BIOENERGY '94 *Presented at the **Sixth National Bioenergy Conference**, Reno/Sparks, Nevada, October 2-6, 1994.*

LUBRICATING QUALITIES OF BIODIESEL AND BIODIESEL BLENDS

Leon G. Schumacher Steve A. Howell

Introduction

On October 1, 1994, the United States government mandated that low sulfur diesel fuel, .05% sulfur, be used for all on road vehicles. This has caused variety of problems in the industry. The problems have been widely attributed to the refining process, called hydrotreating, that is used to reduce the sulfur in diesel fuel to mandated levels. More severe hydrotreating is also used to further reduce the aromatic level of diesel fuel for markets such as California where a lower aromatic content of diesel fuel was been mandated (i.e. 10 vs 35 percent aromatics). In addition to increasing the amount of energy used to create the fuel and the reported increases in fuel consumption, concerns related to the lubricity of the "new fuel" and the reaction of the "new fuel" with existing fuel system elastomers have surfaced.

Purpose and Objectives

The overall purpose of the investigation was to examine the effect of biodiesel and biodiesel blends on the life of the injection pump and related fuel system components. Specifically, the investigation was designed to determine:

1. The lubricating properties of biodiesel and biodiesel blends.
2. The reaction of biodiesel with the diesel fuel injection pump and related fuel system components.

The lubricating properties of diesel fuel are important, especially for rotary and/or distributor type diesel fuel injection pumps. In these pumps, the moving parts are lubricated by the diesel fuel itself, not by the engine oil. The clearances between the moving components in rotary injection pumps are small and any fuel that exhibits low lubricating characteristics promotes the premature failure of the injection pump. As one might expect, the first question that diesel engine operators ask is whether or not the lubricating quality of their fuel is adequate. A similar question surfaced early in the development of biodiesel as a fuel for diesel engines. As such, the lubricity qualities of biodiesel and blends of biodiesel/diesel fuel became the focus of this investigation.

Review of Literature

Lubricity has sometimes been mistakenly compared to the viscosity, or thickness, of the fuel. The following statement from Grigg (1994) explains the issue of lubricity well: "The lubrication of the fuel is not directly provided by the viscosity of the fuel, but by other components in the fuel which prevent wear on contacting metal surfaces." The lubricity of diesel fuel is an indication of the amount of wear or scarring that occurs between two metal parts covered with the fuel as they come in contact with each other. A fuel that is low in lubricity would cause high wear and scarring of adjoining metal surfaces. Fuels that are high in lubricity reduce wear and extend the life of the injection pump components.

Tractor companies such as Case International do not recommend the use of number one diesel fuel in their engines for this reason. Case International operator manuals indicate that number one diesel fuel should not be used in the Case diesel engine (Author, 1985, p. 8): "Use a good grade of Number two diesel fuel in your diesel engine. Do not use other grades of fuel... Only when the temperature is very cold should a mixture of Number one and Number two diesel be used to fuel the engine."

According to Peterson (1992), wearball tests that were conducted with biodiesel indicated that the friction force of biodiesel was slightly higher than number two diesel fuel. Peterson indicated, however, that the difference was statistically insignificant.

According to Exxon, (Author, 1993), the characteristics of diesel fuel with good lubricity are small wear scar, consistent low friction, and consistent formation of protective film. Exxon used a HFRR Machine at 60 degrees Celsius to compare number two low sulfur reference diesel fuel with a 20/80 blend of biodiesel/reference diesel, a 30/70 blend of biodiesel/reference diesel, and reference diesel fuel treated with an Exxon lubricity additive (1000 ppm). The reference fuel (untreated) failed the test. Both the 20 and 30 percent blends of biodiesel produced significant, quantifiable improvements in lubricity that were comparable to one of Exxon's lubricity additives.

Methods and Procedures

Currently, there are no specifications or requirements for the lubricity of diesel fuel. With the recent concerns an ISO committee "Diesel Fuel Lubricity", under the chairmanship of Paul Henderson (Stanadyne Corporation), was formed to determine a standard analytical test method for the measurement of lubricity.

Three different lubricity measuring systems are currently used to determine the lubricity of diesel fuels: BOCLE, HFRR, and B.O.T.S.. Mr. Henderson has used a correlational design to compare these test procedures to determine which method most accurately predicts the lubricity of diesel fuel as it relates to actual part wear. The three testing methods are described below (see Figure 1.).

The BOCLE Machine

The "Ball On Cylinder Lubricity Evaluator" was invented by Dr. Paul Lacy of Southwest Research Institute. A static ball is loaded onto the edge of a rotating disc and the diameter of the subsequent scar on the ball is measured. Most lubricity tests conducted in the United States are run on the BOCLE machine.

The HFRR Machine

The "High Frequency Reciprocating Rig" machine was developed in Europe and is the most common method utilized in the European Community for measurement of diesel fuel lubricity. A transversely oscillating ball is loaded onto a flat surface and the diameter of the scar on the ball is measured.

