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FUELING DIRECT INJECTED DIESEL ENGINES WITH 2% BIODIESEL BLEND

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SUMMARY:
The Agricultural Engineering Department at the University of Missouri-Columbia has monitored the fueling of a 1996 Dodge pickup truck equipped with a 5.9 L (360 in^3) Cummins engine with a two percent blend of methyl-ester soybean oil (soydiesel/biodiesel) and petroleum diesel fuel (B2) for more than 40,608 miles. The pickup averaged 18.61 mile/gal. Analysis of engine lubrication oil suggested that the engine was wearing at a normal rate. Exhaust emissions were measured at Iowa State University. The black exhaust smoke normally observed when a diesel engine accelerates was reduced each time the engine was fueled with B2, but CO, HC, and NO_x were not affected.

KEYWORDS: Biofuels, Biodiesel, Methyl-ester, Horsepower, Exhaust Emissions, Transesterification.

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ABSTRACT

The Agricultural Engineering Department at the University of Missouri-Columbia has monitored the fueling of a 1996 Dodge pickup truck equipped with a 5.9 L (360 in^3) Cummins engine with a two percent blend of methyl-ester soybean oil (soydiesel/biodiesel) and petroleum diesel fuel (B2) for more than 40,608 miles. The pickup averaged 18.61 mile/gal. Analysis of engine lubrication oil suggested that the engine was wearing at a normal rate. Exhaust emissions were measured at Iowa State University. The black exhaust smoke normally observed when a diesel engine accelerates was reduced each time the engine was fueled with B2, but CO, HC, and NO_x were not affected.

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INTRODUCTION

Previous research conducted with diesel engines during the early 1990's in Idaho and Missouri has indicated that diesel engines could be fueled with neat biodiesel fuel and with blends of biodiesel and petroleum diesel fuel (Schumacher, et al., 1991; Peterson et al., 1995). However, little research has been conducted using low-level blends of biodiesel and petroleum diesel fuel. This work was a preliminary investigation with the objective of determining the effect of a two percent blend (B2) on fuel economy, engine exhaust emissions, and engine oil analysis. A secondary objective was to determine if these quantities would differ after a full year of operation.

This study was intended to identify any serious drawbacks or problems associated with the use of low-level blends of biodiesel and petroleum diesel fuel. It will be followed by a more-detailed evaluation of the specific fuel system components that are likely to be affected by biodiesel.

MATERIALS AND METHODS

A 1996 Dodge pickup equipped with a direct-injected turbocharged 5.9 L (360 in^3) diesel engine was the vehicle used in these tests. Specifically, the engine was a 6BTAA, 134 kW (180 hp), Cummins diesel engine. The pickup engine was initially fueled with diesel fuel by the Michigan Soybean Promotion Committee (MSPC). Fueling with a two percent blend of methyl-ester of soybean oil (soydiesel/biodiesel) in petroleum diesel fuel (B2) began after 67,210 km (40,326 miles) of operation. The fuel analysis for the biodiesel and the reference diesel fuel used for emissions testing at Iowa State University can be found in Table 1. Three companies assisted with the fuel

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analysis. System Lab Services of Kansas City, KS analyzed the Philips 66 low sulphur certification fuel. NOPEC Corporation of Lakeland, FL, analyzed the 100% neat biodiesel, and Cleveland Technical Center of Kansas City, KS, analyzed the B2. The data provided for B2 is based on a composite sample of fuel collected from the vehicle at various times throughout the test period. The samples were combined into a single sample and the analysis is given in Table 1.

Table 1. Fuel analysis of Biodiesel, #2 Diesel fuel, and B2 used to test the 1996 Cummins Engine Company 6BTAA, 134 kW (180 hp), automotive rated engine for exhaust emissions.

