Effects of Additives and Biodiesel from Various Feedstock on Lubricity of Ultra Low Sulfur Diesel (ULSD)

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Abstract

The degree of lubricity character that a fuel has is very important in determining the operability of that fuel in "real world" applications. Fuel lubricity affects many parts of the engine; poor lubricity can lead to major engine problems. The lubricity of diesel fuel is of major concern as engines running diesel tend to be of high use (i.e. trucking, heating). In the process of reducing sulfur to ultra low levels due to national mandates, the lubricity of the diesel fuel has been adversely affected. It has already been shown experimentally that adding biodiesel to No. 1 and No. 2 can positively affect the lubricity of Low and Ultra Low Sulfur Diesel.[1] This study is aimed at quantifying these effects, focusing on how effective biodiesel can be on increasing the lubricity of No. 1 and No. 2 diesel fuels at different concentrations. We are also interested in how biodiesel's lubricity effects will compare with current lubricity additives. The lubricity effects of seven different types of biodiesel and three lubricity additives were measured using the High Frequency Reciprocating Rig method (HFRR- a method which determines lubricity of a fuel based on wear scar). Lubricity improvement was seen after just 0.5% of biodiesel was blended, and after a 1% biodiesel blend all seven of the B100 samples studied lowered the average wear scar of all 11 ULSD samples below the recommended 520 µm; these effects being comparable to and in many cases better than the lubricity additives tested.

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Background

Lubricity is an important characteristic of diesel fuel as it helps to determine the degree of wear various components of an engine will undergo over time. Low lubricity in fuel can cause high wear and scarring of essential engine parts (especially those which use only the fuel as a lubricant like rotary and distributor type fuel injection pumps[1]). No. 1 and No. 2 diesel fuels in the United States have been shown to have some of the poorest lubricity in the world.[2] With the EPA enforced sulfur content reduction to 15 ppm in 2006, the lubricity of the diesel in this country has become even worse as a result of the severe hydrotreating that is required to reduce sulfur to "Ultra Low" levels (15 ppm).

It has been shown that biodiesel blends as low as 2% improve the lubricity of No. 1 and No. 2 Low Sulfur Diesel (LSD) fuels significantly.[3] There are also lubricity additives that have in many cases shown to improve the lubricity of LSD fuels. However, the cost and the overall effectiveness of these additives have lead to studies such as these to determine alternative lubricity improvers.

The purpose of this study was to determine the effects that biodiesel has on the lubricity of both No. 1 and No. 2 ULSD from locations around the country, and to compare this to conventional lubricity improving additives. Seven different biodiesel samples were used to complete this study, blended into 11 different ULSD fuel samples randomly selected from around the country from the five PADD territories (see figure 1).

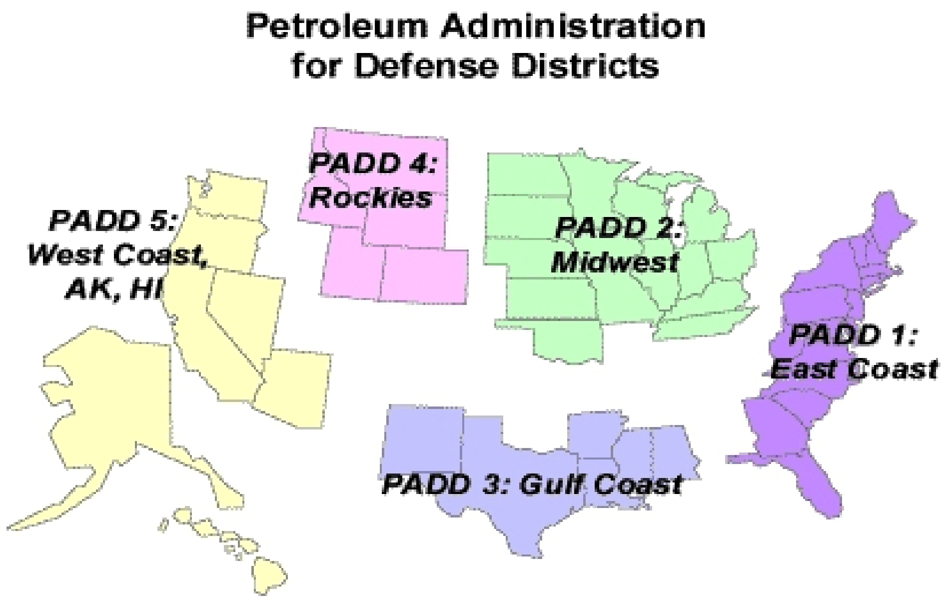


Figure 1. PADD Map for the United States.

