injector tips. Short 2-hour tests were used to visually compare the effects of using different vegetable oils in place of diesel fuel. Although short-term engine test results were promising, Bacon recommended long-term engine testing to determine the overall effects of using vegetables oils as a fuel in diesel engines.

Schoedder (1981) used rapeseed oils as a diesel fuel replacement in Germany with mixed results. Short-term engine tests indicated rapeseed oil had similar energy outputs when compared to diesel fuel. Initial long-term engine tests showed that difficulties arose in engine operation after 100 hours due to deposits on piston rings, valves, and injectors. The investigators indicated that further long-term testing was needed to determine if these difficulties could be adverted.

Auld et al. (1982) used rapeseed oil to study the effects of using an alternative fuel in diesel engines. An analysis of the rapeseed oil showed a relationship between viscosity and fatty acid chain length. Engine power and torque results using rapeseed oil were similar to that of diesel fuel. Results of the short-term tests indicated further long-term testing was needed to evaluate engine durability when rapeseed oil was used.

Bettis et al. (1982) evaluated sunflower, safflower, and rapeseed oils were evaluated as possible sources for liquid fuels. The vegetable oils were found to contain 94% to 95% of the energy content of diesel fuel, and to be approximately 15 times as viscous. Short-term engine tests indicated that for the vegetable oils power output was nearly equivalent to that of diesel fuel, but long-term durability tests indicated severe problems due to carbonization of the combustion chamber.

Engler et al. (1983) found that engine performance tests using raw sunflower and cottonseed vegetable oils as alternative fuels gave poor results. Engine performance tests for processed vegetable oils produced results slightly better than similar tests for diesel fuel. However, carbon deposits and lubricating oil contamination problems were noted, indicating that these oils are acceptable only for short-term use as a fuel source.

Pryor et al. (1983) conducted short and long-term engine performance tests using 100% soybean oil in a small diesel engine. Short-term test results indicated the soybean performance was equivalent to that of diesel fuel. However, long-term engine testing was aborted due to power loss and carbon buildup on the injectors.

Yarbrough et al. (1981) experienced similar results when testing six sunflower oils as diesel fuel replacements. Raw sunflower oils were found to be unsuitable fuels, while refined sunflower oil was found to be satisfactory. Degumming and dewaxing the vegetable oils were required to prevent engine failure even if the vegetable oils were blended with diesel fuel.

Over 30 different vegetable oils have been used to operate compression engines since the 1900's (Quick, 1980). Initial engine performance suggests that these oil-based fuels have great potential as fuel substitutes. Extended operation indicated that carbonization of critical engine components resulted from the use of raw vegetable oil fuels, which can lead to premature engine failure. Blending vegetable oil with diesel fuel was found to be a method to reduce coking and extend engine life.

Pryde (1982) reviewed the reported successes and shortcomings for alternative fuel research. This article stated that short-term engine tests using vegetable oils as a fuel source was very promising. However, long-term engine test results showed that durability problems were encountered with vegetable oils because of carbon buildup and lubricating oil contamination. Thus, it was concluded that vegetable oils must either be chemically altered or blended with diesel fuel to prevent premature engine failure.

Studies involving the use of raw vegetable oils as a replacement fuel for diesel fuel indicate that a diesel engine can be successfully fuel with 100% vegetable oil on a short-term basis. However, long-term engine durability studies show that fueling diesel engines with 100% vegetable oil causes engine failure due to engine oil contamination, stuck piston rings, and excessive carbon build-up on internal engine components. Therefore 100% unmodified vegetable oils are not reasonable diesel fuel replacements.

Vegetable Oil, Diesel Blends as Potential Fuel Sources

Engelman et al. (1978) presented data for 10% to 50% soybean oil fuel blends used in diesel engines. The initial results were encouraging. They reported at the conclusion of a 50-hour test that carbon build-up in the combustion chamber was minimal. For the fuel blends studied, it was generally observed that vegetable oils could be used as a fuel source in low concentrations. The BSFC and power measurements for the fuel blends only differed slightly from 100% diesel fuel. Fuel blends containing 60% or higher concentrations of vegetable oil caused the engine to sputter. Engine sputtering was attributed to fuel filter plugging. They concluded that waste soybean oil could be used as a diesel fuel extender with no engine modifications.

