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Biodiesel Testing in Two On-Road Pickups

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ABSTRACT

Two on-road diesel pickups were operated on a mixture of 20 percent Biodiesel and 80 percent diesel for 80,000 kilometers (km). The engines were unmodified, but modifications were made to the vehicles for the convenience of the test. Fuel mixing was done on-board to extend the driving range to over 5,000 km between Biodiesel fill ups.

Chassis dynamometer testing, injector coking, engine compression, injector valve opening pressures, and engine oil analyses were done at regularly scheduled intervals to monitor the engine performance parameters. RME produced 5 percent less power than D2, while 20RME and 20RAW produced one percent less power than D2. Smoke density was reduced 39 percent with RME, while 20RME increased 18 percent, and 20RAW decreased smoke density by 3.1 times that of D2.

Emissions tests with a chassis transient dynamometer at the Los Angeles Metropolitan Authority Emissions Test Facility resulted in a decrease in HC (20 percent), CO (25 percent), NOx (2.6 percent), PM (10.9 percent), and there was no difference in CO_2 with 20RME compared to D2.

INTRODUCTION

Much interest has been generated in the use of alternative fuels for transportation. The Clean Air Act Amendment of 1990 mandates a phase-in plan for adoption of clean fuels that are not harmful to the environment. The Energy Policy Act of 1992 also mandates fleet operators to begin purchasing alternative fueled vehicles as a percentage of all new vehicles purchased starting in model year 1996. Changes in EPA exhaust emissions requirements for diesel engines have also created much interest in the use of Biodiesel. Legislation and federal policies of these types will significantly increase the attractiveness of the use and expedite the commercialization of fuels, including ethanol and vegetable oils. Increased use of renewable fuels can reduce U.S. dependence on imported oil and help improve air quality by reducing harmful gaseous and particulate emissions.

Emissions from compression ignition engines fueled with vegetable oil contain negligible levels of sulfur dioxide responsible for acid rain. Vegetable oils are also more environmentally friendly in the case of a spill. The fuel is biodegradable and will quickly break down, thus preventing long-term damage to soil or water [1].

Vegetable oil as an alternative to diesel fuel has been studied at the University of Idaho since 1979. Researchers at the UI have pioneered the use of rapeseed oil as a diesel fuel substitute. Through this and other research, it has been shown that raw rapeseed oil is best used for fuel in precombustion chamber type diesel engines as a blend with diesel. Most diesel engines in use in the United States are of the direct injection type. For these engines, it has been found that the rapeseed oil should be transesterified before being used as a diesel fuel substitute. Methyl ester of rapeseed (RME) can be substituted for diesel fuel in unmodified diesel engines without significant reduction in engine performance.

OBJECTIVES

Past research has focused on the development and testing of Biodiesel in controlled environments. The objective of this project was to determine if Biodiesel is a viable transportation fuel using two Biodiesel fueled on-the-road pickups. Specific objectives for achieving this goal were to:

- Operate two pickups for 80,000 kilometers with a blend of 20 percent rapeseed methyl ester (RME), 80 percent number two diesel (D2) [20RME] in one, and a blend of 20 percent raw rapeseed oil./80 percent D2 (20RAW) fuel in the other.
- Design an on-board fuel mixing system to maximize the travel range for each pickup and, at the same time, keep the fuel from congealing.
- From dynamometer testing, both chassis and steady state, determine the percent difference in power, opacity, and fuel economy compared to that of D2.
- Conduct pending ASAE fuel standard tests for 20RME, 20RAW, number two diesel, and 100% RME.

disagreeable odor can be reduced by installing an oxidation catalyst. He also states that engine oil dilution is within relatively tight limits and no sludge is apparent with a suitable lubricating oil.

Alfuso et al. [8] reported on the characterization of the behavior of methyl ester of rapeseed oil in direct injection diesel engines at Istituto Motor of CNR. Regulated and unregulated emissions were monitored using transient and steady state conditions with varied injection timing, with and without a catalytic convertor and exhaust gas recirculation (EGR). Tests indicated that RME promotes a rise in NOx emissions and a decrease in HC and CO, as well as a large reduction of smoke. Particulate matter produced by RME in transient cycles is higher than that obtained with D2. The EGR, in presence of an exhaust oxidating catalyst, showed a reduction in NOx, HC, and CO emissions and low effects on particulate matter with RME.

