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Properties of Biodiesel/Diesel Blends Using Biodiesels From Multiple Feedstocks

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SUMMARY

In a project sponsored by the National Renewable Energy Laboratory, the Institute of Gas Technology is conducting an investigation of biodiesels produced from vegetable- and animal-based feedstocks.

Due to its cost, biodiesel is mixed with diesel to bring much of the beneficial characteristics to diesel equipment, while reducing the overall cost of the fuel. Because biodiesel is usually blended, the primary objective of this study was to determine the characteristics of biodiesels from different feedstocks in varying concentrations with diesel when tested on a consistent basis. Consistent basis in this context is mixtures with the same diesel and tested at one laboratory in a controlled study. It focused on biodiesel/diesel blends, because the basic properties obtained in the testing of pure biodiesel do not necessarily indicate what will happen when mixed with diesel fuel. It was expected that some properties vary in a non-intuitive manner, e.g., not varying linearly with respect to blend fraction.

The results collected add data to concentration ranges that have previously been overlooked in the study of the potential of biodiesel blends. It also adds information concerning feedstocks that have been considered only superficially.

The properties tested were those that would most affect operation of diesels, and consisted of: viscosity, pour point, cloud point, cold filter plugging point, Cetane number, and scuffing load BOCLE. Cetane number did not exhibit any unusual characteristics, with essentially linear variation with respect to blend fraction.

Of particular interest for people considering use of biodiesels in other than B20 or pure applications is the shifts in temperature for various properties tested. The biodiesel blends exhibited a viscosity depression at low concentrations. Conversely, most biodiesels significantly increased pour point, cloud point, and cold filter plugging point at low concentrations (<10-20%), then proceeded more linearly above that. Care should be taken in handling and use due to the temperature increases that occurred for pour point, cloud point, and cold filter plugging point.

The effect on lubricity cited by advocates of biodiesel was verified by the test results. Significant lubricity increases occurs with concentrations at 3% or less of the biodiesels, seeming to confirm the concept that biodiesel additives can improve operation of diesels and extend life of their components. It is fortunate that these concentrations avoid the ranges where temperature increases occur. In particular, further study may be warranted to improve the processing of the beef tallow and pork lard, with a goal of reducing cost while enhancing the characteristics of the methyl esters that improve lubricity.

INTRODUCTION

In a project sponsored by the National Renewable Energy Laboratory, the Institute of Gas Technology is conducting an investigation of biodiesel fuels produced from various vegetable- and animal-based feedstocks. Due to the varying nature of the feedstocks and the processes for converting them into suitable biodiesel fuel (methyl esters), an important part of the study has been the laboratory testing of the properties to determine the characteristics of each fuel.

The basic properties obtained in the testing of pure biodiesel have been documented in the section on the production and properties testing of the biodiesels. However, the basic properties do not necessarily indicate what will happen as a result of mixing it with diesel fuel. Due to the cost, biodiesel usually is mixed with diesel (instead of used straight) to bring much of the beneficial characteristics to diesel equipment, while reducing the overall cost of the fuel. Because of the different compositions and basic differences with diesel, some properties may vary in a non-intuitive manner, e.g., not varying linearly with respect to blend fraction. This section documents the results of the testing of the multi-feedstock biodiesels with diesel at varying compositions.

METHODOLOGY

For this portion of the project, the fuels to be tested were all the fuels produced for this program: the soy methyl ester, canola methyl ester, pork lard methyl ester, edible and inedible beef tallow methyl esters, low free fatty acid (<4%) yellow grease methyl ester, and high free fatty acid (10%) yellow grease methyl ester.

In the first step of this effort, IGT identified a suitable diesel fuel for use as a reference and as the base for mixing with the biodiesels. The reference fuel for this test program was certification diesel fuel obtained from Phillips Petroleum (Lot D434). It is the low-sulfur diesel currently used for testing engine emissions, and as such, is known in terms of its quality and characteristics. Use of the fuel also permits others to acquire the same fuel for testing they may conduct and wish to compare with the results obtained in this project. The properties of this fuel are shown in Table 1.

Table 1. Certification Diesel Fuel Lot D-434 Properties

Property	Lot D-434	ASTM Method
API Gravity	36.28	D-287
Viscosity, cS 40°C	2.5	D-445
Net Heating Value, BTU/lb	18456	D-3338
Cetane Number	46.0	D-613
Carbon, wt%	86.6	D-5291
Hydrogen, wt%	13.4	D-5291
Oxygen, wt%	0	D-5291
Sulfur, ppm	300	D-2622
Nitrogen, ppm	--	D-4629
IBP, F	353.9	D-86
T50, F	498.7	D-86
T90, F	583.7	D-86
EP, F	646.4	D-86
Aromatics, vol%	29.2	D-1319
Olefins, vol%	2.0	D-1319
Saturates, vol%	68.8	D-1319

The second step was the identification of the tests to be conducted. The tests that were selected for the blended fuels were the ones that were expected to vary in a non-intuitive fashion, or that may not be proportional with respect to blend rates.