Description of Study

Collection of Diesel and Biodiesel Samples

Eleven total diesel samples of No. 1 and No. 2 ULSD were collected, originating from each of the Petroleum Administration for Defense Districts (PADDs) around the country. Two samples came from each of PADDs II, III, IV and V, three samples came from PADD I (there are three separate districts within PADD I). Three of the eleven samples were No. 1 ULSD while eight were No. 2 ULSD. No. 1 ULSD was collected in each of PADDs I, II, and V from a northern region of each PADD since these areas were more likely to use No. 1 ULSD in winter months. Some of the ULSD samples that were received seemed to already have been additized with lubricity additive (see baseline testing data in the Appendix). We kept the data for these samples to show the effects that biodiesel blends and additives would have on this type of fuel.

Samples were collected and sent to Magellan LP laboratory[4] in Kansas City, KS. The seven B100 samples in this study were made from a variety of feedstock, including: Recycled Yellow Grease, Beef Tallow, Pork Lard, Soybean Oil, and Canola Oil. For the sake of feedstock neutrality, biodiesel samples will be randomly assigned a numeric label (baseline properties of each of the biodiesel samples is provided in the data section). These B100 samples were either collected by MEG Corp and transported to Magellan during the testing site visit, or were shipped directly to Magellan from the producer.

Four of the seven samples used in this study did not meet the ASTM D6751 specifications for either acid number (0.5 mg KOH/g max) or total glycerine (0.24 wt. % max). Out of specification acid number can be caused by a manufacturing error or by the use of aged fuel as the acid number increases with time, while out of specification total glycerine is strictly a manufacturing error. Since these were commercial fuels at the time, the results were included in the reporting for this study. Interestingly, lubricity values did not vary substantially between the in-spec and out-of-spec biodiesel. While not an original objective of this project, this data would indicate that out of spec biodiesel will still be able to impart lubricity and protect equipment in a similar way as in-specification biodiesel. The industry has made significant improvements in biodiesel fuel quality since these samples were collected.

Preparation of Samples

Five of the B100 samples were blended in concentrations of 1, 2, and 5% into each of the 11 ULSD fuels. The other two B100 samples were blended at 0.5 and 2% into each of the 11 ULSD fuels; they were also blended at 11% into four randomly selected ULSD fuels (these B11 blends are used to determine trends of lubricity at very high concentrations). There were three different lubricity additives (at 150 ppm) used for the study, blended into each of the 11 ULSD fuels. The lubricity additives were of two different types; monomer and synthetic ester based (two different additives were of the ester based type). These additives provided a base of comparison for the effects of the biodiesel blends**.**

Testing of the Samples

All of the samples were tested using the HFRR method. The HFRR is a microprocessor-controlled reciprocating friction and wear test system which provides a fast, repeatable assessment of the performance of fuels and lubricants. It is particularly suitable for wear testing relatively poor lubricants like diesel fuels and for boundary friction measurements of engine oils, greases and other compounds.[5] The wear scar is measured in micrometers (μm), and the current necessary specification for diesel fuel is a wear scar of less than 520 μm (the lower average wear scar, the better lubricating agent the fuel is). (NOTE: The HFRR method precision is ± 40 μm) Baseline testing was performed on each ULSD sample (appendix) before it was mixed with biodiesel and lubricity additives. Baseline testing was also performed on each B100 sample as well (table 1). The laboratory team at Magellan compiled an Excel spreadsheet with all of the HFRR data after following the ASTM D6079 testing method for all samples. The excel sheet was transmitted to MEG Corp when all samples had undergone testing.

Data Analysis

Below is a series of tables with the data of each of the ULSD samples' lubricity measurements in the various blends of additives and biodiesel from different feedstock. The first table is the baseline properties of the biodiesel samples. Tables 2-12 represent the five B100 samples that were blended at 1, 2 and 5% into ULSD fuel. Tables 13 and 14 represent the two B100 samples that were blended at 0.5% and 2% into ULSD fuel. Finally Table 15 represents the two B100 samples that were blended at 11% into four randomly selected ULSD samples. The tables are also organized by which PADD they came from, starting with PADD I, ending with PADD V.

Baseline Testing Data for B100 Samples				
Feed Stock	**Acid # (mg KOH/g)**	**Cloud Pt. (°F)**	**Free Glycerin (mass%)**	**Total Glycerin (mass%)**
Biodiesel 1	0.42	45.5	0.001	0.150
Biodiesel 2	0.61	56.0	0.001	0.157
Biodiesel 3	0.06	52.6	0.009	0.279
Biodiesel 4	1.45	33.5	0.002	0.157
Biodiesel 5	0.39	25.3	0.012	1.050
Biodiesel 6	0.19	34.0	0.002	0.202
Biodiesel 7	0.40	50.0	0.004	0.129

Table 1. Selected ASTM Specifications for Seven Biodiesel Samples

Location: Greensboro, NC	HFRR Average Scar (µm)			
Blend Type		**1%**	**2%**	**5%**
#1 ULSD alone	478			
Ester-based #1	277			
Monomer	234			
Ester-based #2	313			
Biodiesel 1		298	302	247
Biodiesel 2		299	247	255
Biodiesel 3		286	264	193
Biodiesel 4		266	194	172
Biodiesel 5		201	203	224

Table 2. No. 1 ULSD from PADD I, Greensboro, NC.