		Fuel		
Fuel Property	ASTM Test Procedure	Biodiesel	Low Sulfur Reference Diesel	B2 Blend
BTU/Gallon	D2382	N/T	N/T	138,300
Color	D1500	N/T	L 1.5	N/T
Corrosion	D130	1A	1A	1A
Cloud Point	D2500	0° C	-15° C	-17 °C
Pour Point	D97	-3° C	-23° C	-36 °C
Flash Point	D92	141° C	75° C	63 °C
Viscosity	D445	4.8 cS@40°C	2.791 cS@40°C	N/T
Sulphur	D129	0.01%	0.0257%	N/T
Carbon Residue	D524	N/T	.13	N/T
Carbon Residue	D4530	.03%	N/T	N/T
Cetane Index	D976	N/T	47.7	47.8
Ash	D482	0.001%	N/T	N/T
Free Glycerine G.C.		0.033%	N/Ap.	N/Ap.
Total Glycerine	G.C.	0.295%	N/Ap.	N/Ap.
Acid Number	D664	0.25 mg KOH/gm	N/T	N/T
Water and Sediment	1796/4807	0.0%	N/T	N/T
Distillation				
IBP		N/T	176 °C	175 °C
10		N/T	225 ° C	214 °C
20		N/T	236°C	N/T
50		N/T	261°C	264 °C
90		N/T	313 °C	315 °C
End		N/T	338 °C	335°C

N/T = Not tested
N/Ap. = Not applicable
G.C. = Gas Chromatograph

The engine was not modified for use with B2. Polyurethane ester grade tubing and a shut-off valve were installed in the return fuel line. This allowed MSPC personnel to sample fuel that was in the vehicle fuel system without siphoning or pumping fuel directly from the on-board fuel tank.

Mixing only two (2) percent biodiesel with the petroleum diesel fuel had no effect on cold weather operation. Under normal conditions, neat biodiesel will gel at 0° C (32° F). No gelling problems were noted by the MSPC personnel. This was expected as an analysis of the B2 revealed a pour point of -36° C (-34° F).

The pickup engine lubricating oil (Quaker State 15W-40) was changed at approximately 3,000 mile intervals. Engine lubricating oil was sampled at 1,000 mile intervals and analyzed by Cleveland Technical Center. A computer-generated report provided a breakdown of wear metals, contaminants, water and sediment, glycols, oil additives, perchloric base number, soot, oxidative stability, and nitrogen. A review of these analyses showed no indication of abnormal wear. The levels of chromium, copper, silicon, and iron were either below or the same as expected when fueled on diesel fuel.

Emission determinations were made at Iowa State University using a Clayton roll-type chassis dynamometer equipped with 8" rolls. The engine was tested using four (4) test cycles: the Arterial Bus Cycle, the Central Business District Test Cycle (CBD), the Urban Driving Dynamometer Schedule (UDDS), and a 40 mph steady state condition.

Each test cycle is designed to replicate conditions encountered under specific operating conditions. The **UDDS** is designed to test light duty cars and trucks. This test is by far the most difficult to conduct, as the vehicle is accelerated over a predetermined time and power sequence with speeds approaching 60 miles per hour. The **CBD** test cycle was designed to test city buses. The **CBD** accelerates the vehicle quickly to 20 mph and then decelerates to 0. This procedure is repeated every 30 seconds. This cycle repeats twenty times (10 minutes) at which time the emissions profile is calculated. The **Arterial** cycle rapidly accelerates the vehicle to 40 mph. This speed is maintained for 25 seconds, then the vehicle is de-accelerated to 0 mph, for a 10 second idle period. This procedure is repeated four times for a test duration of 370 seconds. The steady state test involved maintaining the speed of 40 mph until engine power, speed, and operating temperatures stabilized. Exhaust emissions readings were recorded during this "stable period."

The vehicle test cell at Iowa State University was capable of conducting the Environmental Protection Agency (EPA) UDDS transient test cycle, but emission measurements approximated the EPA procedure due to the fact that a constant volume sampling system was not available. The pollutant flow rates were calculated using instantaneous exhaust concentration measurements and instantaneous engine air flow rate measurements. These pollutant flow rates were integrated over the cycle and then divided by the total distance traveled during the cycle to obtain grams/mile emissions data.