They also are the tests that have the most direct correlation to the handling and use with diesel engines. The tests are shown in Table 2.

The third step was the identification of the fuel blends to be used. The specific fuel blends were selected to complement the tests that had been conducted on the pure biodiesels.

They also took into account the range of low-concentration biodiesel blends (in the range of diesel fuel additives) that advocates of biodiesel advocates emphasize are beneficial, and that there was little possibility for unusual changes in properties once the biodiesel became the dominant component. The fractions of biodiesel that were tested were: 0.25%, 0.50%, 1%, 3%, 5%, 10%, 20%, 35%, and 50%. In addition, the pure diesel fuel was tested to establish the 0% biodiesel point.

Table 2. Physical and Chemical Tests of Biodiesel Blends

Property	ASTM Method	Importance
Viscosity, mm2/s @ 40°C	D 445	Fuel flow resistance; higher viscosity associated with poorer fuel atomization from injectors and increased engine deposits; also impacts energy requirements and wear of fuel pump and injectors;
Pour Point, °C	D 97	Minimum temperature above which fuel can be poured, i.e., is still a liquid and can be pumped; affecting use in cold climates
Cloud Point, °C	D 2500	Temperature at which fuel begins to cloud (i.e., increases in turbidity), indicating wax is beginning to form (potential for plugging)
Cold Filter Plugging Point, °C	D 4539/ IP 309	Temperature at which fuel will plug a fuel filter
Cetane number	D 613	Measure of ignition delay of a compression ignition fuel; higher values indicate shorter ignition lags, less deposits, lower starting temperatures, reduced engine roughness
Lubricity	D 6078	Measure of the lubricating quality of the fuel; higher values indicate better lubrication
Accelerated Storage Stability	D 2274	Measure of change in fuel oil quality; indicator of"shelf life" of fuel

The fourth step included performing the tests. The test methods used were those listed above. The D 6078 (Scuffing Load Ball On Cylinder Lubricity Evaluator) tests were conducted by Engineering Test Services, and the other tests were conducted by Williams Lab Services.

IGT concluded this study with an analysis of the test results for each of the properties under consideration.

TEST RESULTS

The following tables display the results of the testing on the various biodiesel / diesel blends. The 0% biodiesel concentration is the test result of the pure diesel fuel, and the 100% biodiesel concentration has been carried from the section of the pure biodiesel test results. Tabie 3 contains the results of the viscosity testing, while Table 4 shows the results from the pour point testing.

Table 3. Biodiesel Blend Viscosity Test Results

Biodiesel Concentration	SME	CME	LME	ETME	ITME	LYGME	HYGME
0%	2.453	2.453	2.453	2.453	2.453	2.453	2.453
0.25%	2.505	2.461	2.453	2.453	2.453	2.453	2.453
0.50%	2.453	2.453	2.453	2.453	2.453	2.476	2.461
1 %	2.461	2.461	2.468	2.468	2.476	2.468	2.490
3%	2.392	2.400	2.400	2.487	2.409	2.418	2.400
5%	2.418	2.418	2.444	2.435	2.444	2.452	2.435
10%	2.461	2.496	2.522	2.513	2.522	2.556	2.513
20%	2.966	2.859	2.859	2.894	2.930	3.011	2.876
35%	3.038	3.620	3.145	3.208	3.262	3.387	3.172
50%	2.715	3.396	3.459	3.531	3.593	3.826	3.495
100%	4.546	4.63	4.85	4.908	4.93	5.62	4.66

Table 4. Biodiesel Blend Pour Point Test Results, °C

Biodiesel Concentration	SME	CME	LME	ETME	ITME	LYGME	HYGME
0%	-27	-27	-27	-27	-27	-27	-27
0.25%	-27	-21	-24	-24	-24	-24	-24
0.50%	-27	-24	-24	-24	-24	-24	-24
1 %	-24	-24	-24	-21	-24	-24	-24
3%	-24	-24	-21	-21	-21	-21	-21
5%	-21	-21	-18	-18	-15	-18	-18
10%	-18	-21	-15	-12	-12	-18	-18
20%	-18	-18	9	9	9	9	-12
35%	15	-18	0	-6	-3	-6	-6
50%	9	-15	3	3	3	0	-3
100%	-4	-4	13	16	15	6	

Table 5 contains the results of the cloud point testing of the biodiesel blends, and Table 6 holds the testing results for cold filter plugging point.