CLOSING COMMENTS - Numerous feedstocks for Biodiesel exist, including rapeseed, tallow, soybean, canola, peanut, sunflower, cottonseed, safflower, coconut, palm, and used cooking oils with which methyl or ethyl esters may be produced. Biodiesel reduces smoke by up to 80 percent, decreases power by 6 percent, and increases fuel consumption 4 percent, due to the heat content of Biodiesel being about 11 percent less than D2. It also decreases HC by as much as 50 percent, CO by as much as 40 percent, and increases NOx almost inversely to PM by as much as 10 percent. Injector coking is slightly greater for Biodiesel, with the carbon deposits being harder than diesel deposits.

Fuel properties suggested by ASTM D-975 were reported in most of the papers reviewed, but no ester specific properties were reported such as percent ester of the fuel, percent glycerol, and alcohol content. The percent of fuel that is ester is one factor that determines the quality of the fuel. The percent of Biodiesel which is ester, along with the viscosity, determines the rate at which carbon deposits are formed in the engine combustion chamber [1]. Unmodified triglycerides caused polymerization in the piston ring lands of earlier studies.

MATERIALS AND METHODS

Two blends of Biodiesel and number two diesel fuel (D2) were studied using two diesel powered pickups at the University of Idaho. During the past decade researchers at the University of Idaho have shown that methyl ester of rapeseed is comparable to D2. This study was to verify the use of blends of Biodiesel in on-road vehicles.

FUELS - The feedstock for both fuels in this study is winter rapeseed, Dwarf Essex variety, expelled at the University of Idaho Department of Agricultural Engineering Farm Scale Processing Facility. One blend of fuel was 20 percent raw rapeseed oil and 80 percent D2. The other was a 20 percent blend of rapeseed methyl ester (RME), produced at the farm scale processing facility, and 80 percent D2. The RME was processed using equipment and techniques scaled up and modified from prior research at the University of Idaho [10].

The abbreviations used to denote the different fuels are as follows:

RAW	100 percent raw rapeseed oil from the oil expeller and filtered
20RAW	20 percent RAW and 80 percent D2
RME	100 percent methyl ester of rapeseed
20RME	20 percent RME and 80 percent D2
D2	100 percent number two diesel fuel

The fuels were characterized by evaluating the parameters required in ASAE EP X552. The tests for specific gravity, viscosity, cloud point, pour point, flash point, heat of combustion, total acid value, catalyst, and fatty acid composition were performed at the Analytical Lab, Department of Agricultural Engineering, University of Idaho. The boiling point, water and sediment, carbon residue, ash, sulfur, cetane number, copper corrosion, Karl Fischer water, particulate matter, iodine number, and the elemental analysis were performed at Phoenix Chemical Labs, Chicago Illinois. The HPLC and titration analysis for total and free glycerol, percent of oil esterified, free fatty acids, and mono-, di-, and triglycerides were performed by Diversified Labs Inc., Chantilly, Virginia.

ON-ROAD VEHICLES - Dodge - The first pickup was a Dodge* 3/4-ton powered by a Cummins 5.9 liter turbocharged, intercooled, direct injected, diesel engine. The engine is an in-line six cylinder and has a bore and stroke of 102.0 x 120.0 mm, respectively; has a compression ratio of 17.5:1; is rated at 119 kW at 2,500 RPM; with a peak torque of 542 N-m at 1750 RPM. It was equipped with a Bosch VE distributor type fuel injection pump. This pickup was operated on 20RME.

Ford - The second pickup was a Ford, powered by a Navistar 7.3 liter, naturally aspirated, precombustion chambered V-8 diesel engine. The engine has a bore and stroke of 104 x 104 mm, respectively; has a compression ratio of 21.5:1; is rated at 134 kW at 3,300 RPM; with a peak torque of 467 N-m at 1400 RPM. It was equipped with a Stanadyne rotary type fuel injection pump. A blend of 20 RAW was selected for this pickup because of the precombustion chambered engine.

Check Vehicles - Three other pickups were used as check vehicles. Two were equipped with 5.9 liter direct injection engines, and the other used a 7.3 liter engine with a precombustion chamber. These vehicles were privately owned and were operated on 100 percent diesel fuel to serve as a comparison. Oil samples and analyses were performed at each owner's discretion and analyzed by the same laboratory as the Biodiesel pickups. When possible, these vehicles were dynamometer tested at the same facility as the Biodiesel pickups.