Location: Macon, GA	HFRR Average Scar (µm)			
Blend Type		**1%**	**2%**	**5%**
#2 ULSD alone	613			
Ester-based #1	286			
Monomer	401			
Ester-based #2	498			
Biodiesel 1		345	301	280
Biodiesel 2		349	323	313
Biodiesel 3		343	261	238
Biodiesel 4		344	272	207
Biodiesel 5		301	265	242

Table 3. No. 2 ULSD from PADD I, Macon, GA

Location: Montvale, VA	HFRR Average Scar (µm)

Blend Type		1%	2%	5%
#2 ULSD alone	565			
Ester-based #1	314			
Monomer	379			
Ester-based #2	491			
Biodiesel 1		324	302	194
Biodiesel 2		338	283	253
Biodiesel 3		357	300	232
Biodiesel 4		363	297	199
Biodiesel 5		267	189	153

Table 4. No. 2 ULSD from PADD I, Montvale, VA.

Location: Grand Forks, ND	HFRR Average Scar (μm)			
Blend Type		1%	2%	5%
#1 ULSD alone	635			
Ester-based #1	271			
Monomer	428			
Ester-based #2	591			
Biodiesel 1		423	277	261
Biodiesel 2		394	313	265
Biodiesel 3		418	341	303
Biodiesel 4		408	339	312
Biodiesel 5		271	236	160

Table 5. No. 1 ULSD from PADD II, Grand Forks, ND.

Location: Des Moines, IA	HFRR Average Scar (µm)			
Blend Type		**1%**	**2%**	**5%**
#2 ULSD alone	571			
Ester-based #1	350			
Monomer	414			
Ester-based #2	470			
Biodiesel 1		295	265	257
Biodiesel 2		304	242	215
Biodiesel 3		300	208	158
Biodiesel 4		323	298	228
Biodiesel 5		253	246	231

Table 6. No. 2 ULSD from PADD II, Des Moines, IA.

Location: Montgomery, AL	HFRR Average Scar (µm)			
Blend Type		**1%**	**2%**	**5%**
#2 ULSD alone	596			
Ester-based #1	397			
Monomer	411			
Ester-based #2	559			
Biodiesel 1		364	241	277
Biodiesel 2		360	322	228
Biodiesel 3		337	297	149
Biodiesel 4		269	202	193
Biodiesel 5		314	244	172

Table 7. No. 2 ULSD from PADD III, Montgomery, AL.

Location: Dallas, TX	HFRR Average Scar (µm)			
Blend Type				

		1%	2%	5%
#2 ULSD alone	573			
Ester-based #1	260			
Monomer	335			
Ester-based #2	509			
Biodiesel 1		325	282	243
Biodiesel 2		270	324	251
Biodiesel 3		340	284	190
Biodiesel 4		198	283	203
Biodiesel 5		302	239	233

Table 8. No. 2 ULSD from PADD III, Dallas, TX.

Location: Billings, MT	HFRR Average Scar (µm)			
Blend Type		1%	2%	5%
#2 ULSD alone	402			
Ester-based #1	378			
Monomer	327			
Ester-based #2	388			
Biodiesel 1		290	194	279
Biodiesel 2		317	281	219
Biodiesel 3		335	266	222
Biodiesel 4		286	230	205
Biodiesel 5		201	198	215

Table 9. No. 2 ULSD from PADD IV, Billings, MT.

Location: Missoula, ID	HFRR Average Scar (µm)

Addition		1%	2%	5%
#2 ULSD alone	373			
Ester-based #1	336			
Monomer	344			
Ester-based #2	376			
Biodiesel 1		303	296	240
Biodiesel 2		313	268	249
Biodiesel 3		296	261	211
Biodiesel 4		319	264	264
Biodiesel 5		273	237	249

Table 10. No. 2 ULSD from PADD IV, Missoula, ID.

Location: San Jose, CA CARB	HFRR Average Scar (µm)			
Blend Type		**1%**	**2%**	**5%**
#2 ULSD alone	677			
Ester-based #1	312			
Monomer	445			
Ester-based #2	402			
Biodiesel 1		375	353	233
Biodiesel 2		385	337	288
Biodiesel 3		349	323	196
Biodiesel 4		343	325	198
Biodiesel 5		308	282	268

Table 11. No. 2 ULSD from PADD V, San Jose, CA.

Location: Spokane, WA	HFRR Average Scar (µm)			
Addition		**1%**	**2%**	**5%**
#1 ULSD alone	374			
Ester-based #1	258			
Monomer	325			
Ester-based #2	253			
Biodiesel 1		376	319	297
Biodiesel 2		364	305	255
Biodiesel 3		371	326	287
Biodiesel 4		246	306	264
Biodiesel 5		280	312	279

Table 12. No. 1 ULSD from PADD V, Spokane, WA.

