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POTENTIAL IMPACT OF BIODIESEL ON SDDOT

Study SD2002-12-X
Executive Summary

Prepared by
The Curators of the University of Missouri
The University of Missouri–Columbia
Office of Sponsored Program Administration
310 Jesse Hall
Columbia, Missouri 65211-1230

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This work was performed under the supervision of the SD2002-12 Technical Panel:

Darrell Cassidy .... Internal Services
Bill Connor .... AGSOY
John DeLoache .... Fleet and Travel
Ron Gorder .... SD Soy Council
Chuck Fergen............ Fiscal and Public Assistance
Betty Hansen.................................. SD Soy Council
John Johnson.................................. Mitchell Region
Dan Johnston.. Research
Jeff Karst .... Pierre Region
Dawna Leitzke ...... SD Petroleum Marketers Assn.
Paul Oien .... Research
Brian Moore .... Internal Services
Paul Tokach................ Butler Machinery Company

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16. Abstract

Research was conduced to determine the impact of a 5% blend (B5) of biodiesel with 95% petroleum diesel fuel on the South Dakota Department of Transportation (SDDOT). Biodiesel is made from vegetable oil or animal fat that has been transesterified. This process removes the glycerol from the oil. The transesterified oil can be used as a substitute for, or as an additive to, petroleum diesel fuel. Biodiesel is similar to #2 diesel fuel, but has a higher flash point, and is nontoxic and biodegradable. Biodiesel has a higher cloud point and cold filter plugging point than petroleum diesel fuels. Blending procedures and the impact of cold weather operation were evaluated to determine if a low level blend of biodiesel could be used reliably during South Dakota winters.

Although previous biodiesel research indicated that neat biodiesel caused problems with rubber elastomers, no elastomer problems were noted during the test. The impact of a low level blend on engine performance was evaluated and the SDDOT fleet noted small reductions in fuel economy. The operators did not report reductions in power or torque when fueled with B5. Engine oil analysis suggested that engine component wear was essentially the same (or slightly lower) in vehicles fueled with B5 as compared to diesel fueled engines. Economic analyses of biodiesel fueling indicated a slight increase in fuel costs.

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EXECUTIVE SUMMARY

In its 2002 session, the South Dakota legislature considered legislation mandating use of 2% (B2) biodiesel blend in all South Dakota Department of Transportation vehicles exempt from fuel taxes. This legislation failed, but was expected to resurface during later legislative sessions. Before SDDOT moved to adopt biodiesel blends, it set out to determine the impact that a biodiesel blend might have on its vehicle fleet.

Biodiesel is made from a number of sources including vegetable oil, tallow, lard, and waste cooking oils (yellow grease). Each can be transesterified using an alcohol that has been mixed with a catalyst such as potassium hydroxide or sodium hydroxide. The most commonly used alcohol is methanol. Methanol reacts easily and is less expensive to use than other alcohols such as ethanol.

Converting plant and animal oils into biodiesel results in a fuel that is very much like petroleum diesel fuel. This fuel is renewable, biodegrades quickly in comparison to petroleum diesel fuel, and forms a solution when mixed with petroleum diesel fuel. Biodiesel is naturally oxygenated and burns efficiently and cleanly in a modern diesel engine.

The SDDOT furnished the fuels and fuel storage facilities at four locations in the state. A total of twenty vehicles were initially selected by SDDOT for this research. More specifically, four trucks were selected at Aberdeen, Sioux Falls, and Pierre while eight trucks were identified at Rapid City. At each city half of the trucks were fueled with a B5 blend and half were fueled with petroleum diesel fuel. Also, although not part of the state DOT fleet, four trucks at the Brown County Highway Department were included in the study, with two fueled on the B5 blend and two fueled with petroleum diesel fuel. At each test site, SDDOT collected engine oil analysis data as well as vehicle maintenance data and these data were forwarded to the researchers. The vehicles were operated by SDDOT and Brown County employees for the duration of the project.

