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Engine Oil Analysis of Diesel Engines Fueled with 0, 1, 2, and 100 Percent Biodiesel

by

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SUMMARY:

The Agricultural Engineering Department at the University of Missouri-Columbia has monitored the fueling of 1991, 1992, 1996 and 1998 Dodge pickups equipped with the 5.9 L (360 in^3) Cummins diesel engine from as early as 1991. These pickups have been fueled with one, two and 100% blends of methyl-ester soybean oil (soydiesel/biodiesel). Analysis of engine lubrication oil, taken when the oil was changed on the vehicles, was compared to the analysis of oil samples pulled from 100% petroleum fueled diesel engines. The findings suggested that the biodiesel and biodiesel blend fueled engines were wearing at a normal rate.

KEYWORDS: Biofuels, Biodiesel, Methyl-ester, Engine Oil Analysis, Transesterification.

FUELING DIRECT INJECTED DIESEL ENGINES WITH 2% BIODIESEL BLEND

L. G. Schumacher and J. Van Gerpen[1]

ABSTRACT

The Agricultural Engineering Department at the University of Missouri-Columbia has monitored the fueling of 1991, 1992, 1996 and 1998 Dodge pickups equipped with the 5.9 L (360 in^3) Cummins diesel engine from as early as 1991. These pickups have been fueled with one, two and 100% blends of methyl-ester soybean oil (soydiesel/biodiesel). Analysis of engine lubrication oil, taken when the oil was changed on the vehicles, was compared to the analysis of oil samples pulled from 100% petroleum fueled diesel engines. The findings suggested that the biodiesel and biodiesel blend fueled engines were wearing at a normal rate.

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INTRODUCTION

Previous research conducted with diesel engines during the early 1990's in Idaho and Missouri proved that diesel engines could be fueled successfully with 100% neat biodiesel fuel and with B20, a 20 percent replacement of the petroleum diesel fuel with biodiesel (Schumacher, et al., 1991; Peterson et al., 1995). Schumacher continued to monitor the wear metals in biodiesel fueled diesel engines, (Schumacher, et. al., 1998) and documented wear metals found in the engine lubricating oil after fueling diesel engines with B2. B2 is a two percent replacement of petroleum diesel fuel with biodiesel derived from soybean oil. The work reported in this paper compares the data obtained from previous biodiesel research with data, obtained from B1and B2 fueling.

MATERIALS AND METHODS

Each of the oil samples were taken from Dodge pickups equipped with direct-injected turbocharged 5.9 L (360 in^3) diesel engines. Although the horsepower of each engine was not identical, all were manufactured by Cummins Engine Company. Each pickup engine was initially fueled with diesel fuel for approximately 1500 - 3000 miles. The 1991 & 1992 engines were subsequently fueled with 100% (B100) biodiesel for approximately 90,000 miles. The 1992 engine was torn down, inspected by Cummins, and then rebuilt. The 1992 has now logged 150,000 miles with B2. The 1996, operated by the Michigan Soybean Promotion Committee, logged 40,000 miles with B2. The 1998 has logged approximately 85,000 miles with B1.

Two companies have assisted with the fuel analysis. NOPEC Corporation of Lakeland, FL, analyzed the 100% neat biodiesel, and Cleveland Technical Center of Kansas City, KS, analyzed the B2 (biodiesel/diesel fuel blend).

The engines were <u>not</u> modified in any way to facilitate biodiesel or biodiesel blend fueling. The engines were modified so that a “hot” oil sample could be taken from the engine while the engine was running. A device which looks much like the “needle” used when filling air into a basketball or a football was secured to a short length of polyvinyl tubing. An oil fitting plug on the oil filter housing was removed, and a fitting designed to receive the “needle” was tightened into place. The engine was started, and after it was warmed, the needle was inserted. Oil was then pumped through the needle and tubing into a clean steel can for later analysis.
Table 1. Typical Fuel analysis of Biodiesel and B2 used when fueling 5.9L Cummins Engines.

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Fuel Property	ASTM Test Procedure	Fuel Biodiesel	B2 Blend
BTU/Gallon	D2382	N/T	138,300
Color	D1500	N/T	N/T
Corrosion	D130	1A	1A
Cloud Point	D2500	32^{o} F	0 ^{0}F
Pour Point	D97	26.5^{0} F	-34 ^{0}F
Flash Point	D92	285^{0} F	145 ^{0}F
Viscosity	D445	4.8 Cent@100^{0}C	N/T
Sulphur	D129	0.01%	N/T
Carbon Residue	D524	N/T	N/T
Carbon Residue	D4530	.03%	N/T
Cetane Index	D976	N/T	47.8
Ash	D482	0.001%	N/T
Free Glycerine	G.C.	0.033%	N/Ap.
Total Glycerine	G.C.	0.295%	N/Ap.
Acid Number	D664	0.25 mg KOH/gm	N/T
Water and Sediment	1796/4807	0.0%	N/T
Distillation			
IBP		N/T	346 ^{0}F
5		N/T	N/T
10		N/T	416 ^{0}F
20		N/T	N/T
30		N/T	N/T
50		N/T	506 ^{0}F
70		N/T	N/T
80		N/T	N/T
90		N/T	598 ^{0}F
95		N/T	N/T
End		N/T	634 ^{0}F