ULSD Sample Location	HFRR Average Scar (µm)	
	0.5% Biodiesel 6	**2% Biodiesel 6**
Greensboro, NC	333	244
Macon, GA	358	274
Montvale, VA	372	266
Grand Forks, ND	468	285
Des Moines, IA	349	220
Montgomery, AL	382	269
Dallas, TX	326	232
Billings, MT	341	219
Missoula, ID	345	215
San Jose, CA	362	197
Spokane, WA	313	242

Table 13. Wear Scar of Biodiesel Sample 6 Blended with all 11 ULSD samples at 0.5% and 2%.

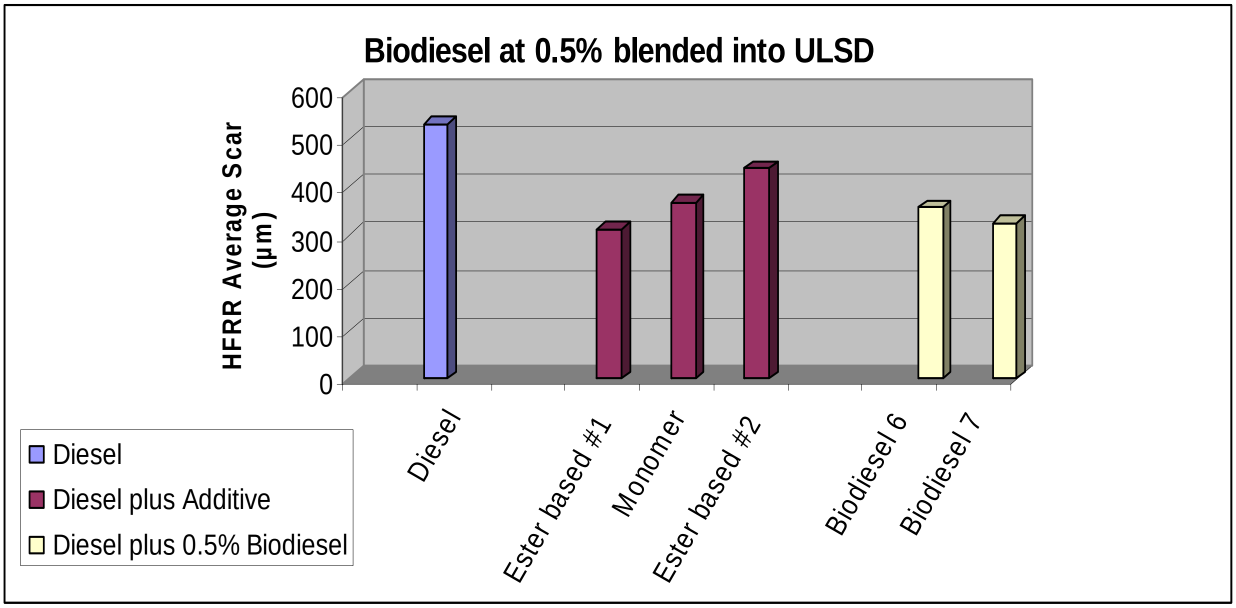
ULSD Sample Location	HFRR Average Scar (µm)	
	0.5% Biodiesel 7	2% Biodiesel 7
Greensboro, NC	292	211
Macon, GA	319	251
Montvale, VA	347	220
Grand Forks, ND	461	236
Des Moines, IA	352	197
Montgomery, AL	375	201
Dallas, TX	336	212
Billings, MT	287	204
Missoula, ID	293	196
San Jose, CA	262	207
Spokane, WA	284	217

Table 14. Wear Scar of Biodiesel Sample 7 Blended with all 11 ULSD samples at 0.5% and 2%.

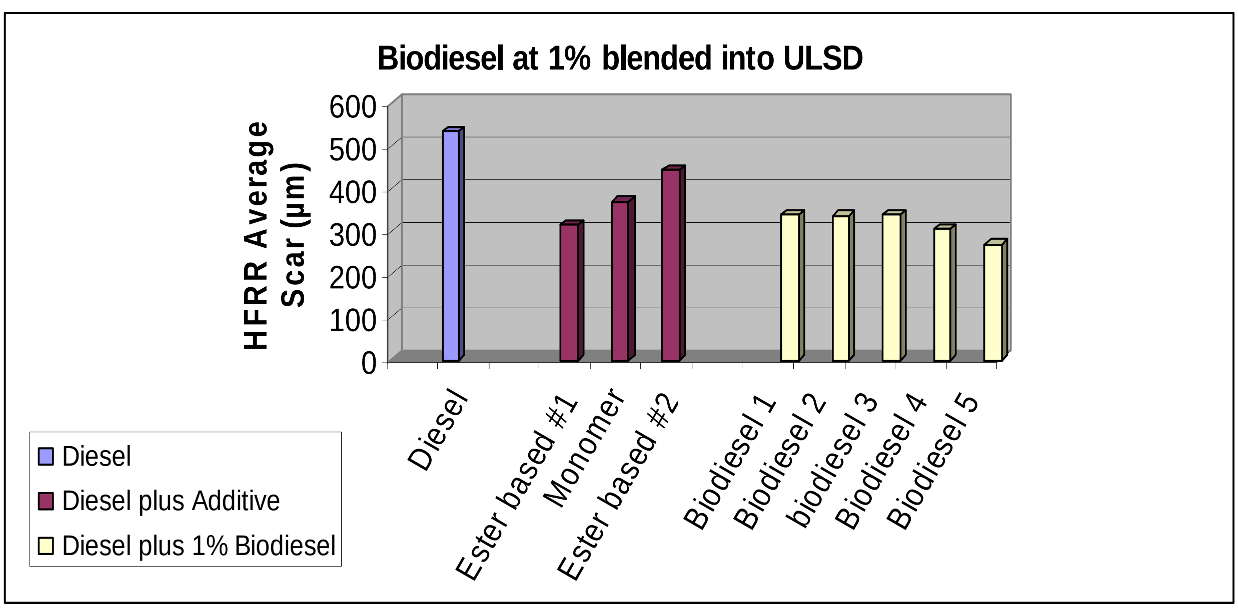
ULSD Location	HFRR Average Scar (µm)	
	Biodiesel Sample 6 11%	Biodiesel Sample 7 11%
Greensboro, NC	178	193
Montvale, VA	164	186
Grand Forks, ND	163	188
Dallas, TX	203	251