Studies in New Zealand by Sims et al. (1981) indicated that vegetable oils, particularly rapeseed oil, could be used as a replacement for diesel fuel. Their initial short-term engine tests showed that a 50% vegetable oil fuel blend had no adverse effects. While in long-term tests they encountered injector pump failure and cold starting problems. Carbon deposits on combustion chamber components was found to be approximately the same as that found in engines operated on 100% diesel fuel. These researchers concluded that rapeseed oil had great potential as a fuel substitute, but that further testing was required.

Caterpillar (Bartholomew, 1981) reported that vegetable oils mixed with diesel fuel in small amounts did not cause engine failure. Short-term research showed that blends using 50/50 were successful, but that 20% vegetable oil fuel blends were better.

Deere and Company (Barsic and Humke, 1981) studied the effects of mixing peanut oil and sunflower oil with Number 2 diesel fuel in a single cylinder engine. The vegetable oil blends were observed to increase the amount of carbon deposits on the combustion side of the injector tip when compared with 100% diesel fuel. The vegetable oil fuel blends were found to have a lower mass-based heating value than that of diesel fuel. Fuel filter plugging was noted to be a problem when using crude vegetable oils as diesel fuel extenders.

International Harvester Company (Fort et al. 1982) reported that cottonseed oil, diesel fuel blends behaved like petroleum-based fuels in short-term performance and emissions tests. The experimental fuels performed reasonably well when standards of judgment were power, fuel consumption, emissions, etc. However engine durability was an issue during extended use of these fuel blends because of carbon deposits and fueling system problems.

Other research at International Harvest Company (Baranescu and Lusco, 1982) was done using three blends of sunflower oil and diesel fuel. Results indicated that the sunflower oil caused premature engine failure due to carbon buildup. It was noted that cold weather operation caused fuel system malfunctions.

Worgetter (1981) analyzed the effects of using rapeseed oil as a fuel in a 43-kW tractor. The goal of running the tractor for 1000 hours on a blend of 50% rapeseed oil and 50% diesel was never achieved as the test was aborted at about 400-hours due to unfavorable operating conditions. The use of rapeseed oil in the fuel resulted in heavy carbon deposits on the injector tips and pistons, which would have caused catastrophic engine failure if the tests had not been aborted. Upon engine tear down, it was found that the heavy carbon deposits on the pistons was the cause of the noted power loss and not the fuel injectors.

Wagner and Peterson (1982) reported mixed results when using rapeseed oil as a substitute fuel. Attempts to heat the oil fuel mixture prior to combustion exhibited no measurable improvement in fuel injection. Severe engine damage was noted during short-term engine testing due to the use of rapeseed oil. A long-term test using a 70% rapeseed, diesel fuel blend was successful for 850 hours with no apparent signs of wear, contamination of lubricating oil, or loss of power.

Van der Walt and Hugo (1981) examined the long-term effects of using sunflower oil as a diesel fuel replacement in direct and indirect injected diesel engines. Indirect injected diesel engines were run for over 2000 hours using de-gummed, filtered sunflower oil with no adverse effects. The direct injected engines were not able to complete even 400 hours of operation on the 20% sunflower oil, 80% diesel fuel mixture without a power loss. Further analysis of the direct injected engines showed that the power loss was due to severely coked injectors, carbon buildup in the combustion chamber, and stuck piston rings. Lubricating oil analysis also showed high piston, liner, and bearing wear.

Engine Testing by Ziejewski and Kaufman (1982) at Allis Chalmers using a 50/50 blend of sunflower oil and diesel was unsuccessful. Carbon buildup on the injectors, intake ports, and piston rings caused engine operating difficulties and eventual catastrophic failure.

Fuls (1983) reported similar findings for indirect and direct injection engines using 20% sunflower oil, diesel fuel blends. Fuls Emphasized that injector coking was the problem with using sunflower oil in direct injected diesel engines.

Caterpillar Tractor Co. (McCutchen, 1981) compared engine performance of direct injection engines to indirect injection engines when fueled with 30% soybean oil, 70% diesel fuel. The results showed that indirect injection could be operated on this fuel blend while the direct injection engine could not without catastrophic engine failure occurring. The direct injection engines showed injector coking and piston ring sticking as a result of using sunflower oil.

