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INVESTIGATION OF SOLUBILITY OF VARIOUS COMPONENTS IN RENEWABLE DIESEL

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1 CONCOURSE PARKWAY • SUITE 800 • ATLANTA, GA 30328

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CRC Project DP-05-22

Investigation of Solubility of Various Components in Renewable Diesel

Gina M. Fioroni, Jennifer Cavaleri, and Robert L. McCormick

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Executive Summary

Renewable diesel (RD) is a biofuel made by hydroprocessing of fats, oils, and greases to create a mixture that is primarily comprised of C15 to C18 normal and isoalkanes, with very limited aromatics. While made from the same feedstocks as biodiesel, RD contains no oxygen and can be isomerized to different extents to create fuels having a range of cloud point. RD is used as a drop-in replacement for petroleum-derived ultra-low sulfur diesel (ULSD) as it can meet the ASTM D975 specification (typically No. 2 grade). The composition of RD can affect its miscibility with other fuels, such as biodiesel (or polar impurities in biodiesel) or polar fuel additives. The objective of Phase I of this study is to provide an assessment of these solubility impacts by testing RD and B100 with a range of cloud points, and B100 to have a range of cold soak filtration times. Blends containing 5%, 20% and 50% biodiesel in two base RD fuels are evaluated utilizing the following ASTM test methods described in more detail below: ASTM D86, ASTM D5773, ASTM D5949, ASTM D8148, ASTM D4176, ASTM D7371, and a modified ASTM D6584.

The property requirements of ASTM D975 No. 2 grade (RD and ULSD), and ASTM D6751 (B100) were utilized to characterize the base fuels to ensure all fuels met the applicable ASTM requirements. Twenty-three blends were prepared from these base fuels and evaluated for cloud point (D5773), pour point (D5949), and distillation curve (D86). Separate samples were then soaked at three different soak temperatures for a period of 24 hours and observed for the presence of precipitates. This was accomplished by measuring the Instrument Haze Rating (IHR) by ASTM D8148 Standard Test Method for Spectroscopic Determination of Haze in Fuels and by D4176 Water Particulate and Phase Separation by Visual Inspection. Samples were then evaluated a second time after standing at room temperature for 24 hours. Additionally, a sample solution was taken immediately after the soak period from both the top and the bottom of the tube and analyzed by ASTM D7371 (FTIR analysis) to evaluate whether there was any settling of the FAME in the RD or ULSD. Precipitate was isolated from samples containing enough for gas chromatography (GC) analysis. A modified ASTM D6584 utilizing a GC with dual FID and MS for simultaneous quantification and identification was used for analysis. The method is further modified to allow for the analysis of steryl glucosides, a common polar impurity in biodiesel.

All base fuels met the applicable ASTM standards. One biodiesel was purposely selected to have a high Cold Soak Filterability Test (CSFT) to evaluate its effect on component solubility in RD compared to ULSD. Blend samples were analyzed for cloud point and pour point and results were as expected. For D86, blends in ULSD had a broader boiling point curve compared to blends prepared in RD. Overall, blends containing less biodiesel had a lower boiling point distribution, with the ULSD blends having a higher final boiling point. It should also be noted that the scope of D86 distillation includes blends up to 20% biodiesel. Blends containing higher levels of biodiesel were measured and data was provided solely for comparison. Instrument Haze Rating readings were completed immediately after cold soaking and after 24 hours of standing at room temperature. In several instances, the Haze Index reading was lower after the sample had been sitting at room temperature indicating that some precipitate dissolved back into solution after warming. In those cases, the sample was visibly less hazy after warming to room temperature over the 24-hour period. There were a total of 17 samples that contained precipitate in sufficient amounts to attempt isolation. Samples made with B100 40348 had the most instances of precipitate formed in the blends. B100 40348, which had a CSFT near the threshold (200 seconds for 1B grade) shows a higher propensity to form precipitates in blends with RD. Additionally, even B100 40349 (high Cloud Point sample), the sample within acceptable CSFT range also shows evidence of precipitate formation in blends with both RD and ULSD. The formation of precipitates was most heavily influenced by the B100 used for blending rather than the base hydrocarbon fuel used as precipitates were noted in both RD and ULSD samples. Precipitate analysis showed that monopalmitin and monostearin were the main components contained in precipitates from B100 40349 blends. There were small amounts of other monoglycerides present, as well as minimal amounts of steryl glucosides. On the contrary, precipitate analysis from B100 40348 blends showed that there were larger amounts of steryl glucosides present when compared to those from 40349.

