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Engine Oil Analysis of Diesel Engines Fueled with Biodiesel Blends

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SUMMARY:

The University of Missouri-Columbia and the University of Idaho have monitored 1991, 1992, 1994, 1995,1996, 1998, and 1999 Dodge pickups equipped with the 5.9 L (360 in^3) Cummins diesel engines from as early as 1991. These pickups have been fueled with zero, one, two, 20, 50 and 100% blends of methyl-esters and ethyl-esters of soybean, canola, and rapeseed oil (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, C. L Peterson, and J. Van Gerpen

ABSTRACT

The University of Missouri-Columbia and the University of Idaho have monitored 1991, 1992, 1994, 1995,1996, 1998, and 1999 Dodge pickups equipped with the 5.9 L (360 in^3) Cummins diesel engines from as early as 1991. These pickups have been fueled with zero, one, two, 20, 50 and 100% blends of methyl-esters and ethyl-esters of soybean, canola, and rapeseed oil (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

Over one hundred years have passed since the invention of the compression ignition engine (www.hydrogenappliances.com, 2001). Mr. Diesel saw his engine as a solution to the high polluting and inefficient steam engines of his time (www.hempcar.org, 2001). During the 1880's, a steam engine was, at best, 10 percent efficient and produced large amounts of smoke as it operated. By 1896, Diesel's engine had demonstrated mechanical efficiency of 75.6 percent (www.invent.org, 2001).

Rudolph Diesel's early designs used coal dust as a fuel. However, at the 1889 World's Fair in Paris, France (**Rovito**, www.cgsinc.com/particle_1.htm, 2001), Diesel powered his new engine with peanut oil. Petroleum-based fuel (diesel), a by-product of the gasoline manufacturing process, exhibited characteristics that were quite similar to vegetable oils. This inexpensive by-product became the fuel of choice for Diesel's engine and nearly all research that followed for the next 70 years focused on how to make Diesel's engine operate on petroleum-based diesel fuel.

Research conducted largely with 5.9L Cummins diesel engines from the early 1990's to present (7/2001) in Idaho and Missouri has proven that diesel engines can be fueled successfully with biodiesel and biodiesel blends. Diesel engines were fueled with B1, B2, B20, B50, and B100 or "neat" biodiesel fuel (B20 is a 20 percent replacement of the petroleum diesel fuel with biodiesel) (Schumacher, et al., 1991, 1996; Peterson et al., 1995, 1996, 1999).

Engine oil analysis is a simple way to determine the condition of an engine. A small amount of oil is drawn from the engine after the engine has been warmed to ensure that the oil and any contaminants are thoroughly mixed. The sample is sent off for analysis by an independent laboratory (Peterson, 2001). The sample is then analyzed for the presence of metallic elements (wear metals). Spectrometric analysis is used to determine the amount of wear metals in parts per million (ppm) by weight.

In the spectrometer, the oil is electrically excited to the point where light is emitted. Each element present in the burning oil emits light of its own particular color and frequency. Spectrometers translate the intensity of these colors into a computerized readout. The computer compares the output with a fresh oil sample as well as to samples that were previously taken from the same engine to establish wear treads.

Missouri and Idaho researchers have monitored the wear metals found in the lubricating oil of biodiesel-fueled diesel engines while fueling their engines (Schumacher, et. al., 1998). Both Universities have documented the wear metals found in the engine lubricating oil after fueling diesel engines with biodiesel blends through tests conducted by independent oil analysis laboratories. The work reported in this paper compares the data obtained from research spanning 10 years of biodiesel fueling with 12 vehicles.

MATERIALS AND METHODS

Each of the oil samples were taken from direct-injected diesel engines. Although the horsepower of each engine was not identical, all but one were 5.9L engines manufactured by Cummins Engine Company. Table 1 outlines specific information about each engine.

Table 1. Vehicles that were monitored using engine oil analysis by researchers at the University of Idaho and the University of Missouri: 1991 - 2001.