Table 5. Biodiesel Blend Cloud Point Test Results' °C

Biodiesel Concentration	SM E	CME	LME	ETME	ITM E	LYGME	HYGME
0%	-18	-18	-18	-18	-18	-18	-18
0.25%	-20	-18	-18	-16	-16	-15	-18
0.50%	-17	-18	-17	-16	-17	-14	-15
1%	-16	-18	-17	-15	-17	-16	-15
3%	-16	-17	-16	-13	-14	-16	-15 5
%	-16	-17	-15	-12	-13	-16	-14
10%	-15	-17	-14	9	-10	-13	-13
20%	-14	-15	-3	-2	-6	-6	-8
35%	9	-12	-3	0	0	5	-6
50%	9	-10	-2	3	4	13	-3
100%	3	-3	13	19	16	24	8

Table 6. Biodiesel Blend Cold Filter Plugging Point Test Results, °C

Biodiesel Concentration	SM E	CM E	LME	ETME	ITM E	LYGME	HYGME
0%	-20	-20	-20	-20	-20	-20	-20
0. 25%	-20	-20	-20	-20	-21	-20	-20
0. 50%	-20	-20	-20	-20	-20	-20	-21
1%	-21	~-20	-20	-20	-20	-19	-20
3%	-19	-18	-19	-19	-21	-18	-20
5%	-19	-18	-18	-17	-18	-17	-19
10%	-18	-18	-17	-14	-15	-14	-18
20%	-1 7	-1 8	-8	-3	-11	-1	-1 4
35%	-17	-17	4	5	-6	7	-12
50%	-17	-16	6	6	-1	9	-6
100%	-2	4	1 1	1 4	1 0	1 1	1

Table 7 contains the results of the Cetane number testing of the biodiesel blends, and Table 8 holds the results for scuffing load BOCLE lubricity testing. The high and low reference results are those required to verify the accuracy of the SLBOCLE test.

Table 7. Biodiesel Blend Cetane Number Test Results

Biodiesel Concentration	SM E	CME	LME	ETME	ITM E	LYGME	HYGME
0%	47	47	47	47	47	47	47
0.25%	47.2	47.1	47	47	47.1	46.8	47.1
0.50%	47.1	46.9	47	47.1	47.1	47.1	47
1 %	47.2	47.3	47.3	47.1	47.3	47.2	47.2
3%	47.3	47.2	47.4	46.9	47.5	47.3	47.2
5%	47.4	47.6	47.4	47.3	48	47.5	47.7
10%	47.7	47.9	48	47.7	48.4	47.6	47.8
20%	4g.2	48.8	47.9	48.4	49.8	48.7	49.3
35%	50.4	49.6	50	49.2	50.9	- 50	51.4
50%	51.4	50.6	51.2	49.8	51.9	50.8	51.6
100%	59	53.9	64.8	54.3	52.2	53.2	

Table 8. Biodiesel Blend Scuffing Load BOCLE Test Results

Methyl Ester Concentration	Soy	Canola	Inedible Tallow	Edible Tallow	Lard	Low FFA Yellow Grease	High FFA Yellow Grease
0%	3600	3600	3600	3600	3600	3600	3600
0.25%	4700	4600	4050	3800	4400	4700	4650
0.50%	4950	4750	4700	4300	4700	5100	4850
1 %	5600	4950	5550	4900	5500	5500	5450
3%	5600	5300	5850	5950	6150	6050	5650
5%	5400	5950	6550	6100	6500	6550	5800
10%	6100	6550	>7000	6350	6700	6650	6150
20%	6150	>7000	>7000	6400	>7000	>7000	>7000
35%	5850	>7000	>7000	6500	>7000	>7000	>7000
50%	6000	>7000	>7000	>7000	>7000	>7000	>7000
100%	6050	>7000	>7000	>7000	>7000	>7000	>7000
High Reference Cat 1K	5950	6200	6250	6250	6000	6000	6100
Low Reference Isopar M	1900	2200	2000	2000	2100	1900	2050

ANALYSIS

The following charts display the test results contained in the tables above. Figure 1 shows the results of the viscosity tests for each of the biodiesel blends. Viscosity affects fuel atomization by the injectors, engine deposits (increased viscosities associated with increased deposits), and energy use (higher viscosities require more energy by the fuel pump). At low concentrations (<10%), there

appears to be a moderate level of viscosity reduction between 1% and 5%, returning back to a blend fraction-dependent mix of the two fuels' viscosity by the 10% level. The maximum amount of reduction occurs with the soy methyl ester at 3%, with a total reduction of approximately 2.5%. The fact that this occurs with each of the biodiesels indicates that it is a general artifact, independent of any particular feedstock-derived characteristic.