Table 15. Biodiesel Samples 6 and 7 Blended at 11% with ULSD from 4 Randomly Selected Locations

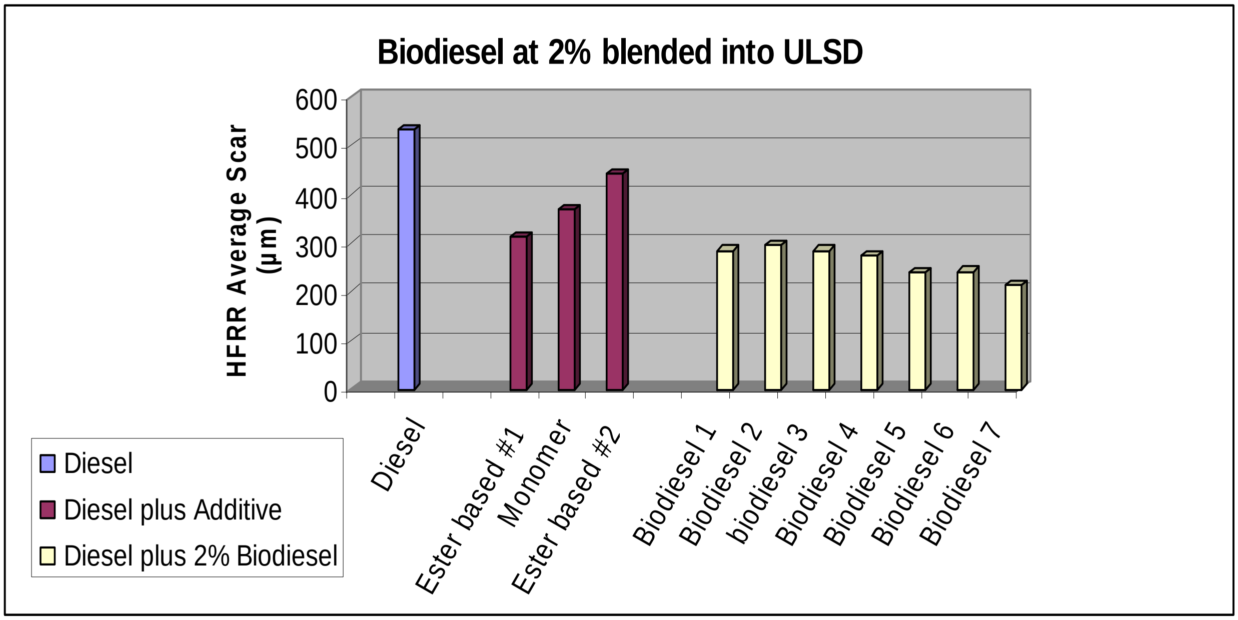
The following graphs represent the average wear scar of the 11 ULSD samples when blended with different percents of biodiesel. Each Biodiesel Sample data was averaged over all the locations to see the overall effect of that biodiesel at a certain percent blended.