Year/Model	Displacement	Manufacturer	Fuel Source	% BD	Miles
1991	B - 5.9L	Cummins	MO - SME	100	79,451
1992	B - 5.9L	Cummins	MO - SME	100	100,050
1992	B - 5.9L	Cummins	MO - SME	2	151,225
1996	B - 5.9L	Cummins	MO - SME	2	95,560
1998	B - 5.9L	Cummins	MO - SME	1	103,765
1992	B - 5.9L	Cummins	ID - RME	20	101,937
1994	B - 5.9L	Cummins	ID - REE	100	99,487
1995	B - 5.9L	Cummins	ID - REE	100	93,000
1997	3406E - 14.6L	Caterpillar	Hysee (Soybean)	50	202,682
1995	B - 5.9L	Cummins	Baseline DF	0	37,732
1992	B - 5.9L	Cummins	Baseline DF	0	58,200
1992	B - 5.9L	Cummins	Baseline DF	0	110,470

MO - SME = Fueled with methylesters of soybean oil and logged at U of Missouri.
ID - RME = Fueled with methylesters of rapeseed or canola oil and logged at U of Idaho.
ID - REE = Fueled with ethylesters of rapeseed or canola oil and logged at U of Idaho.
Hysee = Fueled with ethylesters of hydrogenated soybean oil and logged at U of Idaho.
DF = Pump run diesel fuel.

Each engine was broken in according to engine manufacturer recommendations. Some were fueled for a short time on diesel fuel before they were fueled with biodiesel/biodiesel blends. Some were fueled with a biodiesel blend from the first day of ownership. The 1992 B100 MO - SME engine was shipped to Columbus, IN, torn down and inspected by Cummins, and then rebuilt by Missouri technicians. This engine has now logged 151,225 additional miles with B2 (Table 1). The 1992 ID - RME engine was also shipped to Columbus, IN (Cummins Engine Co.) torn down and inspected by Cummins, and then rebuilt by Idaho technicians and put back into service. The 1994 ID - REE B100 and the 1995 ID - REE B100 were also respectively torn down at the University of Idaho and a Cummins dealership. Both engines were inspected by Cummins personnel, rebuilt by Idaho technicians, and then put back into service. The tear down evaluations in all engines were within specifications. (Peterson, et. al., 1998, Taberski, et. al., 1999, Peterson and Thompson, 1999). The 1997 HySee engine was torn down by Caterpillar and "passed with flying colors" (Chase, et. al., 2000)

The diesel fuel that was blended with the biodiesel was purchased at local diesel filling stations in Idaho, 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, B2, B20 ...). 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 1997 HySee fueled truck was fueled through a blending valve which drew fuel from a diesel nurse tank and a biodiesel nurse tank. The 1992 - ID B20 engine had an on-board mixing system (Peterson, et. al., 1998).

Two companies assisted with fuel analysis. NOPEC Corporation of Lakeland, FL, provided the analysis of the 100% neat biodiesel, and Cleveland Technical Center of Kansas City, KS, analyzed the B2 (biodiesel/diesel fuel blend) (Table 2). The Idaho samples were analyzed by the U of Idaho Analytical Laboratory and by Phoenix Chemical, Chicago, IL. Additional information concerning fuel analysis can be found in papers previously published by the authors.

The engines were <u>not</u> modified in any way to facilitate biodiesel or biodiesel blend fueling. Oil recommended by the manufacturer was used in the engine. The Missouri engines used 15W-40 Cummins Blue lubricating oil. Idaho, for the most part, used 15W-40 Delo 400 engine oil in its engines. The exception was the 1997 Kenworth which used 15@-40 Penzoil. Some of 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.

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

The descriptive statistics were conducted using SAS (© 1989-1996 Sas Institute Inc., Cary, NC, USA) & SPSS © SPSS Inc. Chicago, IL, USA) to determine the levels of iron, copper, chromium, silicon, lead, and aluminum wear metals in each sample (Table 3). Analysis of variance (ANOVA, © 1989-1996 Sas Institute Inc., Cary, NC, USA) was conducted to determine if differences existed among the wear metal means. When differences were noted among these means, the multiple range test lsmeans was used to determine these statistical differences. An alpha of .05 was used to determine when means were statistically different.