Fuel analyses were conducted to determine cetane, flash point, cloud point and cold filter plugging point as compared to petroleum diesel fuels. Blending procedures and the impact of cold weather operation were evaluated to determine if a low level blend of biodiesel could be used reliably during South Dakota winters. Although previous biodiesel research indicated that neat biodiesel caused problems with rubber elastomers, no elastomer problems were noted during the B5 test.

The impact of a low level blend on engine performance was evaluated and the SDDOT B5 fleet noted small differences in fuel economy. The operators did not report reductions in power or torque when fueled with B5. Engine oil analyses suggested that engine component wear was essentially the same in vehicles fueled with B5 as compared to diesel engines that had been fueled on 100% petroleum diesel fuel.

Economic analyses of biodiesel fuel use indicated that the substitution of the higher priced B100 (when blending) had a very small impact on price, generally from 1 to 5 cents per gallon, depending upon the B100 price used and the blend percentage. Based on the fleet trial results, vehicle maintenance costs for B5 biodiesel blended fuel were similar to costs for vehicles fueled with

petroleum diesel fuel. Diesel engines, for the most part, had higher maintenance costs for preventative maintenance, engine replacement, and fuel system repairs. Biodiesel (B5) engines, for the most part, had higher repair costs for lubrication and inspection, engine repairs, exhaust, and other repairs.

Findings and Conclusions

Survey Other State Transportation Departments

A total of 31 DOTs had used, or considered using, a biodiesel blend. Nineteen DOTs had used the fuel in pilot projects or conducted tests that compared the performance of a biodiesel blend with petroleum diesel fuel. A total of 15 states have tested B20, two states have tested B2, and one state has tested B5 and B10. A total of eight DOTs experienced fuel filter plugging problems during warm weather operation. However, none of the agencies reported continuing problems with fuel filters. The renewable component of the blend was in most cases derived from soybean oil. Of the 48 states that responded, only Minnesota had a mandate that will require general use of a biodiesel blend by agencies and the public. Missouri, Kansas, and Washington reported limited state agency (DOT) mandates to use a blended fuel. The aggregated responses from the survey suggest that the biodiesel blend was a seamless replacement for petroleum diesel fuel.

Review SDDOT's Vehicle Inventory

Over 1200 diesel engines are used in the SDDOT fleet. These engines are made by 35 different engine manufacturers (Cummins, Detroit Diesel, etc.). Further, SDDOT has vehicles that are manufactured by 78 different companies (John Deere, Ford, etc.).

Two findings surfaced in this review. The first issue is that Case New-Holland (CNH) is the manufacturer responsible for the largest share of the SDDOT diesel fleet. Because of the recent merger of Case and New Holland, CNH is responsible for approximately 50% of the engines in the SDDOT fleet. Caterpillar, Cummins, Ford, Detroit, and Deere each have less than 10% of the total fleet respectively. Second, and perhaps most important, is that over fifty percent of the SDDOT fleet is less than five years old. This is important because by 1996 most of the engine manufacturers changed the composition of their fuel system gaskets to prevent leaks that surfaced with the introduction of low sulfur diesel fuel (500 ppm). The composition of these gaskets is such that the newer engine fuel systems should not see any adverse affects from fueling with a biodiesel blend.

CNH identified four issues that they felt must be addressed when fueling with a biodiesel blend[1]. As noted below, these issues pertained to biodiesel solvency, blending, material compatibility, and fuel quality.

- Fuel Quality—In the US, the biodiesel fuel is unregulated and biodiesel fuel quality is sometimes lower than the specifications in the ASTM Standard. Fuel quality issues can have a significant impact on engine reliability and performance. In Europe, where more stringent

[1] G. Stanek (personal communication to Brian Adams, June 20, 2003)

standards for biodiesel fuel are in place, engines are warranted using higher blends of rape methyl ester (RME) biodiesel fuel.