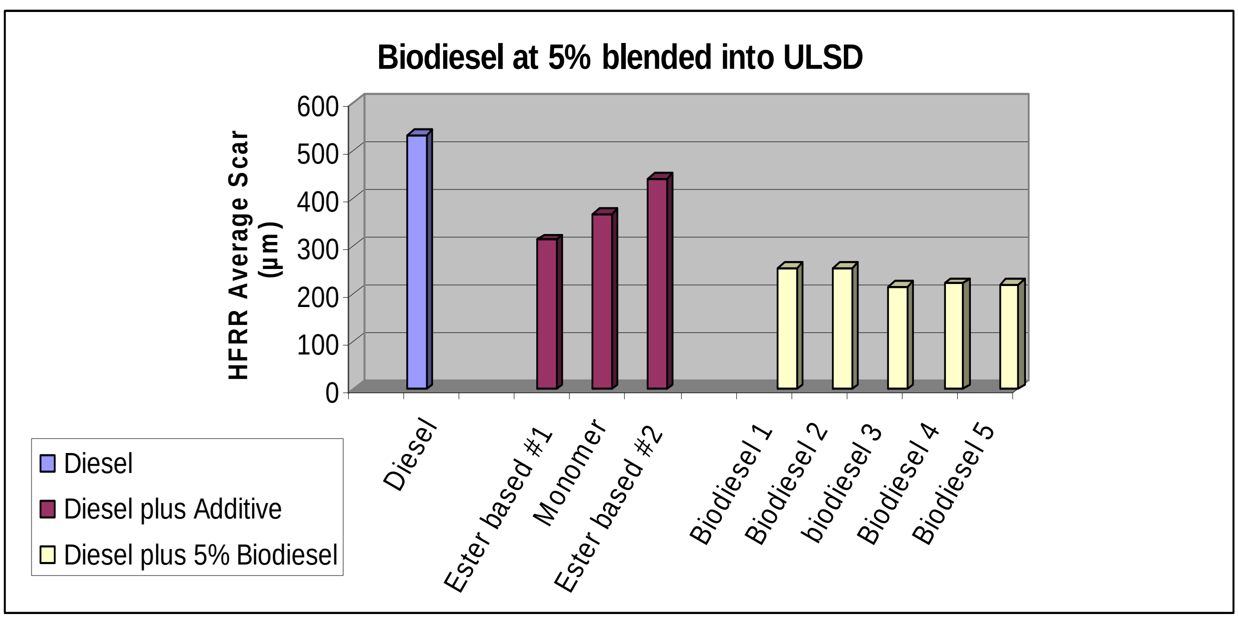
Graph 1. Average wear scar of ULSD, ULSD + additives, and ULSD + 0.5% Biodiesel



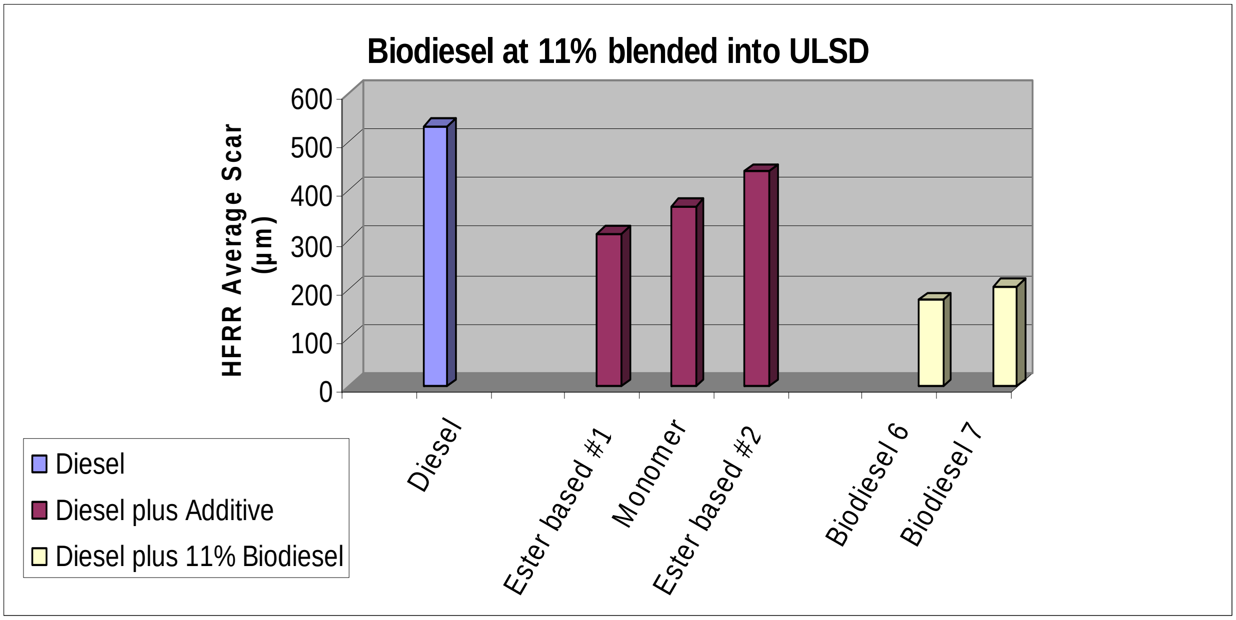
Graph 2. Average wear scar of ULSD, ULSD + additives, and ULSD + 1% Biodiesel