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Introduction

Renewable diesel (RD) is a biofuel made by hydroprocessing of fats, oils, and greases to create a mixture that is primarily comprised of C15 to C18 normal and isoalkanes, with very limited aromatics. (*1*) While made from the same feedstocks as biodiesel (fatty acid methyl esters or FAME), RD contains no oxygen and can be isomerized to different extents to create fuels having a range of cloud point. RD is used as a drop-in replacement for petroleum-derived ultra-low sulfur diesel (ULSD) as it can meet the ASTM D975 specification (typically No. 2 grade). The composition of RD can affect its miscibility with other fuels, such as biodiesel (or polar impurities in biodiesel) or polar fuel additives.

The cloud point of biodiesel is predominantly related to the degree of unsaturation (double bonds) in the fatty acid chains and hence varies with feedstock. (*2*) More saturated biodiesel made from, for example, tallow or palm oil has a much higher cloud point than more unsaturated biodiesel such as that made from soy or canola oils. In blends with ULSD, polar impurities in biodiesel such as steryl glucosides (*3*,*4*) and saturated monoglycerides (*5*,*6*,*7*) can, in some cases, cause precipitate formation and low-temperature operability problems (e.g fuel filter clogging, filter pressure rise, and injector fouling risks) above cloud point. Based on all-weather heavy-duty chassis dynamometer studies conducted by CRC, a cold soak filtration test was added to the biodiesel (B100) standard ASTM D6751. (*8*,*9*) In this test (ASTM D7501), biodiesel (B100) is stored at 4.5°C for 16 h, allowed to warm to 25°C, and then vacuum filtered under well-defined conditions while the time to filter is recorded. This test limited the amounts of polar materials that could precipitate above the cloud point. A similar test known as cold soak filter blocking tendency (CAN/CGSB-3.0 no. 142.0-2024) was developed in Canada.

Because RD contains almost no aromatics or heteroatoms, it is much less polar than ULSD. This can possibly affect the solubility of biodiesel, biodiesel impurities, or fuel additives in RD. The objective of Phase I of this study is to provide an assessment of these solubility impacts by testing RD and B100 with a range of cloud points, and B100 have a range of cold soak filtration times. Blends containing 5%, 20%, and 50% biodiesel are evaluated.

Methods

Fuels Used in this Study

There were six base fuels received for this study from commercial suppliers. A list of the base fuels received, and the specific criteria of the desired fuels is contained in Table 1. Samples were received in aluminum cans (RD and ULSD) or plastic containers (B100). Upon receipt, samples were blanketed with nitrogen and stored under ambient laboratory conditions. From these six base fuels, 23 blends were prepared as described in Table 2. Prior to blend preparation, the B100 was ‘thermally erased’ in the environmental chamber at 60°C for 3 hours. Thermally erasing B100 is a way to remove the sample’s thermal history by heating the sample above a specific temperature to ensure that any separated materials are dissolved in the sample. Samples were removed and allowed to warm to ambient laboratory temperature overnight. Blends were prepared by hand blending the samples using Class A volumetric graduated cylinders. The weight of each portion of the fuel was also recorded.

Table 1: List of base fuels received and desired criteria

#	Criteria Description	Unique ID Code
1	Conventional #2 summer grade marketplace diesel (ULSD) with aromatics content ~25 to 35 volume % meeting the ASTM D975 standard.	39615
2	Renewable diesel with a high cloud point (RD1) ranging from 0°C to 5°C and meeting the ASTM D975 No. 2 Grade standard.	39616
3	Renewable diesel with a low cloud point (RD2) ranging from -7°C to -20°C and meeting the ASTM D975 No. 2 Grade standard	39724
4	Biodiesel with a low cloud point, approximately ranging from -5°C to +2°C (made from soybean oil or similar vegetable oil), meeting the ASTM D6751 standard (Grade No. 1-B S15 LM).	40347
5	Biodiesel with a high cloud point (made from animal fat, palm oil or other highly saturated feedstock) ranging from +5°C to + 20°C and meeting the ASTM D6751 standard (Grade No. 1-B S15 LM).	40349
6	Biodiesel that has a cold soak filtration time value of > 200 seconds but < 360 as per ASTM D7501 meets the ASTM D6751 standard (Grade No. 2-B, S15, LM).*	40348