Table 2. Typical Fuel analysis of Biodiesel and B2 used when fueling 5.9L Cummins Engines. Additional fuel analysis information can be found in Peterson, et. al, (1998), Chase, et. al., (2000), Taberski, et. al., (1999), and Peterson and Reece, (1996a, 1996b).

Fuel Property	ASTM Test Procedure	Fuel: Biodiesel	Fuel: B2 Blend
BTU/Gallon	D2382	N/T	138,300
Color	D1500	N/T	N/T
Corrosion	D130	1A	1A
Cloud Point	D2500	32° F	0 °F
Pour Point	D97	26.5° F	-34 °F
Flash Point	D92	285° F	145 °F
Viscosity	D445	4.8 cSt@100°C	N/T
Sulphur	D129	0.01%	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 °F
10		N/T	416 °F
50		N/T	506 °F
90		N/T	598 °F
End		N/T	634 °F

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

With the exception of the 1997 Kenworth (Caterpillar) engine, the samples that were included in this analysis were taken when the engine oil was changed. The 1997 Kenworth was sampled at 6,000 mile intervals and oil was changed at approximately 25,000 miles (~574.5 hr). Nine of the Cummins engines oil change interval varied from 3141 - 4364 miles (~ 72.2 to 100.3 hr) of operation. Two of the Cummins engines had the oil changed between 5934 - 6609 miles (~ 136.4 - 151.9 hr) of operation.

In 1988, Schumacher collected oil samples from 98 diesel fueled tractors at seven locations in Missouri. A very small number of these diesel fueled tractor engines were equipped with 5.9L Cummins engines, but, for the most part, this was the exception. The tractor engine oil samples that had less than 50 hours or greater than 150 hours of use were excluded from these analyses since none of the pickup oil samples had fewer than 50 hours or greater than 150 hours.

The time it takes to obtain a representative number of samples for statistical analysis from the same engine that has performed the same type of work makes data collection from the "same engine" impractical. As such, the researchers used different engines in an effort to establish a diesel fueled base-line. Hence, a rationale to use oil analysis data from the three diesel fueled Cummins engines and the farm tractors in this analysis.

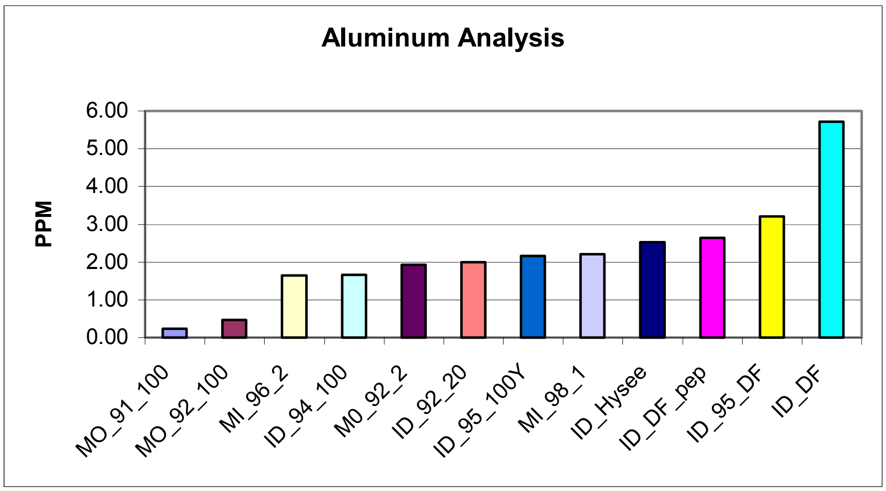
Data were also compared to data published by the Minnestota Valley Testing Laboratory (Schumacher, L.G , J.C. Frisby, and W.G. Hires,1991) and Trigard Oil Analysis Laboratory (Author, 2001a).

RESULTS

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 aluminum reflects piston wear; iron reflects cylinder walls/liners, valve shafts, and/or gear wear; copper reflects bearings and bushing wear and may be high if the engine has a copper oil cooler; lead reflects bearing wear; and chromium reflects piston ring wear. Silicon was also examined, as this reflects the wear material that moves through the air filter and into the engine. Silicon can also reflect additives in the lubricating oil and may also give a false reading if silicon sealant has recently been used in the engine.