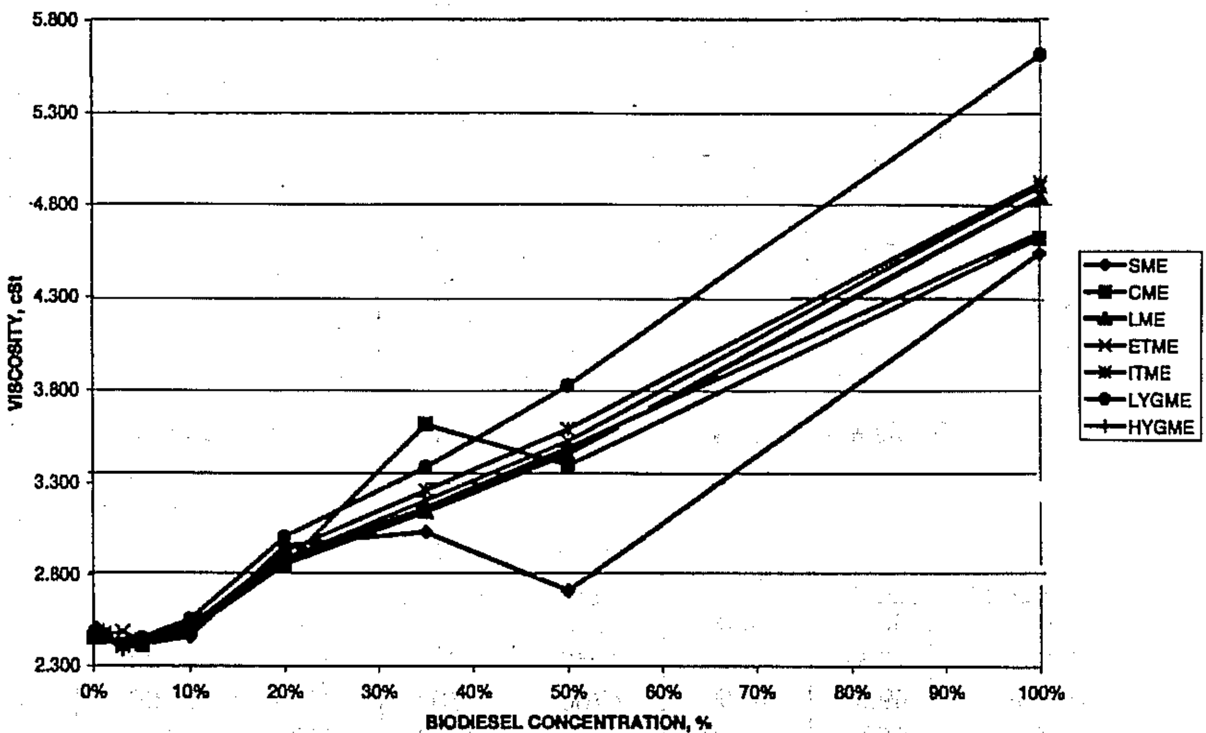

Figure 1. Biodiesel/Diesel Blend Viscosity Test Results

Figure 2 shows the test results for pour point. Pour point, the temperature above which the fuel will pour, is important because it directly affects the usability of the fuel in colder climates. The high pour points of many of the biodiesels significantly limit their use in the pure form in cold weather. Even though the blends show much better pour point temperatures at lower concentrations, the handling of the pure biodiesels before mixing will require insulation and heating of the tanks to ensure that the liquid can be moved prior to mixing. It also affects the way in which mixing occurs, so that an adequate temperature of the biodiesel is maintained until thorough blending can occur. Unlike the viscosity results, the pour point results demonstrate a fairly rapid rise in pour point up to a 10% concentration, at which time the trend is more linear with respect to blend fraction. This indicates that the presence of biodiesel, even at the low concentrations when used as a diesel additive, will increase the pour point of the blend by approximately 5°C.