RESULTS AND DISCUSSION

Fuel efficiency fluctuated, depending on how the pickup was operated. The overall fuel economy was 8.2 km/l (18.6 mile/gal). Comparisons between fueling logs made prior to B2 fueling and after B2 fueling revealed that B2 fuel efficiency was similar to that obtained when the engine was fueled with diesel fuel.

Table 2 presents an abbreviated version of the engine oil analysis data. These data were compared with engine lubricating oil samples taken from diesel-powered farm tractor engines in 1991 and 1991 and 1992 Dodge pickups fueled on 100% biodiesel (Schumacher et al., 1991) and with normal ranges reported by the Minnesota Valley Testing Laboratory. The tractor engine oil samples that had greater than 90 hours of use were excluded from this analysis. These samples were excluded since none of the pickup oil samples had been used in excess of 90 h. It was interesting to note that although not statistically different, slightly lower levels of chromium and iron were noted as compared to when other diesel engines were fueled on either 100% biodiesel or 100% diesel fuel. In all cases, the ppm levels of wear metals were slightly lower than when the tractors were fueled with petroleum diesel fuel.

Table 2. T-test analysis between engines grouped by tractor and pickup.

Wear metal		N	Mean (ppm)	StDev (ppm)
Iron	(D)	46	38.39	28.88
	(B)	40	8.40	10.55
	(B2)	36	7.55	3.88
	(M)		10-40	
Lead	(D)	46	9.09	8.12
	(B)	40	1.37	2.78
	(B2)	36	1.11	0.89
	(M)		1-12	
Copper	(D)	46	10.22	34.42
	(B)	40	2.00	2.14
	(B2)	36	6.41	5.46
	(M)		3-15	
Chromium	(D)	46	3.28	4.20
	(B)	40	2.80	5.86
	(B2)	36	.48	.49
	(M)		0.5-8	
Silicon	(D)	46	4.91	2.81
	(B)	40	1.75	1.70
	(B2)	36	4.44	3.93
	(M)		0-12	

D = Oil samples from farm tractors, operated on 100% diesel fuel.
B = Oil samples from Dodge pickups, operated on 100% biodiesel.
B2 = Oil samples from Michigan pickup, operated on 2% biodiesel.
M = Rule of thumb averages developed by Minnesota Valley Testing Laboratories.

The 1996 Dodge pickup had 40,326 miles when the first (pre) emissions and performance tests were conducted. The second (post) emissions and performance test was conducted after the engine had logged 39,656 miles on B2. This information is found in Table 3.

An Arterial Bus Cycle, the Central Business District Test Cycle, and the Urban Driving Dynamometer Schedule transient chassis dynamometer tests and the steady state dynamometer tests were conducted by the Department of Mechanical Engineering at Iowa State University.
Each of the numbers listed is a composite average of a cold-start test and a hot-start test, except for the steady state test which was conducted after the engine was fully warmed up. The hot-start measurement used for the transient tests was the average of 3 or 4 separate tests. The diesel fuel used was EPA emissions certification fuel and the B2 fuel was a 2% blend of biodiesel in the certification fuel.

The carbon monoxide (CO) measurement indicates very little change as the fuel was switched from diesel fuel to B2. There were significant differences between the CO levels measured between the two test dates. The CO levels measured at the second test date are 15 - 40% lower than the first date. While these changes could be due to changes in the engine emissions, it should also be noted that a different CO measurement instrument was used for the two tests. Part of the difference may be due to differences in the instrument response.

The NOx emissions did not appear to be significantly affected by switching from diesel fuel to B2. The NOx increased slightly for some tests when B2 was used and decreased for others. Again, there are some differences between the data collected on the two test dates, although the differences are smaller than observed with CO. The NOx data were corrected for humidity, but the differences in ambient conditions on the two test days may have contributed to the variation in the data.