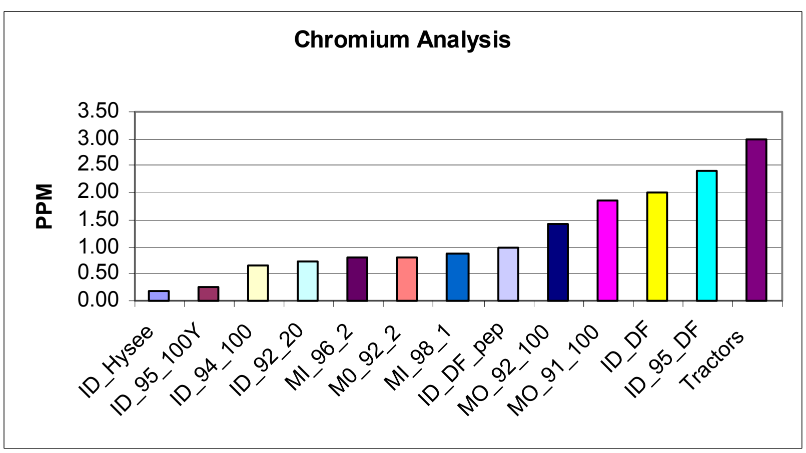
Aluminum

Tractor oil sample data were not available for aluminum wear metals. The data were compared to determine if differences existed among the pickup wear metal mean values. The ANOVA had 11 degrees of freedom between groups and 186 degrees of freedom within groups. The F value was 20.857 with a probability that exceeded .0001. Data were grouped to determine if a "feedstock effect" had contributed to the variance found in the data. An F value of 3.03 with a probability of 0.083 suggested that no statistically significant differences existed between soybean- and rapeseed-derived biodiesel means. Data were next grouped to determine if a fuel effect existed in the data. An F value of 9.99 and a probability of 0.002 suggested that statistical differences existed among the biodiesel/biodiesel blend mean values and the mean values reported for the diesel fueled engines.



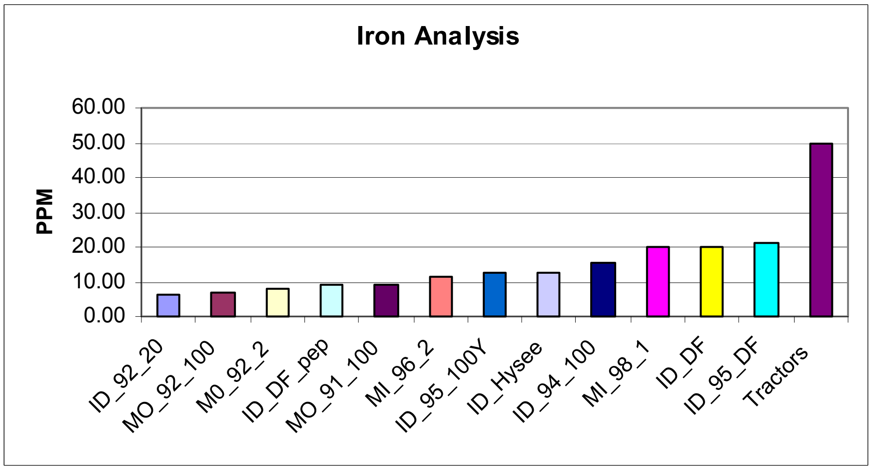
Chromium

The ANOVA had 12 degrees of freedom between groups and 235 degrees of freedom within groups. The F value was 16.267 with a probability that exceeded .0001. Data were grouped to determine if a "feedstock effect" had contributed to the variance found in the data. An F value of 3.03 with a probability of 0.083 suggested that no statistically significant differences existed between soybean- and rapeseed-derived biodiesel means. Data were next grouped to determine if a fuel effect existed in the data. An F value of 9.99 and a probability of 0.002 suggested that statistical differences existed among the biodiesel/biodiesel blend mean values and the mean values reported for the diesel fueled engines.