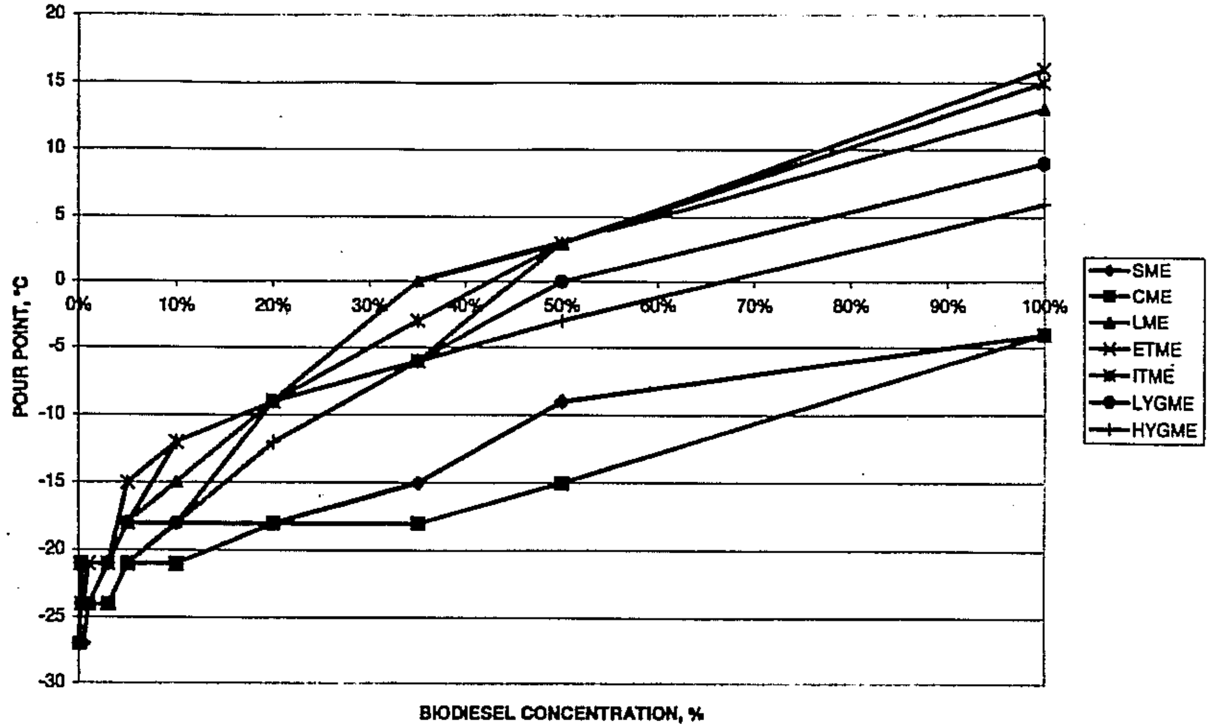

Figure 2. Biodiesel/Diesel Blend Pour Point Test Results

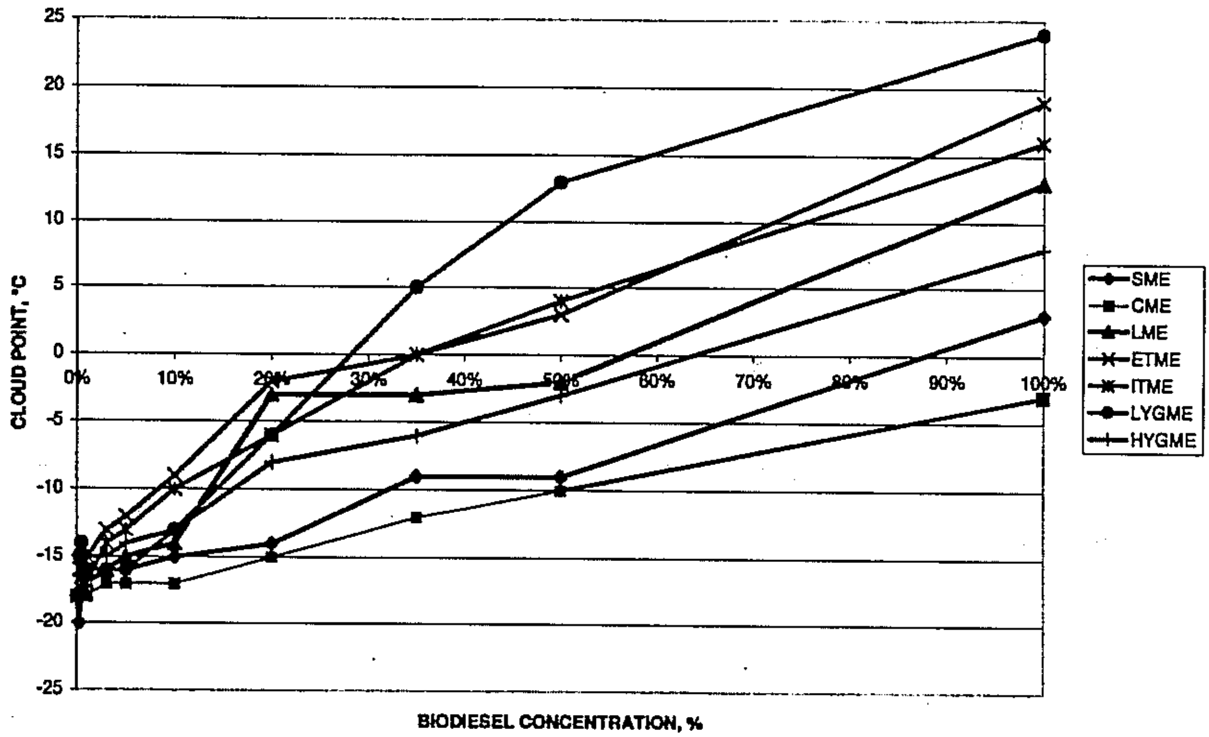

Figure 3. Biodiesel/Diesel Blend Cloud Point Test Results

Figure 3 shows the results of the cloud point testing. The cloud point is an important measure because it is the temperature at which components of the fuel begin to crystallize, forming a visible clouding of the liquid. When circulating in the fuel system, the components that produce the clouding