The HC data taken during the first test appear to show a small but consistent reduction in HC when the engine was operated on B2. All four test cycles show this behavior. However, during the second test period, three of the four test cycles showed a small increase in HC when operated on B2. We have concluded that the changes in HC are due to measurement variation.

The data shown for soot emissions was collected by measuring the exhaust smoke level using an opacity meter and then converting the % opacity levels to instantaneous exhaust soot levels. These instantaneous soot levels were converted to soot flow rates using the measured intake air flow rate and then integrated to give the total emitted for the cycle. The soot emissions measurement is strongly influenced by the rate of acceleration of the vehicle and therefore is more prone to test variation than the other emission quantities. There was a consistent reduction of the measured soot emissions when the engine was operated on B2. The low level of biodiesel used makes it difficult to understand why the soot would decrease by the amounts shown. However, the consistency and size of the reduction indicate that further work in this area would be justified.

Table 3. Hot start engine exhaust emissions produced by a 1996, 5.9 L turbocharged, intercooled, direct injected Cummins diesel engine using four chassis dynamometer testing procedures. Note: All units are expressed as grams/mile.

Arterial Bus Cycle-Hot Start Data

Fuel	CO		NOx		HC		Soot	
Date	05/20	02/25	05/20	02/25	05/20	02/25	05/20	02/25
D	1.437	1.051	4.773	5.862	8.804	5.49	0.409	0.3
B2	1.505	0.912	4.679	5.834	6.938	5.722	0.315	0.232

Central Business District Cycle- Hot Start Data

Fuel	CO		NOx		HC		Soot	
Date	05/20	02/25	05/20	02/25	05/20	02/25	05/20	02/25
D	2.243	1.525	7.052	8.99	10.99	7.398	1.259	0.728
B2	2.206	1.543	8.221	9.175	9.585	7.57	0.931	0.504

Urban Dynamometer Driving Schedule-Hot Start Data

Fuel	CO		NOx		HC		Soot	
Date	05/20	02/25	05/20	02/25	05/20	02/25	05/20	02/25
D	2.298	1.137	5.188	7.055	10.845	6.422	2.463	0.388
B2	1.997	1.028	6.134	6.888	9.474	6.217	2.099	***

Steady State-Hot Start Data

Fuel	CO		NOx		HC		Soot	
Date	05/20	02/25	05/20	02/25	05/20	02/25	05/20	02/25
D	0.984	0.798	3.006	3.446	4.078	3.702	0.482	0.720
B2	0.965	0.743	3.039	3.594	4.028	3.872	0.414	0.384

D = Emissions tests conducted using 100% low sulphur diesel fuel.
B2 = Emissions tests when the pickup was operated on 2% biodiesel.
*** = Data not available due to equipment failure

CONCLUSIONS

Although the findings from the vehicle are far from conclusive, the results from this study were positive concerning the use of B2 as a fuel for diesel engines. As such, the following conclusions were drawn from the investigation:

1. The amount of wear metals noted in the engine lubricating oil samples should not be significantly different when compared to an engine fueled with petroleum diesel fuel.
2. The level of soot (black smoke) and carbon monoxide appears to be slightly reduced when the engine is fueled with B2.
3. Fueling with B2 will have no measurable impact on the fuel economy of a diesel engine.

RECOMMENDATIONS

The findings from this investigation cannot be considered conclusive, because the study was very limited in scope. Interpretations made from the data must be done with caution.

Based on these observations and the conclusions which were drawn, the following recommendations were made:

1. An experimental research design should be determined which would quantify the amount of wear metals found in used engine lubricating oil samples compared to an engine that has been fueled with petroleum diesel fuel.
2. This experimental research design should be used to evaluate the performance of several engine families and designs.
3. Additional engine exhaust emissions testing should be conducted on different engines to determine if the lower levels of soot (black smoke) and carbon monoxide that were noted can be generalized to all types of diesel engines .
4. Fuel economy should be monitored throughout all testing.

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