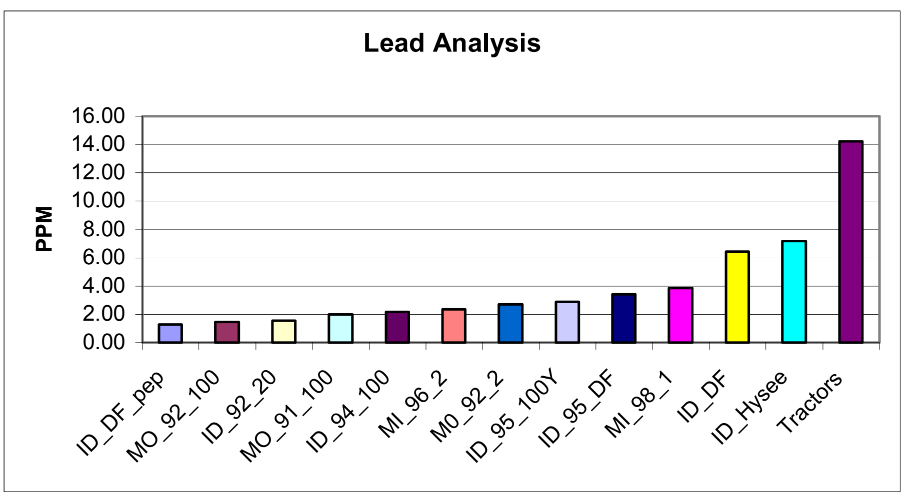
Iron

The ANOVA had 12 degrees of freedom between groups and 235 degrees of freedom within groups. The F value was 4.71 with a probability that exceeded .0001. Data were grouped to determine if a "feedstock effect" had contributed to the variance found in the data. An F value of 0.01 with a probability of 0.903 suggested that no statistically significant differences existed between soybean- and rapeseed-derived biodiesel means. Data were next grouped to determine if a fuel effect existed in the data. An F value of 17.76 and a probability of 0.0001 suggested that statistical differences existed among the biodiesel/biodiesel blend mean values and the mean values reported for the diesel fueled engines.



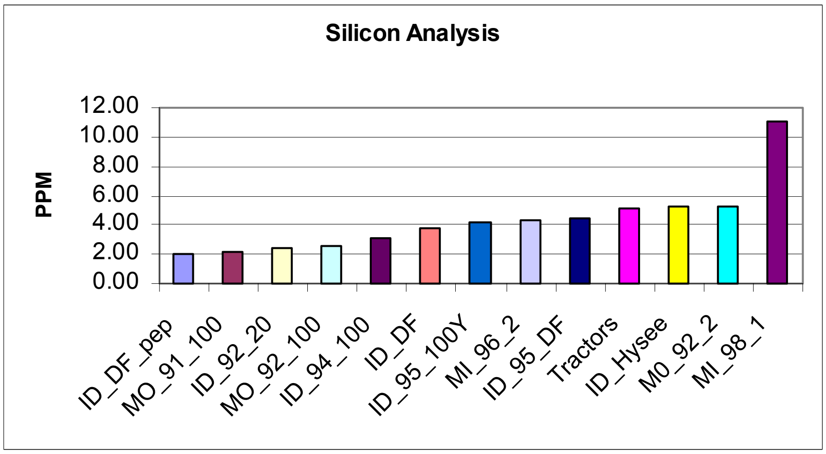
Lead

The ANOVA had 12 degrees of freedom between groups and 235 degrees of freedom within groups. The F value was 7.54 with a probability that exceeded .0001. Data were grouped to determine if a "feedstock effect" had contributed to the variance found in the data. An F value of 0.05 with a probability of 0.832 suggested that no statistically significant differences existed between soybean- and rapeseed-derived biodiesel means. Data were next grouped to determine if a fuel effect existed in the data. An F value of 7.28 and a probability of 0.0075 suggested that statistical differences existed among the biodiesel/biodiesel blend mean values and the mean values reported for the diesel fueled engines.