can be captured in filters, or cause components to wear due to the solidification of the lubricants. The cloud point exhibits a larger increase at low concentrations of biodiesel, but to a lesser extent than the pour point tests. In general, avoiding complications due to this effect will require measures similar to those for addressing the high pour point.

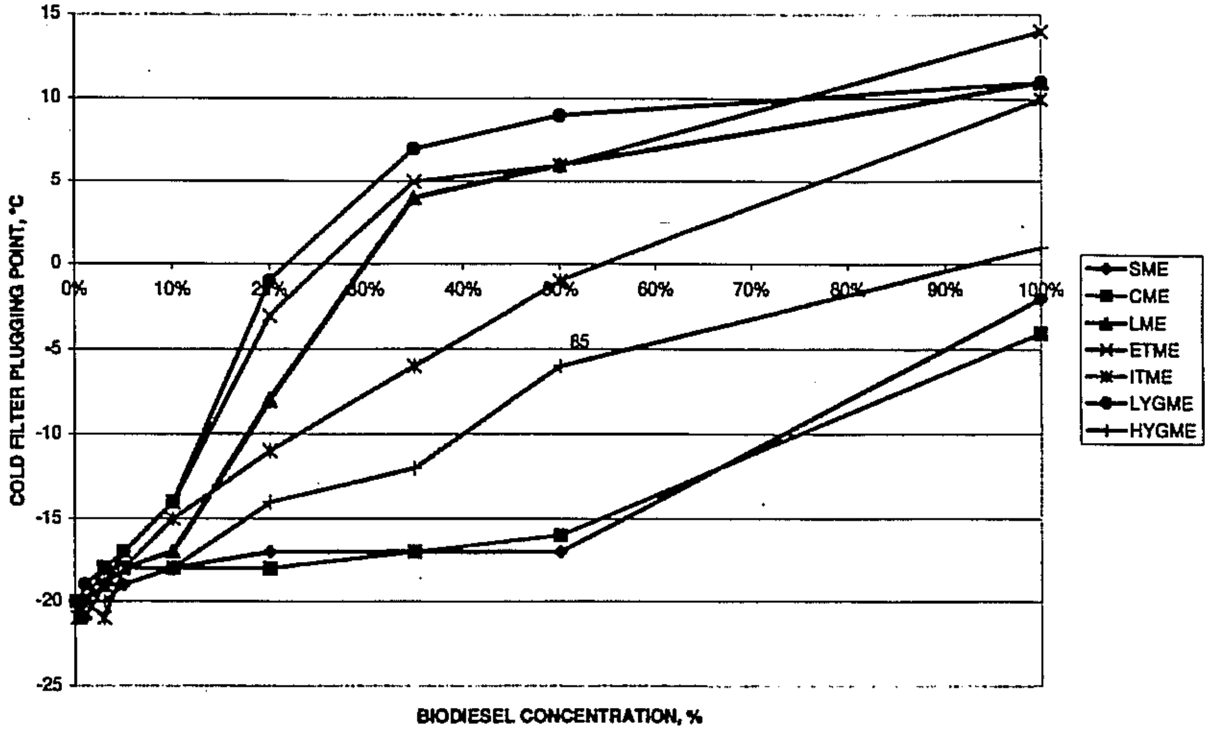

Figure 4. Biodiesel/Diesel Blend Cold Filter Plugging Point Test Results

Figure 4 shows the results of the cold filter plugging point testing. It measures the temperature at which it would be expected that a cold filter would be plugged when attempting to handle the fuel. The relationship between increase in temperature and biodiesel fraction is more linear than in the pour point or cloud point results for most of the biodiesels at the lower concentrations. However, the pork lard, edible beef tallow, and low free fatty acid yellow grease methyl esters exhibited higher than expected increases in the 20% to 50% concentration range. Since these also had the highest cold filter plugging point measurements as pure biodiesel, it appears that this characteristic is dominant until low biodiesel concentrations are reached. Conversely, the soy and canola methyl esters show a temperature depression through the same concentration range (20-50%) that the others displayed an increase. These blends were close to the pure diesel temperature (within 5°C) through 50%. The biodiesels significantly varied in their impact on cold filter plugging point, where three inflated, two depressed, and two had a linear effect on cold filter plugging point with respect to concentration. Since the two sets of biodiesels from similar sources showed differing actions (tallow and yellow grease biodiesels), it is not likely to be feedstock dependent. It is possible that processing differences caused this effect, especially since the treatment of the high free fatty acid yellow grease was handled in two steps, unlike the others.