The B.O.T.S. Machine

The "Ball On Three Seats" machine is a modified version of an earlier "Four Ball" machine. The ball is loaded onto the three seats, which are held static, and rotated by a chuck. The lubricity is measured by the weight loss, due to wear, of the three seats.

The BOCLE Machine was selected to analyze the lubricity effects of biodiesel when blended with low sulfur low aromatic and low sulfur high aromatic number two diesel fuel.

The scuffing BOCLE was used in this series of tests because it appears to be the leading analytical technique for the measurement of lubricity and is under consideration as the standard for the lubricity measurement of diesel fuel by the ASTM.

Technicians at Southwest Research Institute added a total of 0, .2, 2, 5, 10, and 20 percent biodiesel to each diesel fuel (low sulfur/low aromatics, low sulfur/high aromatics). Table 1 reports the sulfur and aromatic content of each diesel fuel that was blended with the biodiesel. The blended mixes, as well as the neat fuels, were subsequently tested using the BOCLE Machine. The results for the BOCLE test are reported in grams of weight added to the apparatus before failure of the fuel to lubricate. The higher the weight added, the better the lubricity of the fuel.

Table 1. Aromatic and sulfur content of diesel fuel tested for lubricity using a BOCLE Machine.

Fuel	Percent Aromatics	Percent Sulfur
CARB Reference Fuel (Low sulfur/ low aromatic)	5.6	.043
ASTM Lubricant Certification Fuel (Low sulfur/ high aromatic)	28.0	.042

Real world lubricity testing has also been initiated by the researchers. A 1992 Ford pickup equipped with a Stanadyne injection pump has been fueled with a 40/60 blend of biodiesel/diesel fuel for 110,000 miles. The diesel fuel injection pump was removed after 49,610 miles of operation and forwarded to the Stanadyne Corporation for testing and analysis.

The Mayflower Company of St. Louis has confirmed the use of six school buses for similar testing. Stanadyne tested and measured six diesel fuel injection pumps that were subsequently installed in the school buses during July, 1994. Three buses will be fueled using a 20/80 blend of biodiesel/diesel fuel. Three buses will operate as control vehicles (100 percent diesel fuel). The diesel fuel injection pumps will be removed after approximately 50,000 miles of operation and forwarded to Stanadyne Corporation for testing and analysis. A similar real world experiment is being set up with BOSCH rotary diesel fuel injection pumps.

Results

According to Dr. Paul Lacy of Southwest Research Institute, a diesel fuel with good lubricity provides BOCLE numbers in the 4,500 - 5,000 gram range. A diesel fuel low in lubricity will provide a BOCLE number below 3000 grams. The analytical variation of the BOCLE testing apparatus must also be considered when interpreting these results. According to Dr. Lacy, the BOCLE test provides results that are accurate to approximately plus or minus 200 grams. Therefore, two fuels with readings differing by 300 grams (say 4,000 and 4,300) may not be statistically different.

The results at a 20% bildiesel blend, and especially the neat (100%) biodiesel, are statistically significant and show an improvement in lubricity (Table 2). The BOCLE results at low biodiesel concentrations show no statistically significant improvement in lubricity. There currently is no lubricity standard for petrodiesel fuel but, as a reference point, the BOCLE number presently used as a temporary standard in the State of California is at or above 3,300 grams.

Table 2. BOCLE Machine* results for low sulfur/ low aromatic diesel fuel, low sulfur/ high aromatic diesel fuel, biodiesel, and blends of biodiesel and low sulfur/ low aromatic and low sulfur/ high aromatic diesel fuel.

Percent Biodiesel Added	Low Aromatic Fuel BOCLE Result (grams)	High Aromatic Fuel BOCLE Result (grams)
0 (neat petrodiesel)	3,500	4,200
0.2	3,300	3,900
2.0	3,500	4,400
5.0	3,600	4,500
10.0	3,800	5,200
20.0	4,100	5,200
100.0 (neat biodiesel)	6,100	6,100

*Analysis performed by Southwest Research Institute. These results are not an endorsement of biodiesel by Southwest.

The BOCLE results from both neat (100%) petrodiesel fuels and the neat (100%) biodiesel fuel show that biodiesel exhibited superior lubricity. Given that a fuel with high lubricity yields BOCLE results of 5,000 grams, neat biodiesel with BOCLE results of 6,100 may be superior to much of the petrodiesel supplied in the U.S. today.

Compared to the low sulfur/low aromatic, low sulfur/high aromatic diesel fuel, biodiesel had essentially no effect on lubricity in concentrations below 5% biodiesel. Although the numbers did fluctuate, they were all within the variation of the test method. At the 10% level, biodiesel made a substantial improvement in the lubricity of the low sulfur/high aromatic diesel fuel. Although lubricity improved with a 10% biodiesel blend in the low aromatic/low sulfur petrodiesel, it may not be significant as it is within the analytical variation of the test. At the 20% level, substantial improvement was seen with both the low sulfur/low aromatic diesel fuel and the low sulfur/high aromatic diesel fuel. Biodiesel seemed to have a greater impact on the low sulfur/high aromatic petrodiesel. The reason for this is unclear and may warrant further study.