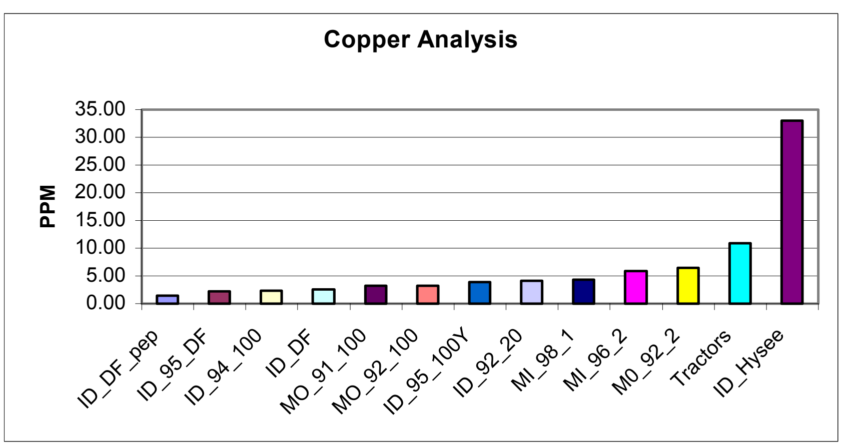
Silicon

The ANOVA had 12 degrees of freedom between groups and 235 degrees of freedom within groups. The F value was 2.44 with a probability that exceeded .0052. Data were grouped to determine if a "feedstock effect" had contributed to the variance found in the data. An F value of 11.45 with a probability of 0.0008 suggested that differences existed between soybean- and rapeseed-derived biodiesel means. Data were next grouped to determine if a fuel effect existed in the data. An F value of 0.01 and a probability of 0.904 suggested that no statistically significant differences existed among the biodiesel/biodiesel blend mean values and the mean values reported for the diesel fueled engines. An lsmeans multiple range test (SAS, Inc.) was used to determine where differences existed. The oil samples taken from the1998 Dodge Pickup (1% BD) were significantly different (.05 alpha) from the rest of the samples that were analyzed.



Copper

The ANOVA had 12 degrees of freedom between groups and 235 degrees of freedom within groups. The F value was 7.22 with a probability that exceeded .0001. Data were grouped to determine if a "feedstock effect" had contributed to the variance found in the data. An F value of 0.15 with a probability of 0.702 suggested that no statistically significant differences existed between soybean- and rapeseed-derived biodiesel means. Data were next grouped to determine if a fuel effect existed in the data. An F value of 0.00 and a probability of 0.971suggested that no statistical differences existed among the biodiesel/biodiesel blend mean values and the mean values reported for the diesel fueled engines. An lsmeans multiple range test (SAS, Inc.) was used to determine where differences existed. The oil samples taken from the1997 Kenworth truck (50% BD) were significantly different (.05 alpha) from the rest of the samples that were analyzed.



DISCUSSION

As noted by Schumacher, et. al (2000), 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 copper. The copper level for the 1997 Kenworth over-the-road truck was significantly greater when compared to any of the other samples. The manufacturer of the Caterpillar engine (Kenworth truck) suggested that the high levels of copper in the lubrication oil during the first 50,000 miles of operation was probably due to a copper oil cooler. The Kenworth had a copper oil cooler and the samples that were taken during the first 50,000 miles of operation (2-3 samples) were two to three times higher in copper than any sample taken after that point.

All wear elements, except silicon, were statistically different when compared to the samples taken from the diesel-fueled engines. 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.

An important observation to note was that the samples that were taken from engines fueled with soybean-derived biodiesel were not statistically different from those taken from engines fueled with rapeseed-derived biodiesel. This documents the lack of a "feedstock" effect concerning the use of biodiesel.

It was interesting to note that there was **not** a difference for the wear element silicon when the biodiesel-derived oil samples were compared with the diesel fuel derived fuel samples. In a sense this was good, as it suggests that even though the tractors and the pickups were operated under different operating conditions, the amount of wear material that entered the lubricating oil (and normally increases the wear of the engine) was essentially the same. However, when grouped by feedstock (soybean vs rapeseed), this was not the case. A closer examination of the data revealed that one sample from the 98' Dodge from Missouri was of a magnitude that was nine times higher than any other sample taken from this engine. This was the first oil sample taken from this engine. Due to the fact that engine manufacturers have started using silicon to form gaskets in recent years, the researchers hypothesized that this sample may be higher for this reason. If one removes this sample from the analysis and re-runs the ANOVA, there is no longer a feedstock effect for silicon.