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

The diesel fuel that was blended with the biodiesel was purchased at local diesel filling stations in Michigan and Missouri. Mixing of the blend was done in the OEM fuel tank. A predetermined volume of biodiesel was first added to the fuel tank. The operator then topped off the tank with the amount necessary to prepare the respective blend (B1 or B2). Mixing occurred while filling the tank and while the operator drove the vehicle, a procedure that is commonly used in the industry to mix ethanol in gasoline before it is delivered to the local filling station.

The engine lubricating oil was changed at approximately 3,000 mile intervals for the 1991- B100, 1992- B100, 1996- B2, 1998- B1 pickups. The engine oil was changed on the 1992- B2 pickup at 6000 - 7000 mile intervals. Although engine lubricating oil was sampled and analyzed at 1000 mile intervals, only the data obtained when the oil was changed was included in the analysis.

The data were analyzed by MFA Labs in Columbia, MO and Cleveland Technical Center in Kansas City, MO. A computer-generated report provided a breakdown of wear metals, contaminants, water and sediment, glycols, and oil additives.

The descriptive statistics were conducted using Corel Quattro Pro (C)1997 Corel Corporation to determine the levels of iron, copper, chromium, silicon, lead, and aluminum wear metals in each sample(Table 2). Analysis of variance (ANOVA, (C)1997 Corel Corporation) were conducted to determine if differences existed among the wear metal means. When differences were noted among these means, t-tests were conducted to determine these statistical differences. An alpha of .05 was used to determine when means were statistically different.

The tractor engine oil samples that had less than 50 hours or greater than 150 hours of use were excluded from these analysis. These samples were excluded since none of the pickup oil samples had fewer than 50 hours or greater than 150 hours.

Data were also compared to rule of thumb data established by the Minnestota Valley Testing Laboratory.

RESULTS AND DISCUSSION

The wear metals that reflect the condition of the engine were examined by the researchers to determine if the engines were wearing at a normal rate. The wear element element aluminum reflects piston wear, iron reflects cylinder wear, copper and lead reflect bearing wear, and chromium reflects ring wear. Silicon was also examined as this reflects the wear material that moves through the air filter and into the engine.

Aluminum

Tractor oil sample data were <u>not</u> available for aluminum wear metals. The data were compared to determine if differences existed among the pickup wear metal mean values. The ANOVA had 4 degrees of freedom between groups and 115 degrees of freedom within groups. The F value was 4.73 with a probability that exceeded .001. A review of the data suggested that differences would noted if the samples were grouped into two groups: 100% biodiesel (Mean = 0.37) or 1-2% biodiesel (Mean = 1.72). The t value of 7.61 was statistically significant at the .05 alpha level.

Iron

The ANOVA for iron had 5 degrees of freedom between groups and 294 degrees of freedom within groups. The F value was 69.82 with a probability that exceeded .001. A review of the data suggested that differences would noted if the samples were grouped into two groups: Tractors (Mean = 49.46) or Pickups (Mean = 8.02). The t value of 7.69 was statistically significant at the .05 alpha level.

Chromium

The ANOVA for chromium had 5 degrees of freedom between groups and 294 degrees of freedom within groups. The F value was 17.86 with a probability that exceeded .001. A review of the data suggested that differences would noted if the samples were grouped into two groups: Tractors (Mean = 3.00) or Pickups (Mean = 1.27). The t value of 3.16 was statistically significant at the .05 alpha level.

Lead

The ANOVA for lead had 5 degrees of freedom between groups and 294 degrees of freedom within groups. The F value was 31.03 with a probability that exceeded .001. A review of the data suggested that differences would noted if the samples were grouped into two groups: Tractors (Mean = 14.24) or Pickups (Mean = 1.94). The t value of 5.05 was statistically significant at the .05 alpha level.

Silicon

The ANOVA for silicon had 5 degrees of freedom between groups and 294 degrees of freedom within groups. The F value was 4.87 with a probability that exceeded .001. A review of the data suggested that differences would noted if the samples were grouped into two groups: Tractors (Mean = 5.16) or Pickups (Mean = 4.83). However, the t value of 0.23 was statistically not significant at the .05 alpha level.

Copper

The ANOVA for copper had 5 degrees of freedom between groups and 294 degrees of freedom within groups. The F value was 3.66 with a probability of .003 Several t-Tests were conducted to determine where the differences among the means existed. The different groupings of the data included: pickups vs tractors, BD100 vs 0,1,& 2% BD, BD100 vs 1 & 2% BD, and BD100 and 100 percent diesel fuel. None of these comparisons yielded any statistical differences. The closest among these was the BD100 vs 100 percent diesel fuel. The t statistic for this comparison was 1.39 with a probability of .165. (Note, the comparison between pickups and tractors also produced a t statistic of 1.38, but the probability was .171).