*Highest CSFT sample that was obtained was 199s

Table 2. Fuel blends prepared for cold soaking

1	5% Biodiesel (Low Cloud point) with ULSD
2	5% Biodiesel (Low Cloud point) with RD1
3	5% Biodiesel (Low Cloud point) with RD2
4	5% Biodiesel (High Cloud point) with ULSD
5	5% Biodiesel (High Cloud point) with RD1
6	5% Biodiesel (High Cloud point) with RD2
7	5% Biodiesel (CSFT > 200 to < 360 s) with ULSD
8	5% Biodiesel (CSFT > 200 to < 360 s) with RD1
9	5% Biodiesel (CSFT > 200 to < 360 s) with RD2
10	20% Biodiesel (Low Cloud point) with ULSD
11	20% Biodiesel (Low Cloud point) with RD1
12	20% Biodiesel (Low Cloud point) with RD2
13	20% Biodiesel (High Cloud point) with ULSD
14	20% Biodiesel (High Cloud point) with RD1
15	20% Biodiesel (High Cloud point) with RD2
16	20% Biodiesel (CSFT > 200 to < 360 s) with ULSD
17	20% Biodiesel (CSFT > 200 to < 360 s) with RD1
18	20% Biodiesel (CSFT > 200 to < 360 s) with RD2
19	30% Biodiesel (High Cloud Point) with RD1
20	30% Biodiesel (CSFT > 200 to < 360 s) with RD 1
21	50% Biodiesel (High Cloud Point) with RD1
22	50% Biodiesel (CSFT > 200 to < 360 s) with RD 1
23	50% RD1 with ULSD

Base Fuel and Blend Analysis

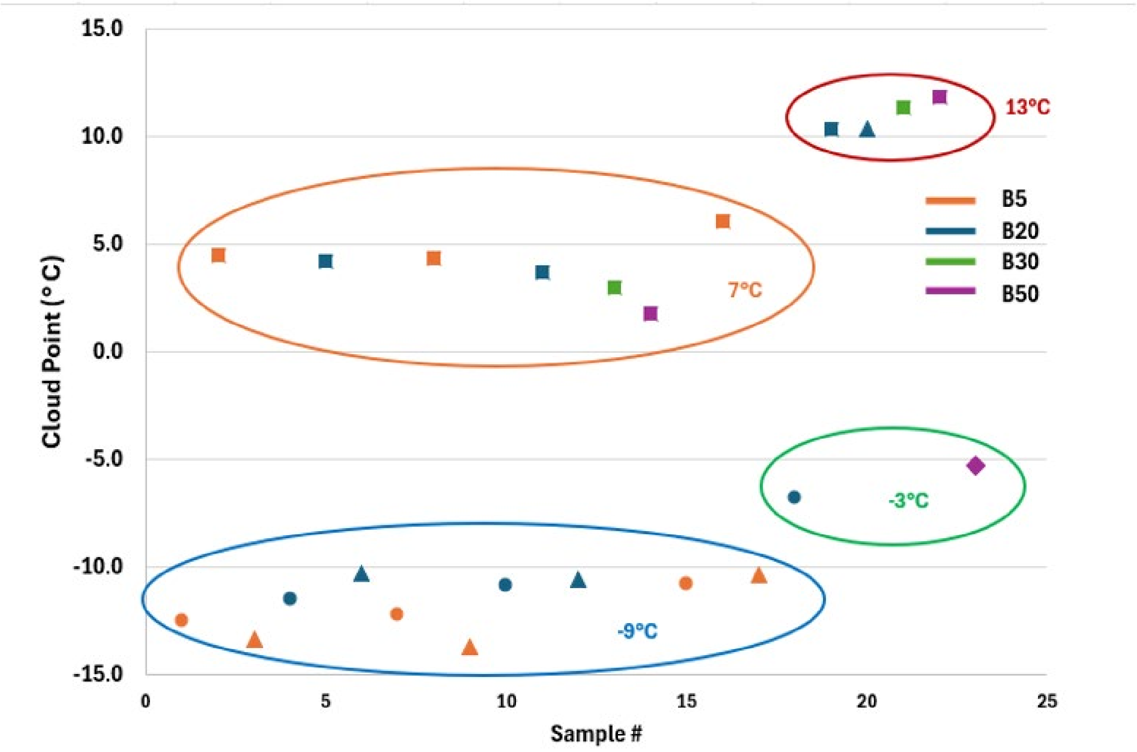
The property requirements of ASTM D975 (RD and ULSD), and ASTM D6751 (B100) were utilized to characterize the base fuels. In some cases, the fuel property data were recorded on the Certificate of Analysis that came with the fuel. All other properties were acquired from Southwest Research Institute or measured by NLR. The B100 were also characterized for the fatty acid profile by gas chromatography coupled with mass spectrometry (NLR Laboratory Analytical Procedure method based on American Oil Chemists' Society Ce 1i-07) [10] and the cold soak filter blocking tendency method (CSFBT) per CAN/CGSB-3.0 no. 142.0-2024. The twenty-three fuel blends were analyzed for cloud point (ASTM D5773), pour point (ASTM D5949), and distillation by ASTM D86 prior to cold soaking.