FUEL MIXING SYSTEM - The fuel delivery systems in the Biodiesel pickups were modified to provide for on-board mixing of the fuel. On-board mixing greatly extends the range of the vehicles compared to the original equipment. A 210 liter

*The use of manufacturer's names or trade products does not represent an endorsement of the product nor discrimination toward similar products which are not named.

compression was tested and the injector valve opening pressure was also checked. The Dodge pickup, Cummins engine, has direct access to the combustion chamber and cylinder walls rough the injector bore in the cylinder head. A fiberoptic oorescope was used for this engine to visually inspect the amount of carbon build up on the piston crown and valve heads and to check for any abnormal cylinder wear.

Oil samples were taken at each oil change, which was 4,800 km for the Biodiesel pickups, and at the convenience of the owners of the control vehicles. The oil samples were analyzed at a commercial oil analysis laboratory for wear metals, and physical tests were performed, including antifreeze, fuel dilution, water, and viscosity. An infrared analysis for soot, sulfur, nitration, and oxidation of the engine oil was also conducted. The reportable limits for each metal were supplied by the oil analysis lab.

The emissions tests were conducted at the Los Angeles Metropolitan Transit Authority Emissions Testing Facility (ETF) in Los Angeles, California. This facility has instrumentation to measure all regulated emissions: total hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter (PM). Peterson and Reece [10] report on comprehensive emissions testing, materials and methods, procedures, and results from the MTA ETF using methyl and ethyl esters of rapeseed oil.

Two test cycles were utilized for this program. The first was a modified arterial cycle (arterial). The standard form of this test was doubled, creating a 758 second, eight event cycle. The terial cycle, as used, had eight repetitions of acceleration to 64 km/h and decelerating to 0 km/h. The second cycle was the EPA Dynamometer Driving Schedule for Heavy-Duty Vehicles [11]. The EPA cycle took a total of 1060 seconds.

RESULTS AND DISCUSSION

FUELS - A complete summary of the fuel characterization data is listed in Table 1 for each fuel used in this study. Important observations on a few of the parameters are listed below.

Viscosity - The RAW fuel had a viscosity 15.7 times greater than D2 at 40°C, while RME was only 1.8 times greater than D2. The 20RME had a similar viscosity as D2.

Cloud and Pour Point - The pour point for D2 was -23°C and -15°C to -17°C for Biodiesel and blends. RME had a cloud point of 0°C and D2 was -12°C, the RAW and blends were within 1°C of D2.

Sulfur - D2 (not low sulfur diesel) had 18 times more sulfur than RME and 10.5 times more than RAW.

Heat of Combustion - The gross heat of combustion for D2 is 5.6 percent greater than RME fuel and 11 percent greater than RAW oil on a mass basis.

Flash Point - A flash point of 74°C was measured for D2 while the RME was measured at 179°C and RAW at 274°C. The higher flash points of Biodiesel indicate that it is safer to use, store, and handle based on fire safety concerns.

ON-ROAD VEHICLES - The addition of the fuel tanks and heating system added approximately 230 kilograms to the total mass of the vehicle, with the Biodiesel tank filled to capacity. There was no noticeable change in power, acceleration or fuel economy with the added mass.

Dodge - The Dodge pickup accumulated 89,150 total kilometers, with 85,950 km on the 20/80 blend. The fuel economy for the first 3,180 km using 100 percent D2 was 8.55 km/L. The average fuel economy with the blend was 8.3 km/L. The vehicle consumed 6,881 liters of diesel and 2,793 liters of RME, for a blend of 28.8 percent RME and 71.2 percent D2. This was 8.8 percent above the target value of the 20 percent blend of RME.

Rust was observed in the steel tanks at 48,280 km and continued to be a problem until the tanks were converted to stainless steel. The rust may have been due to the heating and cooling of the fuel in the tank during the winter, condensing the moisture in the atmospheric air, and/or a very small amount of catalyst in the RME fuel, which is basic and would speed up the oxidation reaction. After converting to stainless steel tanks there was unusual fuel filter plugging during the winter months. A wax-like substance in the fuel filter was analyzed and it was determined to be 50 percent diesel fuel and 50 percent Biodiesel. Fuel filter plugging ceased as the ambient temperature increased during the spring and summer.

Ford - The Ford pickup accumulated 89,160 total kilometers with 85,910 km on the 20/80 blend. The fuel economy for the first 2,680 km using 100 percent D2 was 7.37 km/L. The average fuel economy with the blend was 6.96 km/L. This truck consumed 9,433 liters of diesel and 2,670 liters of rapeseed oil, for a blend of 22.5 percent RAW and 77.5 percent D2. This was 2.4 percent above the target value of the 20 percent blend.