- Solvency—Biodiesel fuel acts as a solvent. When used in older vehicles, the biodiesel fuel can dissolve deposits left from previous fuels. When these particles enter the fuel system, filter plugging is the most common problem.
- Blend—The higher the blend of biodiesel, the more problems should be expected. A B5 fuel would not be expected to cause any problems. When the blend is increased beyond B20, the effects associated with solvency and material compatibility can increase.
- Material Compatibility—In newer engines (post 1996) material compatibility should not be a concern for B5 blends. In older engines, particularly with worn and cracked fuel lines, problems are more likely to occur. Materials of concern are fuel lines, diaphragms in fuel transfer pumps, and seals and o-rings in fuel pumps.

Several engine manufacturers (Deere, Cummins, Detroit, and International as well as the Engine Manufacturers Association) have issued position statements concerning fueling with a biodiesel blend. These statements can be found in the Appendix B.

TEST ENGINE COMPONENTS

Although previous biodiesel research indicated that neat biodiesel caused problems with rubber elastomers, no elastomer problems were noted during the B5 test. The National Renewable Energy Laboratory (NREL) recently completed a set of tests of five common fuel system polymers using a B20 biodiesel blend, a comparison petroleum diesel fuel and a 15% ethanol-diesel fuel blend. Samples exposed to the reference diesel fuel and the B20 biodiesel blend generally behaved the same. The polymers were affected to a much greater degree by the 15% ethanol blend than by the biodiesel blend. NREL is in the process of completing a more extensive biodiesel elastomer project, which will include highly oxidized fuel samples, as well as engine fuel pump endurance tests with biodiesel blends. Information from this study is currently expected to be released to the general public and the SDDOT in the spring of 2005. Since many of the diesel fueled vehicles in service at SDDOT are late model vehicles and engines, this data should provide insight concerning material compatibility for these engines.

EVALUATE OPERATIONAL PERFORMANCE

Blending procedures used to mix biodiesel and petroleum diesel fuel were a concern identified by the SDDOT technical panel. An incident occurred during the research project that prevented one truck operator from refilling his fuel tank at the Brown County site in Aberdeen. The researchers believe that this may have been a result of improper blending of the biodiesel and diesel fuel. The biodiesel blend stock was kept at room temperature (~70°F) to facilitate blending. However, the ambient temperature was approximately 0°F at the time that biodiesel was blended with a new shipment of diesel fuel. It was not possible to confirm the sequence and duration of events used in blending that day and thus identify the exact cause of the problem. However, biodiesel fuel has a higher density than petroleum diesel fuel, and warm biodiesel added to very cold diesel fuel could settle to the bottom of the tank. Without adequate agitation during the blending process this fuel would cool and solidify at the bottom of the tank. In this case the operator was unable to pump fuel from the B5 tank the day following the blending. No other incidents of cold flow problems were reported during the research project, and no truck was taken out of service due to cold weather operation as a result of fueling with a biodiesel blend. The B5 fuel that had caused filter blockage was recirculated in its tank and was eventually able to be pumped in a normal way. This incident, occurring with one of the above-ground storage tanks involved in the study, emphasizes the need for a thorough understanding of the impact of blending fuels under adverse conditions, and for the strict adherence to appropriate procedures established for blending as published by the National Renewable Energy Laboratory (NREL).

It is important to note that, while two of the Brown County trucks could not draw fuel from the fuel supply tank (on that cold day), the trucks had been filled the night before and completed their work for that day while using the B5 blend (the fuel that was left in their tank from the day before). Further, the testing spanned two winters and no truck was taken out of service due to cold weather operation (13 trucks were fueled with a B5 blend) as a result of fueling with a biodiesel blend (B5).

The impact of a low level biodiesel blend on engine performance was evaluated and the SDDOT fleet noted very small reductions in fuel economy (B5=4.7 mpg and Diesel Fuel= 4.9 mpg). This was expected, as the energy value [British Thermal Unit (BTU)] of a B5 blend is slightly lower than 100% petroleum diesel fuel. The operators did not report reductions in power or torque when fueled with B5. Engine oil analysis suggested that engine component wear was essentially the same in vehicles fueled with B5 as compared to diesel fueled engines.