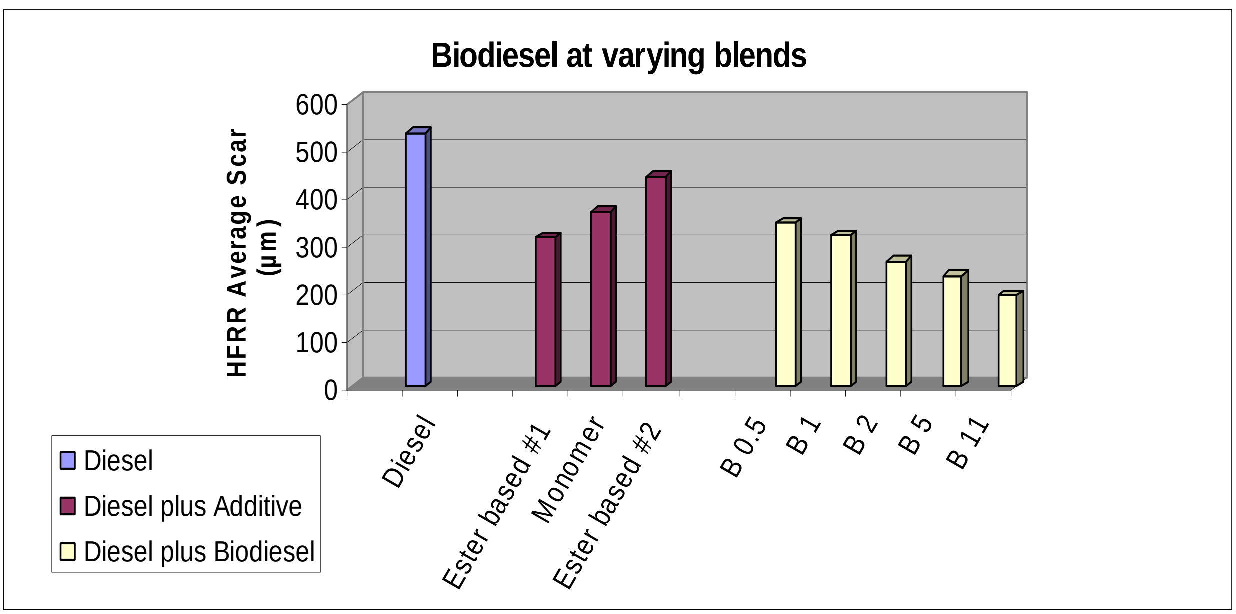
Graph 3. Average wear scar of ULSD, ULSD + additives, and ULSD + 2% Biodiesel



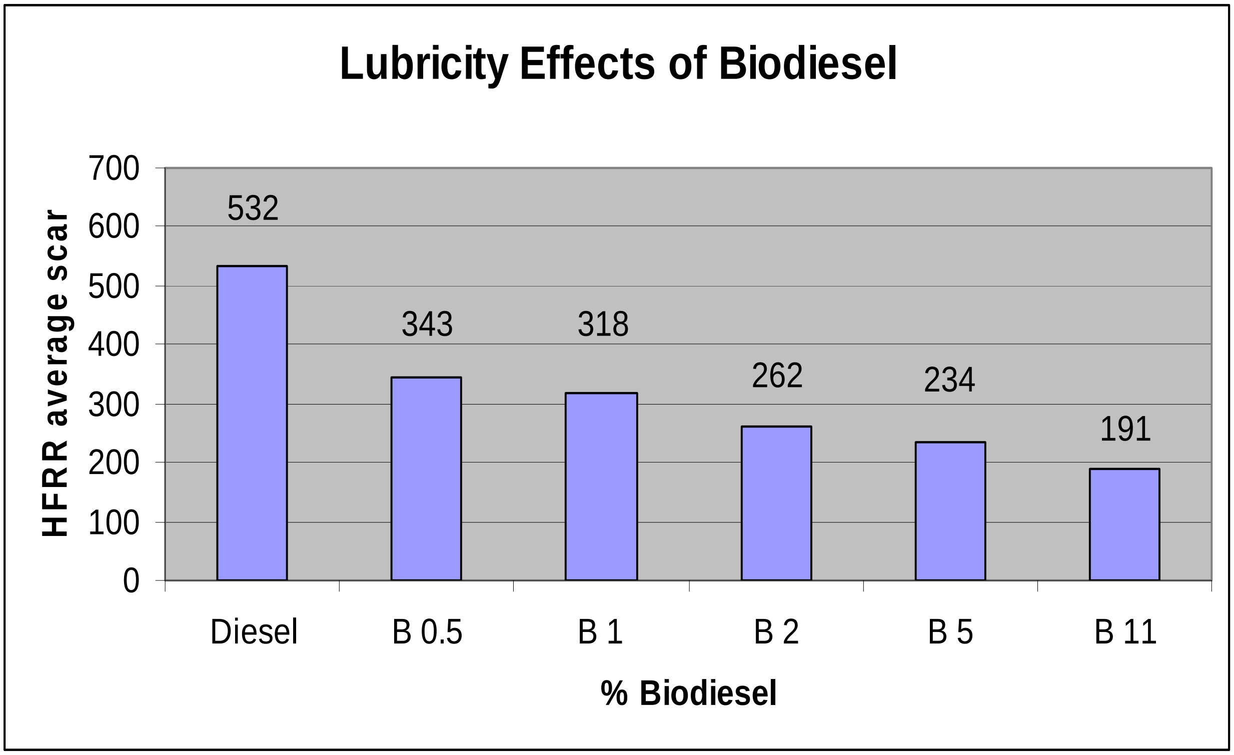
Graph 4. Average wear scar of ULSD, ULSD + additives, and ULSD + 5% Biodiesel



Graph 5. Average wear scar of ULSD, ULSD + additives, and ULSD + 11% Biodiesel



Graph 6. The average lubricity of biodiesel blends compare to lubricity additives.