The Stanadyne diesel fuel injection pump used to fuel the 7.3 Navistar engine experienced no problems in the field from the operators during the 49,000 miles of operation. The pump components, upon tear down, showed no heavy or abnormally high wear on any component. Most parts were found to have less than average wear with the exception of two components - the median valve arm and cam roller. According to Roman (1993), the wear on these components, although moderate, could not be attributed to the use of biodiesel.

Roman did observe an above average accumulation of varnish deposites on various internal components of the injection pump, however, the deposits did not impact the performance of the pump. A much higher than average accumulation of varnish and gum deposits were observed at the bottom exterior of the pump housing. This was caused by greater than normal weepage past the drive shaft seals. Since this type of weepage occasionally occurs with petroleum diesel fuel, it can not be attributed to the use of the biodiesel blend (Roman, 1993).

Conclusions:

The lubricity qualities of biodiesel when blended with low sulfur/low aromatic and low sulfur/ high aromatic diesel fuel were positive. Exxon (Author, 1993) and Peterson (1992) noted improvements in fuel lubricity as the concentration of biodiesel in diesel fuel increased. The findings of this investigation parallel these earlier findings. Specific conclusions drawn from the findings of this investigation include:

1. Biodiesel in concentrations less than 5% appear to have no measurable improvement concerning the lubricity of diesel fuel.

2. Biodiesel concentrations of 20% show significant lubricity improvement when blended with both low sulfur/high aromatic and low sulfur/low aromatic diesel fuel.

3. Biodiesel improved the lubricity of low sulfur/high aromatic diesel fuel more than it improved the lubricity of low sulfur/low aromatic diesel fuel.

4. BOCLE results confirmed earlier HFRR results that demonstrated a significant lubricity improvement of diesel fuel after it had been blended with biodiesel.

5. Results from field tests indicated that the use of biodiesel/ diesel fuel blends did not reduce the length of service normally provided by a diesel fuel injection pump.

Recommendations/Considerations for Further Study

The use of biodiesel should be considered to prevent premature failure of injection pump components that is associated with the used of a fuel that is low in lubricity. Findings of the investigation indicated that concentrations of 20 percent biodiesel provide protection from lubricity related failure equally as well as some of the diesel fuel lubricity additives that are currently available.

Further study to differentiate the lubricity improvement at blends between 5% and 20% biodiesel may be warranted. It was also recommended by Dr. Lacy that diesel fuel that exhibits exceptionally low lubricity (i.e. BOCLE results around 1,500) be tested using the BOCLE machine with biodiesel blends.

Additional study of the effects of biodiesel and biodiesel blends in rotary fuel pumps is warranted. The increased lubricity of biodiesel may lead to reduced wear and longer component life as well as providing a potential solution to low lubricity diesel fuel.

The impact of varnish formation and the identification of varnish reducing additives when using biodiesel blends is also worth further investigation.

Work in Progress

MARC-IV and Dr. Schumacher are in the process of testing a 20/80 blend of biodiesel/diesel fuel over an extended period of time and miles. As noted earlier in the manuscript, Stanadyne has cooperated by providing six injection pumps that have been pre-inspected and tested for use in Mayflower buses at St. Louis, Missouri. Control vehicles fueled with 100 percent diesel fuel will be monitored to provide a solid baseline with which to compare the biodiesel data. At the end of the test, the injection pumps will be evaluated by Stanadyne to determine wear, deposits, and other data. This test will conclude in approximately 15 to 18 months. This test will provide valuable field data on 20 percent biodiesel/diesel blends, which is the most common biodiesel/diesel blend currently used in the United States. A similar project has been planned using BOSCH diesel fuel injection pumps.

Bibliography

Author, (1985). 2096 Tractor Operators Manual. J.I. Case Company. Technical Publications Department. Racine, Wisconsin.

Author, (1993). Lubricity Update #1 and #3. Bucyrus, Kansas.

Grigg, H. C. (1994). Reformulated Diesel Fuels and Fuel Injection Equipment. New Fuels and Vehicles for Cleaner Air Conference. January 11-12, 1994. Phoenix, Arizona.

Peterson, C. L., Reece, D. L., Cruz, R., and Thompson, J. (1992). A Comparison of Ethyl and Methyl Esters of Vegetable Oil as Diesel Fuel Substitutes. Proceedings of an Alternative Energy Conference- Liquid Fuels from Renewable Resources. December 14-15, 1992. Nashville, Tennessee.

Roman, D. and Henderson, P. (1993). Laboratory Report Number 1516. Stanadyne Corporation. June 18, 1993, Windsor, Connecticut.

Figure 1.

Lubricity Test Machines