An on-farm study using six John Deere and Case tractors by German et al. (1985) averaged 1300-hours of operation. Carbon deposits on the internal engine components were greater for the tractors fueled with 50/50 sunflower oil/diesel than for those fueled with a 25/75 sunflower oil/diesel fuel blend. All the test engines had more carbon build-up than normally seen in an engine fueled with diesel fuel. The results of this study indicated that neither of the fuel blends could be use as a replacement for petroleum based fuels on a permanent basis without shortening engine life.

Peterson et al. (1982) used rapeseed oil as a diesel fuel extender to study the long-term effects of using vegetable oils as a fuel source. Fuel composed of 70% rapeseed oil and 30% Number 1 diesel fuel was successfully used to operate a small single cylinder engine for 850 hours. No adverse operating conditions were reported at the conclusion of this engine study. A short-term performance test using a 100% sunflower oil caused severe piston ring gumming and catastrophic engine failure. This study highlighted the need for significant long-term engine testing before recommendations of using vegetable oil as a fuel could be made.

Nag et al. (1995) did studies involving the use of seed oils grown natively in India. Performance tests using fuel blends as great as 50-50 seed oil from the Indian Amulate plant and diesel fuel exhibited no loss of power. Knock free performance with no observable carbon deposits on the functional parts of the combustion chamber were also observed during these tests. Although this seed oil was not yet commercially available at the time of this study, it was hoped that it soon would be.

Sapaun et al. (1996) reported that studies in Malaysia, with palm oils as diesel fuel substitutes, exhibited encouraging results. Performance tests indicated that power outputs were nearly the same for palm oil, blends of palm oil and diesel fuel, and 100% diesel fuel. Short-term tests using palm oil fuels showed no signs of adverse combustion chamber wear, increase in carbon deposits, or lubricating oil contamination.

Ryan et al. (1984) characterized injection and combustion properties of several vegetable oils. The atomization and injection characteristics of vegetable oils were significantly different from that of diesel fuel due to the higher viscosity of the vegetable oils. Engine performance tests showed that power output slightly decreased when using vegetable oil fuel blends. Injector coking and lubricating oil contamination appeared to be a more dominate problem for oil-based fuels having higher viscosities.

Pestes and Stanislao (1984) used a one to one blend of vegetable oil and diesel fuel to study piston ring deposits. Premature piston ring sticking and carbon build-up due to the use of the one to one fuel blend caused engine failure. The severest carbon deposits were located on the major thrust face of the first piston ring. These investigators suggested that to reduce piston ring deposits a fuel additive or a fuel blend with less vegetable oil was needed.

Other studies by Hofman et al. (1981) and Peterson et al. (1981) indicated that while vegetable oil fuel blends had encouraging results in short term testing, problems occurred in long-term durability tests. They indicated that carbon build-up, ring sticking, and lubricating oil contamination was the cause of engine failure when vegetable oils were used in high percentages (50% or more) as diesel fuel substitutes.

Due to engine durability problems encountered using raw vegetable oils as a fuel in the early 1980's, most researchers opted to use chemically modified vegetable fuels more commonly known as biodiesel in place of unrefined vegetable oils. Thus, in recent years there has been little literature concerning the feasibility of using raw vegetable oils as a fuel additive.

McDonnell et al. (2000) studied the use of a semi-refined rapeseed oil as a diesel fuel extender. Test results indicated that the rapeseed oil could serve as a fuel extender at inclusion rates up to 25%. As a result of using rapeseed oil as a fuel, injector life was shortened due to carbon buildup. However, no signs of internal engine wear or lubricating oil contamination were reported.

Conclusions

Many studies involving use of un-modifed vegetable oils in blend ratios with diesel fuel exceeding 20 percent were conducted in the early 1980's. Short-term engine testing indicates that vegetable oils can readily be used as a fuel source when the vegetable oils are used alone or are blended with diesel fuel. Long-term engine research shows that engine durability is questionable when fuel blends contain more than 20% vegetable oil by volume. More work is needed to determine if fuel blends containing less than 20% vegetable oil can be used successfully as diesel fuel extenders.

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