Graph 7. Effects of Biodiesel on the Lubricity of Diesel fuel.

Discussion

The percent reductions in wear scar that each blend type induced in all the ULSD fuels samples were averaged (Table 16). This average percent reduction was used to compare all the blends of additives and the commercial biodiesel available at the time of this project to give an overall picture of how biodiesel blends would affect the lubricity of ULSD fuel.

Blend Type	Average Percent Reduction from ULSD alone
Ester-based #1	41%
Monomer	40%
Ester Based #2	17%
Biodiesel @ 0.5%	36%
Biodiesel @ 1%	40%
Biodiesel @ 2%	51%
Biodiesel @ 5%	56%
Biodiesel @ 11%	64%

Table 16. Average percent reduction in wear scar for all blend types.

As shown by the table above, the more biodiesel that is blended into the ULSD fuel sample, the better its lubricity becomes. It only took 2% biodiesel to reduce the lubricity to a wear scar below that of what the additives accomplished. Ester-based #1 showed the greatest scar reduction of all the additives at 41%, but all biodiesel blends at 2% and higher improved lubricity more than this additive, and biodiesel blends of 1% showed comparable lubricity. Ester-based #2 only showed a 17% reduction in average scar, proving it to be the poorest lubricity improver overall (shown in red). At 0.5% biodiesel blended the lubricity of the ULSD fuel is well below the necessary 520 maximum wear scar as defined by ASTM standards.

Conclusion

Overall, an increase in the amount of biodiesel blended into the ULSD correlated to an increase in the lubricity of the fuel. All of these bio-blends decreased the lubricity standard of the fuel to within specifications. It was shown by this study that biodiesel can not only be comparable to lubricity additives but in most cases biodiesel blends can be an improvement over the lubricity effects of commercial additives. This was true with both in-specification and out of specification biodiesel, as several of the commercial biodiesel samples analyzed for this project did not meet D6751 specifications. Using biodiesel in place of lubricity additives could be a cost-effective and environmentally responsible way to achieve excellent lubricity in ULSD fuels. Biodiesel is also a way to support our internal fuel economy, as well as the agricultural community responsible for producing bio-fuels.

References

1) National Biodiesel Board website, "Fuel Fact Sheets". Accessed June 27, 2007. http://www.biodiesel.org/pdf_files/fuelfactsheets/Lubricity.PDF

2) 2 "Fuel Lubricity Reviewed", Paul Lacey, Southwest Research Institute, Steve Howell, MARC-IV Consulting, Inc., SAE paper number 982567, International Fall Fuels and Lubricants Meeting and Exposition, October 19-22, 1998, San Francisco, California.

3) "Fuels for Diesel Engines—Diesel Fuel Injection Equipment Manufacturers Common Position Statement", Signed by Delphi Diesel Systems, Stanadyne Automotive Corp., Denso Corporation, and Robert Bosch GmbH, issued June, 2000.

4) Magellan Midstream Partners' Laboratory Services group specializes in providing personalized customer focused programs. They possess extensive experience in the inspection and testing of refined petroleum products, supporting customers utilizing our transportation and terminal system since 1938. Laboratory are locationed in Texas and Kansas

5) PCS Instruments. http://www.pcs-instruments.com.

Appendix

Baseline Testing Data for ULSD Samples								
Sample Description	**API Gravity (°)**	**10% Rec. Point (°F)**	**50% Rec. Point (°F)**	**90% Rec. Point (°F)**	**Cloud Point (°F)**	**Sulfur (ppm)**	**Cetane Index**	**Lubricity (µm)***
#2 ULSD Montana	35.7	400	494	599	-5	6	46.1	402
#2 ULSD Texas	33.2	438	529	627	8	6	46.2	573
#1 ULSD N. Carolina	35.3	424	508	604	8	6	47.2	478
#2 ULSD Alabama	36.0	416	506	608	9	6	48.1	596
#1 ULSD N. Dakota	39.5	380	435	525	-42	4	43.0	635
#2 ULSD Iowa	34.7	422	518	626	13	8	47.4	571
#2 ULSD California	38.2	387	477	609	10	3	47.9	677
#2 ULSD Idaho	36.0	414	507	614	5	4	48.3	373
#1 ULSD Washington	43.0	355	379	437	-71	45	36.8	374
#2 ULSD Georgia	36.6	406	494	599	6	7	47.6	613
#2 ULSD Virginia	35.2	427	514	614	8	5	47.8	565