The mean values of the measured wear elements did not vary much regardless of the biodiesel blend. The only exception to this trend was for the wear element aluminum. Based on the data, it appears that increasing the amount of biodiesel reduces the amount that aluminum parts wear in a diesel engine.

The wear elements iron, chromium and lead were statistically different. An examination of these mean wear metal values suggests that biodiesel, even when substituted in small amounts, can retard the wear of iron, chromium, and lead in a diesel engine.

No conclusions can be drawn from the copper wear metal data. A careful review of the data revealed that two oil samples skewed the analysis of the data. As a result, even though the ANOVA resulted in a significant F statistic, the researchers were unable to isolate specific differences between means. However, an examination of the mean values for copper suggests that increasing the amount of biodiesel may reduce the amount that copper parts wear in a diesel engine.

It was interesting to note that there was **not** a difference for the wear element silicon. In a sense this was good, as it suggests that even though the tractors and the pickups were operated under different operating conditions, that the amount of wear material that entered the engine (and normally increases the wear of the engine) was essentially the same.

Table 2. N, Mean, and Standard Deviation for Wear Metals Found in Oil Samples Taken from Dodge Pickups and Farm Tractors.

Wear metal		N	Mean (ppm)	StDev (ppm)
Iron	92' Dodge @ 100%	24	6.79	3.95
	92' Dodge @ 2%	14	8.00	3.66
	91' Dodge @ 100%	13	9.00	12.10
	96' Dodge @ 2%	9	9.88	1.72
	98' Dodge @ 1%	5	24.00	11.26
	Tractors	50	49.46	37.23
	Minnesota Valley Testing		10-40	
Lead	92' Dodge @ 100%	24	1.46	1.80
	92' Dodge @ 2%	14	1.56	1.22
	91' Dodge @ 100%	13	2.00	3.04
	96' Dodge @ 2%	9	2.71	0.86
	98' Dodge @ 1%	5	5.00	3.39
	Tractors	50	14.24	16.89
	Minnesota Valley Testing		1-12	
Copper	92' Dodge @ 100%	24	3.25	3.63
	92' Dodge @ 2%	14	6.43	21.24
	91' Dodge @ 100%	13	3.23	3.19
	96' Dodge @ 2%	9	7.67	5.59
	98' Dodge @ 1%	5	7.40	10.31
	Tractors	50	10.94	32.98
	Minnesota Valley Testing		3-15	
Chromium	92' Dodge @ 100%	24	4.22	1.42
	92' Dodge @ 2%	14	0.79	0.41
	91' Dodge @ 100%	13	1.85	2.80
	96' Dodge @ 2%	9	0.77	0.45
	98' Dodge @ 1%	5	0.79	1.36
	Tractors	50	3.00	2.86
	Minnesota Valley Testing		0.5-8	
Silicon	92' Dodge @ 100%	24	2.58	2.04
	92' Dodge @ 2%	14	5.43	1.59
	91' Dodge @ 100%	13	2.15	1.79
	96' Dodge @ 2%	9	3.00	1.56
	98' Dodge @ 1%	5	24.2	32.93
	Tractors	50	5.16	2.75
	Minnesota Valley Testing		0-12	
Aluminum	92' Dodge @ 100%	24	0.23	0.64
	92' Dodge @ 2%	14	0.46	0.88
	91' Dodge @ 100%	13	0.23	0.42
	96' Dodge @ 2%	9	1.69	0.47
	98' Dodge @ 1%	5	0.71	0.67
	Tractors		N/A	
	Minnesota Valley Testing		N/A	

Minnesota Valley Testing = Rule of thumb averages developed by Minnesota Valley Testing Laboratories.

CONCLUSIONS

Although the findings from this analysis were not conclusive, the results from this study were positive concerning the use of biodiesel and biodiesel blended fuel for diesel engines. As such, the following conclusions were drawn from the investigation:

1. Replacing the diesel fuel with biodiesel reduced the wear of aluminum components in a diesel engine.

2. Replacing the diesel fuel with biodiesel reduced the wear of iron, chromium and lead components in a diesel engine.

RECOMMENDATIONS

The findings from this investigation cannot be considered conclusive, as some of the data points were not under the complete control of the researchers. Therefore, any 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 noted in used engine lubricating oil samples as compared to an engines which have been fueled with petroleum diesel fuel.

2. Additional monitoring of diesel engines which are fueled with biodiesel and blends of biodiesel and petroleum diesel fuel should be conducted. For example, visual differences were noted between means for the wear element copper, but the means were not statistically different. Additional data are needed to clarify this issue.

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