CONDUCT PHYSICAL AND CHEMICAL TESTS

The diesel fuel met or exceeded the specifications established by ASTM D975. The biodiesel (B100) met or exceeded all specifications established by ASTM D6751 except flashpoint. The flashpoint for the B100 sample was slightly lower than the standard in D6751 (114°C and 118° C vs. 130°C). The researchers then examined ASTM D6751 in more detail. The flashpoint for biodiesel is intended to be 100°C minimum. However, the specification for flashpoint in D6751 is set 30°C higher than this specification. This document explains that flashpoint was set higher when the ASTM committee developed D6751 because the committee members realized that meeting this criterion was a cost effective way to determine if excess amounts of unreacted alcohol remained in the finished biodiesel. The researchers also noted that since the biodiesel would be mixed with diesel fuel (flashpoint minimum for ASTM D975 ranges from 38°C to 52°C), that the flashpoint of the B5 blend would still be significantly higher than the flashpoint specification established for either number one or number two diesel fuel in ASTM D975.

Stability of diesel fuel is important as oxidative breakdown or biological conversion of the fuel can leave residues that can plug filters and adhere to injector pump parts reducing pump life. Stability is of particular concern in biodiesel as its compounds are considered to be more susceptible to oxidation than petroleum products. Fuel can be tested for changes in filterable residues over time as a measure of the stability of the fuel.

Two types of stability tests were conducted on samples of the B5 blended fuel. A test of total insolubles filtration (ASTM D2276) was conducted on B5 that had been aged in the fuel tanks of two infrequently used trucks. An identical test was conducted on a sample of B5 that had been stored undisturbed in a barrel for the duration of the research project A sample of B5 was also subjected to an accelerated oxidative stability test (ASTM D2274) at the outset of the project. The accelerated test provided a total insolubles level of 3.2 mg/1000ml. Storage of the fuel in the truck fuel tanks for periods of approximately 6 months and one year respectively caused total insolubles in both samples to rise from a level of 2 to a level of 3 mg/1000 ml. The sample of fuel stored in a barrel for the duration of the project produced a total insolubles filtration result of 4 mg/1000ml. The results are in agreement with the accelerated test and are well below the 10 ppm level threshold that some major municipalities (New York) have set as a maximum allowable level for delivered diesel fuel. The researchers contacted the fuel suppliers to determine if any anti-oxidants or other fuel additives had been added to either the biodiesel or the diesel fuel. The biodiesel suppliers reported that only pour point depressants had been added to the biodiesel. The importance of these findings is significant. First, this means that the fuel which was delivered for use with the project was a fuel that met the standards as established by ASTM D975 and ASTM D6751. Second, and more importantly, this finding suggests that, if the fuel tank of a vehicle were topped off with B5 and subsequently not used for several months, the B5 fuel should not age prematurely.

Evaluate Vehicle Maintenance Histories

Engines fueled with diesel fuel had higher maintenance and repair costs than did the B5 fueled engines. Several comparisons were made with the data from the engine oil analysis samples to see if differences in engine wear might be apparent. All engine oil analyses data were found to be within normal levels for both the B5 and the diesel fueled engines. In short, these comparisons showed no differences between the levels of wear metals found in the used engine oil analysis samples regardless of the fuel used.

The trucks were in a good state of repair at the beginning of the test, and only a limited number of parts were replaced on the diesel fueled engines and the B5 fueled engines. The researchers felt that the parts that were replaced were items that would have been replaced regardless of the fuel used to fuel the engine. For example, the copper tubes surrounding the injectors in the heads cracked on an engine that was fueled with diesel fuel. One B5 fueled engine underwent a major overhaul. In this case a valve keeper came loose and allowed the valve to contact the piston with the result that the valve was imbedded into the top of the piston, destroying the piston and damaging nearby pistons. One of the diesel fueled engines experienced a main bearing failure. The engine for this truck was replaced with a factory rebuild and put back into service. In each case the repairs that resulted were not attributed to the fuel (diesel versus B5) used to fuel the engine.