The mixture of rapeseed oil varied from 14 percent to a high of 41 percent (when the pickup would not start.) Fuel economy varied from 5 km/L to 8.3 km/L. During the first 77,700 km of testing, the percent of rapeseed oil was as high as 40. This was higher than the target of 20 percent and caused excessive carbon buildup on the injector tips. The injectors were removed and cleaned at 73,145 km, after which the performance of the pickup noticeably improved.

FUEL HEATING SYSTEM - The fuel heating system on both pickups worked very well through the course of testing. After the initial installation of the heating system, the pickups were parked outside over a period of three days and nights with temperatures below -9°C. The ambient and Biodiesel fuel temperatures were monitored with thermocouples and a data acquisition system for the three day period. As the ambient temperature dropped below -9°C, the Biodiesel fuel maintained a temperature of 12.7 to 15.5°C.

DYNAMOMETER TESTING - Dodge - Figure 2 is a graphical comparison of the power and smoke density with each of the three fuels tested over a period of five dynamometer tests. On the average, 100 percent RME produced 5 percent less power than D2 and 20RME produced one percent less than D2. Also, smoke density was reduced 26 percent with 100 percent RME, while 20RME was reduced by 10 percent over D2.

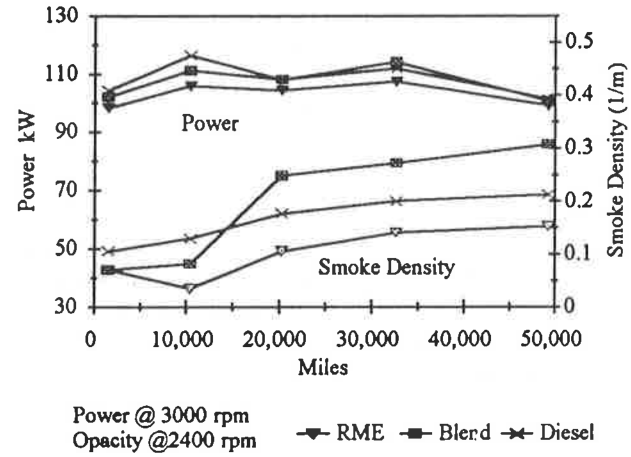

Figure 2: Dodge power and smoke density at five dynamometer tests

Ford - Figure 3 is a graphical comparison of the horsepower and smoke density for both fuels tested over a period of five dynamometer tests. The 20RAW produced one percent less power, and 11 percent less smoke compared to D2.

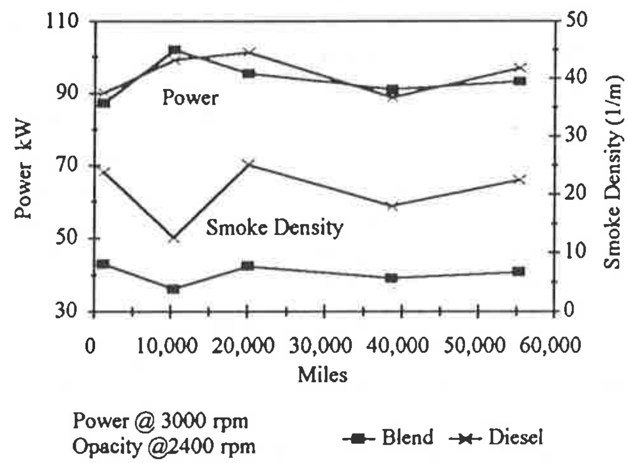

Figure 3: Ford power and smoke density at five dynamometer tests

Check Vehicles - The Ford check vehicle was dynamometer tested twice. At 62,235 km, a power rating of 92.5 kW at 3,000 RPM and 11.7 percent opacity for the snap idle test was recorded. The compression was comparable to the Biodiesel and the injector VOP was 1.38 MPa lower. The Dodge check pickups were equipped with automatic transmissions, which are not compatible with the dynamometer.

ENGINE OIL ANALYSIS - Chevron Delo Multigrade SAE 15W-40 heavy duty engine oil was used. Wear data for the Dodge pickup was at acceptable levels without any significant differences between the sampling reports. The Ford Biodiesel pickup indicated high iron after 45,000 km. The Ford check vehicle also indicated high iron throughout the

CONCLUSIONS

At the conclusion of 80,500 km with two pickups operating ¡ 20 percent Biodiesel (raw or RME), there is no indication of abnormal wear or performance. The on-board mixing system, designed and reported on in this paper, was essential only for this experiment. It should be clear, however, that for commercial use the blending would take place at the fuel plant, eliminating the on-board mixing system.

Emission tests show that a 20 percent blend of RME and 80 percent diesel produced a reduction in four of the five emissions, CO_2 being the exception. Specific conclusions from the results of this testing are presented below.