Figure 5 shows the results of the Cetane number testing. Higher Cetane numbers indicate higher ignition rates, which tend to reduce carbon and lacquer formation and engine deposits, and decrease engine roughness. It appears to be linear with respect to biodiesel concentration, except for the outlying points for the soy and edible tallow methyl esters.

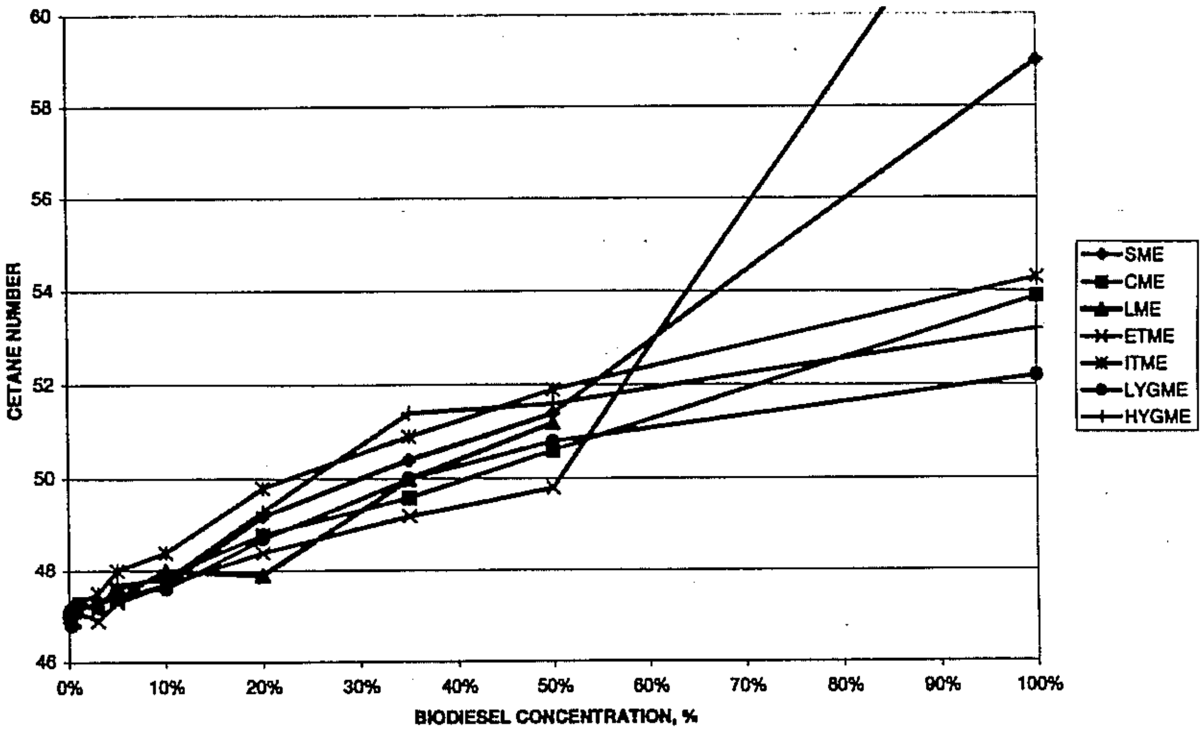

Figure 5. Biodiesel/Diesel Blend Cetane Number Test Results

Figure 6 shows the results of the scuffing load BOCLE tests. Although the chart indicates that the blends stopped at 7000 grams, they were in fact higher. Due to limitations, testing was stopped at 7000 grams. The reference line of 3100 grams indicates the minimum acceptable level for EMA specification of diesel. The test on the reference fuel from Philips was at 3600 grams. The dramatic increase in lubricity is the primary reason that advocates recommend the use of biodiesel as an additive, if not used as a substantial fraction of the fuel, e.g., as B20. In general, the lubricity improved by 10% on average with just 0.25% biodiesel present, and by 30%+ at 0.5%. Most of the blends had reached 50% improvement with 1% biodiesel, and all exceeded 50% at 3%. The first blend to reach the maximum value was the edible beef tallow at 10%, followed by the pork lard, canola, and both yellow grease methyl

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[1] Dunn, R. O., Shockley, M. W., and Bagby, M. O. "Improving the Low-Temperature Properties of Alternative Diesel Fuels: VegetableOil-Derived Methyl Esters." Journal of Amer. Oil Chem. Soc., 73 (1996): 1719-1728.