Assess Costs, Benefits, and Economic Impact

Diesel fueled engines had a higher mortality rate, resulting in higher engine repairs for these engines and ultimately the total replacement of one diesel fueled engine. The failure mode of the engine, as reported by the technicians, was not a result of fuel used, but normal engine mortality. As such, these expenses were removed from the calculations, reducing the difference in maintenance costs per mile for the diesel fueled and B5 fueled engines to five cents. Maintenance costs for B5 biodiesel blended fuel were similar to petroleum diesel fuel. Diesel engines, for the most part, had higher maintenance costs for preventative maintenance, engine replacement, and fuel system repairs. B5 engines, for the most part, had higher repair costs for lubrication and inspection, engine repairs, exhaust, and other repairs.

Economic analyses of biodiesel fueling indicated that the substitution of the higher priced B100 (when blending) had a very small impact on price, generally from 1 to 5 cents per gallon ($0.02/gallon). This price varied depending on the B100 price used and the blend used to fuel the engine. Also, the cost differential for implementation of a B5 blend may be less as the cost of petroleum diesel fuel approaches $2.00 per gallon. This is due to the fact that as petroleum costs increase the cost of petroleum moves closer to the market cost of biodiesel. Currently, 100% biodiesel sells for approximately $2.30 per gallon.

Prepare Guidelines and Specifications

A survey of fuel storage tanks at SDDOT was conducted to determine how SDDOT stores fuel across the state. The survey indicated that over 98 percent of SDDOT’s fuel is stored underground. This type of fuel storage reduces the likelihood that fuel would gel even in extremely cold weather and provides a relatively constant temperature for the fuel, improving fuel stability. Finally, if the biodiesel could not be blended prior to delivery, the higher temperature below ground during cold weather would facilitate homogenous blending of the biodiesel with the petroleum diesel fuel. This is due to the fact that underground fuel tanks are typically set below the frost line, resulting in a more uniform daily fuel temperature in the storage tank.

Much of the knowledge developed as a result of this task is found in the Implementation Recommendations section of this report. These recommendations were developed based on the findings of the investigation, the aforementioned fuel storage investigation, as well as the researchers’ review of literature.

Implementation Recommendations

The researchers outlined the following implementation plan for SDDOT. The importance of purchasing biodiesel that meets or exceeds the specifications set forth by the ASTM D6751 cannot be overemphasized. In addition, regular fuel tank maintenance and fuel filter maintenance procedures recommended by the original equipment manufacturer must be adhered to by the truck drivers and truck maintenance personnel.

The biodiesel that is purchased for blending must meet or exceed the standards set forth in ASTM D6751. This is a requirement that all engine manufacturers expect of fuel for the engine.

The biodiesel must be readily available. A contract will need to be drawn up with the local fuel distributors with an option to provide petroleum diesel fuel in the event that the fuel distributor is unable to deliver a biodiesel blend as required.

In the event that fuel is not available, the SDDOT should have the option of using standard diesel fuel. Since low level blends, (such as B5), are interchangeable with standard diesel fuel, changing fuels can be done as necessary to accommodate market issues or availability.

- **Cleaning of fuel storage tanks prior to a change to a blended fuel is not required.** *It is not common practice among fuel distributors to clean tanks unless the tank is to be used for gasoline rather than diesel fuel. The cost to clean each tank and dispose of the fuel from the bottom of the tank as hazardous waste is substantial. Further, since few of the tanks have manhole access, it is virtually impossible to remove all of the debris that has settled to the bottom of the tank. If SDDOT feels a need to clean these tanks it should be a result of a regular tank cleaning system/program and not because it has decided to change to a biodiesel blend.*
- **Storage tank fuel filters should have a water trap incorporated into the filter.** *This type of filter is readily available, and should already be in place at each fueling station.*
- **The distributor should deliver pre-blended fuel.** (Cenex has already adopted this policy for their customers.)
- **Inform <u>all</u> vendors who bid on the biodiesel blend contract regarding expected procedures for blending biodiesel with the petroleum diesel fuel.** (Note the Biodiesel Handling and Guidelines available from the National Renewable Energy Laboratory, NREL/TP-540-36182; November 2004)
- **Follow SDDOT's existing plan for number one vs. number two usage patterns.** (October through April is when number one fuel is used.)