- Fuel characterization data show some similarities and differences between RME and D2. a) Specific weight is higher for RME, viscosity is 1.8 times that of D2 at 40°C, and the heat of combustion is 5.6% lower than D2. b) Sulfur content for RME is 67% less than D2.
- Visually, all injector coking was low with 20RME. The 20RAW injector tips had accumulated excessive deposits and were cleaned at 73,200 km with a noticeable improvement in performance. The Dodge injectors were cleaned at 79,340 km due to rust.
- The fuel heating systems performed acceptably during the test period. The fuel combining systems were updated twice, due to continual adjustments, to achieve the targeted 20 percent blend.
- On the average, RME produced 5 percent less power than D2 and 20RME produced one percent less power than D2. The 20RAW produced one percent less power than D2.
- On the average, smoke density was reduced 39 percent with RME, while 20RME increased 18 percent over D2. The D2 had a smoke density 3.1 times that of 20RAW.
- The average fuel economy for RME was 4 percent higher than that of D2, 1.8 percent higher for 20RME, and 2.6 percent higher for 20 RAW. The differences in fuel consumption and power reflect the differences in heat of combustion and density between the two fuels.
- Emissions tests with the arterial cycle showed decreases in HC (55 percent), CO (42 percent), NOx (9.1 percent), PM (6.8 percent), and an increase in CO_2 (0.7 percent) when 100 percent RME is compared to D2.
- The 20RME fuel decreased HC(20 percent), CO (25 percent), NOx (2.6 percent), PM (10.9 percent), and there was no difference in CO_2 compared to D2.
- Statistical analysis showed significant differences with HC, CO, and NOx from diesel ($p<=0.05$), and no significant difference was determined for CO_2 and PM.

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REFERENCES

1. Peterson, C.L., D. Reece, J. Thompson, S. Beck, and X. Zhang, "Development of Biodiesel for use in high-speed diesel engines", Proceedings of Commercialization of Biodiesel-Establishment of Engine Warranties, National Center for Advanced Transportation Technology at the University of Idaho, Moscow, ID, 1994.
2. Peterson, C.L., G.L. Wagner, K.N. Hawley, P.G. Mora, "Long-term endurance testing of vegetable oils as diesel fuel substitutes - Yanmar engines", *The Potential of Vegetable Oil as an Alternate Source of Liquid Fuel for Agriculture In the Pacific Northwest - III*, College of Agriculture and Engineering, University of Idaho, Moscow, ID, 1983.
3. Schumacher, L.G., W.G. Hires and S.C. Borgelt, "Fueling diesel engines with methyl-ester soybean oil", *Proceedings of the First Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry*, Vol 3: 1598-1606, NREL, Golden, CO, 1993.
4. Holmberg, W.C. and J.E. Peeples, "Biodiesel: A technology, performance, and regulatory overview", Prepared for the National SoyDiesel Development Board, Jefferson City, Missouri, 1994.
5. Pischinger, G.H., R.W. Siekmann, A.M. Falcon, and F.R. Fernandes, "Results of engine and vehicle tests with methyl esters of plant oils as alternative diesel fuels", Paper presented at V International Symposium on Alcohol Fuel Technology, Aukland, New Zealand, 1982.
6. Mittelbach, M. and P. Tritthart, "Diesel fuel derived from vegetable oils, III: emission tests using methyl esters of used frying oil", JAOCS, 65(7):1185-1187, 1988.
7. Shafer, Ansgar. 1994. Engine warranty policy - Mercedes Benz. Proceedings of Commercialization of Biodiesel-Establishment of Engine Warranties, National Center for Advanced Transportation Technology, University of Idaho, Moscow, ID, 1994.
8. Alfuso, S., M. Auriemma, G. Police, and M. Vittoria Prati, "The effect of methyl-ester of rapeseed oil on combustion and emissions of DI diesel engines," SAE Paper 932801, SAE, Warrendale, PA, 1993.
9. Korus, R.A., J. Jo, and C.L. Peterson, "A rapid engine test to measure injector fouling in diesel engines using vegetable oil fuels", JAOCS, 62(11):1563-1567, 1985.
10. Peterson, C.L. and D.L. Reece, "Emissions tests with an on-road vehicle fueled with methyl and ethyl esters of rapeseed oil", ASAE Paper No. 946532, Warrendale, PA, 1994.
11. Code of Federal Regulations 40, Parts 86 to 99, Appendix I, Cycle D. U.S. Government Printing Office, Washington D.C., 1993.