[2]Midwest Biofuels Inc. Biodiesel Pour Point and Cold Flow Study. Report to National Soydiesel Development Board, September 30, 1993, St. Louis, MO.

esters at 20%. Although the soy methyl ester also increased the lubricity of the diesel by over two-thirds, it did not reach the maximum test value that the others encountered. If the biodiesels derived from tallow, lard, or yellow grease can be produced at a cost lower than the soy or canola biodiesels, while retaining their impact on lubricity, they could favorably impact the biodiesel additive market.

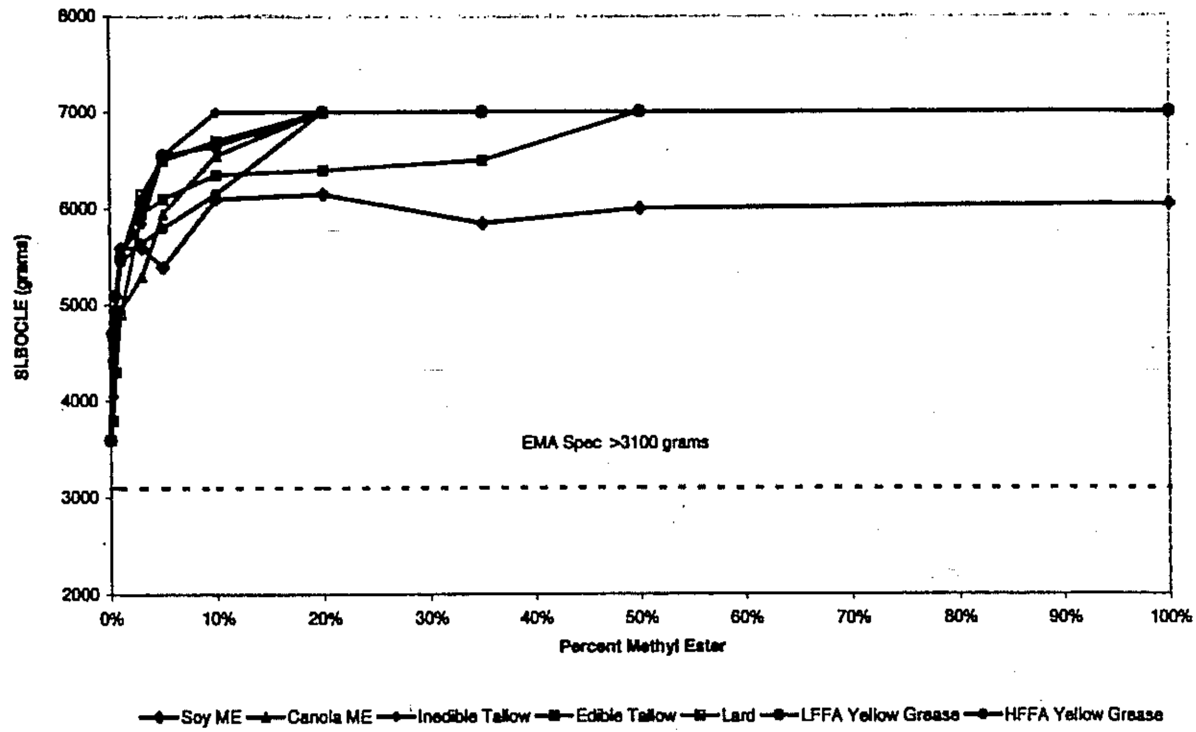

Figure 6. Biodiesel/Diesel Blend SLBOCLE Test Results

CONCLUSIONS

The primary objective of this study was to determine if biodiesels from different feedstocks exhibit different characteristics in varying concentrations with diesel when tested on a consistent basis. Consistent basis in this context is mixtures with the same diesel and tested at one laboratory in a controlled study.

The results collected add data to concentration ranges that have previously been overlooked in the study of the potential of biodiesel blends. It also adds information concerning feedstocks that have been considered only superficially.

Of particular interest for people considering use of biodiesels in other than B20 or pure applications is the shifts in temperature for various properties tested. Care should be taken in handling and use due to the temperature increases that occurred for pour point, cloud point, and cold filter plugging point. In terms of lubricity, the significant increase that occurs with even concentrations at 3% or less of the biodiesels seems to confirm the concept that biodiesel additives can improve operation of diesels and extend life of their components. It is fortunate that these concentrations avoid the ranges where temperature increases occur. In particular, further study may be warranted to improve the processing of the beef tallow and pork lard, with a goal of reducing cost while enhancing the characteristics of the methyl esters that improve lubricity.