CONCLUSIONS

Although the findings from this analysis were not conclusive, the results are positive concerning the use of biodiesel and biodiesel blended fuels for diesel engines. The following conclusions were drawn from the investigation:

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

2. The amount of wear metals found in the lubricating oil of rapeseed-derived biodiesel was not statistically different from the amount found in soybean-derived lubricating oil samples.

3. Biodiesel has not resulted in wear rates that appear to be worse than diesel fuel.

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. For example, the researchers relied upon persons who are **not** trained in research (lay persons) to collect the oil samples at specific intervals. At the same time, the researchers do **not** know for certain that the lay person collected every sample according to the instructions that were provided. Ideally, the researchers want data from the exact same engine so that valid comparisons can be made between biodiesel fueled engines and diesel fueled engines. Ideally, the engine would be operated under identical conditions (weather, load, driving habits, the same driver) to facilitate this comparison. The time necessary to log miles on an engine is still another significant issue that limits the ability of a researcher to obtain identical data from the same over-the-road engine. Based on these assumptions, the researchers feel that it is impossible to duplicate the exact conditions over-the-road so that direct comparisons can be made between biodiesel and diesel fueling on the same engine. Therefore, any interpretations made from these 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. Specifically, a greater number of biodiesel fueled vehicles must be monitored and in conjunction with an equal number of control vehicles (diesel fueled).

Table 3. N, Mean, and Standard Deviation for Wear Metals Found in Oil Samples Taken from Dodge Pickups, a Kenworth over the road truck, and Farm Tractors.

Wear metal		N	Mean (ppm)	StDev (ppm)
Iron	92' MO - Dodge @ 100%	24	6.79	4.03
	92' MO - Dodge @ 2%	14	7.85	3.88
	91' MO - Dodge @ 100%	13	9.00	12.59
	96' MO - Dodge @ 2%	14	11.28	1.72
	98' MO - Dodge @ 1%	14	20.14	7.68
	92' ID - Dodge @ 20%	30	6.23	2.26
	94' ID - Dodge @ 100%	18	15.5	3.88
	95' ID - Dodge @ 0%	5	21.2	4.54
	95' ID - Dodge @ 100%	25	12.4	6.32
	ID Pepsi Trk - Dodge @ 0%	17	8.94	4.14
	ID McGregor Trk - Dodge @ 0%	7	20.28	8.01
	97' ID - Kenworth @ 50%	17	12.47	6.06
	MO - Tractors	50	49.46	37.23
	Minnesota Valley Testing		10-40	
	Trigard Oil Analysis Lab		20-60	
Lead	92' MO - Dodge @ 100%	24	1.46	1.84
	92' MO - Dodge @ 2%	14	2.71	1.26
	91' MO - Dodge @ 100%	13	2.00	3.16
	96' MO - Dodge @ 2%	14	2.36	1.28
	98' MO - Dodge @ 1%	14	3.86	2.34
	92' ID - Dodge @ 20%	30	1.53	0.63
	94' ID - Dodge @ 100%	18	2.17	1.15
	95' ID - Dodge @ 0%	5	3.40	1.67
	95' ID - Dodge @ 100%	25	2.88	1.30
	ID Pepsi Trk - Dodge @ 0%	17	1.29	0.58
	ID McGregor Trk - Dodge @ 0%	7	6.42	5.09
	97' ID - Kenworth @ 50%	17	7.18	4.51
	MO - Tractors	50	14.24	17.06
	Minnesota Valley Testing		1-12	
	Trigard Oil Analysis Lab		5-25	
Copper	92' MO - Dodge @ 100%	24	3.25	3.70
	92' MO - Dodge @ 2%	14	6.43	22.04
	91' MO - Dodge @ 100%	13	3.23	3.32
	96' MO - Dodge @ 2%	14	5.86	5.44
	98' MO - Dodge @ 1%	14	4.28	6.91
	92' ID - Dodge @ 20%	30	4.07	6.16
	94' ID - Dodge @ 100%	18	2.39	2.38
	95' ID - Dodge @ 0%	5	2.20	1.64
	95' ID - Dodge @ 100%	25	3.88	6.45
	ID Pepsi Trk - Dodge @ 0%	17	1.47	0.80
	ID McGregor Trk - Dodge @ 0%	7	2.57	1.13
	97' ID - Kenworth @ 50%	17	33.00	21.44
	MO - Tractors	50	10.94	32.98
	Minnesota Valley Testing		3-15	
	Trigard Oil Analysis Lab		5-40	

Table 3. N, Mean, and Standard Deviation for Wear Metals Found in Oil Samples Taken from Dodge Pickups, a Kenworth over the road truck, and Farm Tractors. (Con't.)

Wear metal		N	Mean (ppm)	StDev (ppm)
Chromium	92' MO - Dodge @ 100%	24	1.42	4.23
	92' MO - Dodge @ 2%	14	0.79	0.43
	91' MO - Dodge @ 100%	13	1.85	2.91
	96' MO - Dodge @ 2%	14	0.78	0.43
	98' MO - Dodge @ 1%	14	0.86	1.03
	92' ID - Dodge @ 20%	30	0.73	0.45
	94' ID - Dodge @ 100%	18	0.67	0.59
	95' ID - Dodge @ 0%	5	2.40	1.34
	95' ID - Dodge @ 100%	25	0.24	0.44
	ID Pepsi Trk - Dodge @ 0%	17	1.00	0.00
	ID McGregor Trk - Dodge @ 0%	7	2.00	1.53
	97' ID - Kenworth @ 50%	17	0.18	0.39
	MO - Tractors	50	3.00	2.89
	Minnesota Valley Testing		0.5-8	
	Trigard Oil Analysis Lab		1-10	
Silicon	92' MO - Dodge @ 100%	24	2.58	2.08
	92' MO - Dodge @ 2%	14	5.29	1.77
	91' MO - Dodge @ 100%	13	2.15	1.86
	96' MO - Dodge @ 2%	14	4.36	4.80
	98' MO - Dodge @ 1%	14	11.00	22.86
	92' ID - Dodge @ 20%	30	2.43	1.14
	94' ID - Dodge @ 100%	18	3.05	1.80
	95' ID - Dodge @ 0%	5	4.40	0.55
	95' ID - Dodge @ 100%	25	4.12	4.81
	ID Pepsi Trk - Dodge @ 0%	17	2.06	0.97
	ID McGregor Trk - Dodge @ 0%	7	3.71	1.11
	97' ID - Kenworth @ 50%	17	5.23	1.52
	MO - Tractors	50	5.16	2.75
	Minnesota Valley Testing		0-12	
	Trigard Oil Analysis Lab		1-15	
Aluminum	92' MO - Dodge @ 100%	24	0.46	0.64
	92' MO - Dodge @ 2%	14	1.93	0.92
	91' MO - Dodge @ 100%	13	0.23	0.44
	96' MO - Dodge @ 2%	14	1.64	0.50
	98' MO - Dodge @ 1%	14	2.21	0.58
	92' ID - Dodge @ 20%	30	2.00	1.17
	94' ID - Dodge @ 100%	18	1.67	0.84
	95' ID - Dodge @ 0%	5	3.20	0.84
	95' ID - Dodge @ 100%	25	2.16	1.07
	ID Pepsi Trk - Dodge @ 0%	17	2.65	1.22
	ID McGregor Trk - Dodge @ 0%	7	5.71	2.13
	97' ID - Kenworth @ 50%	17	2.53	0.87
	MO - Tractors	50	N/A	
	Minnesota Valley Testing		1-8	
	Trigard Oil Analysis Lab		1-15	

Minnesota Valley Testing = Rule of thumb averages developed by Minnesota Valley Testing Laboratories.
Trigard Oil Analysis Laboratory = Averages published at www.hampeloil.com/trigardlab/metals.asp

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