Cold Soaking Procedure

Cold soaking for the fuels was carried out in a Test Equity environmental chamber with a +/- 1°C temperature-controlled environment. All samples (under a nitrogen atmosphere) were thermally erased for 3 hours at 60°C and allowed to cool to ambient laboratory conditions overnight. Samples were then transferred to two separate 100 mL glass centrifuge tubes and placed in the environmental chamber at both 20°C and 10°C for 24 hours. Fresh aliquots of sample were placed into the 100 mL centrifuge tubes for each test temperature. A third soak temperature was determined by grouping samples with similar cloud points and soaking at a temperature about 2°C above the cloud point. The final selection of temperatures is shown in Figure 1. Note that the highest soak temperature group includes only the high cloud point B100 (40349) blended into RD samples at 20 vol% and higher. The second highest soak temperature group is made up entirely of blends of the high cloud point RD (39616). The two lower soak temperature groups contain fuels made from a broader range of blendstocks.

Once the 24-hour soak was completed, samples were removed from the chamber and immediately photographed (within 5 minutes of removal) and inspected for the presence of precipitate. A photo box with a black background stage with consistent lighting was utilized (Figure 2). This photo box was equipped with a bright light on the top that allowed for consistent lighting and a common background for all samples. (Sample photos are contained in a separate data folder by soak temperature due to file size).

For samples containing precipitate, the second centrifuge tube was centrifuged for 10 minutes while cold using a Rotanta 460R centrifuge set to 0°C and operated at 1600 revolutions per minute. The supernatant was decanted and then a wash of cold n-heptane was added to the tube to remove residual fuel residue (10 mL). The precipitate was resuspended by shaking the tube which was then centrifuged again at 0°C for 10 minutes at 1600 revolutions per minute and then the heptane wash was decanted. The centrifuge tube was then dried under nitrogen purge for 15 minutes at room temperature. The precipitate was weighed and analyzed by GC-MS as described below.



● 39615 = ULSD
■ 39616 = RD 1 High CP
▲ 39724 = RD 2 Low CP
◆ 50/50 blend 39615/39616

Figure 1. Selected groupings for third soak temperature with final soak temperature defined

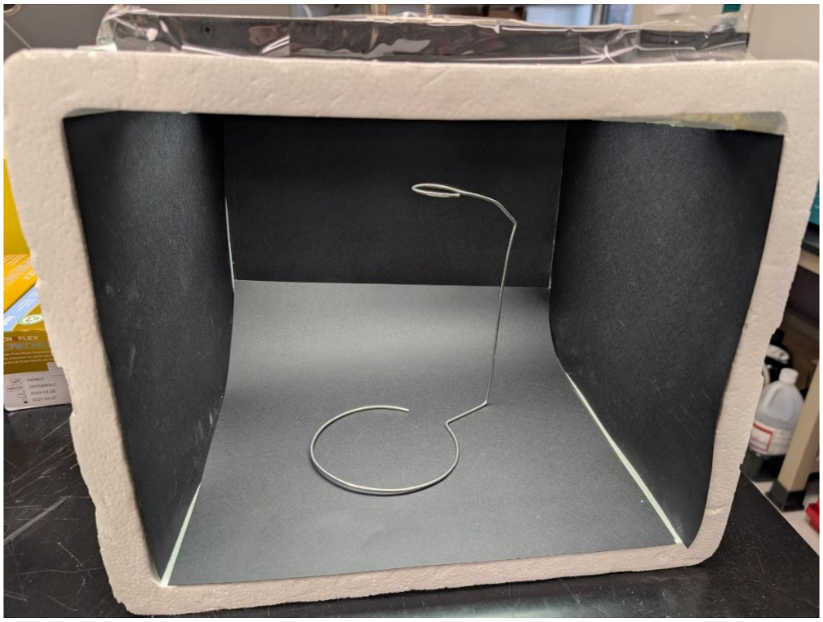


Figure 2. Photo box with black background for precipitate photos

Fuel Analysis After Cold Soaking

All samples were visually inspected for insolubles and photographed in the black background photo box to capture any precipitate. All photographs are included as a zip file as Supplementary Data. Visual haze was assessed by ASTM D4176 Haze by Visual and by ASTM D8148 Haze Clarity Index by Spectroscopy within five minutes of removal from the cold chamber and after warming to room temperature for 24 to 28 hours. A Clarity Choice Phz handheld meter was utilized for performing these analyses. These samples were also photographed a second time after warming for the 24–28-hour hold period.

Fourier Transform Infrared (FTIR) Analysis

A 1 mL aliquot from both the top and the bottom was removed for analysis by ASTM D7371. These samples were taken from the approximately 95 mL line in the centrifuge tube for the top sample and the 5 mL centrifuge tube line for the bottom samples utilizing a glass pipette (see Figure 3). If precipitate was present, the sample for the bottom was taken 5 mL above the precipitate in the tube. Top and bottom aliquots for all samples were analyzed using ASTM D7371. Two sets of standards using B100 40347 were prepared at the volumes shown in Table 3 in both 39724 (RD2) and 39616 (ULSD) to vary aromatic content of the standard solutions used for calibration. Both sets were run to generate two separate calibration curves from 0-10% biodiesel content and 10-50% biodiesel content for a total of four calibration standard sets.

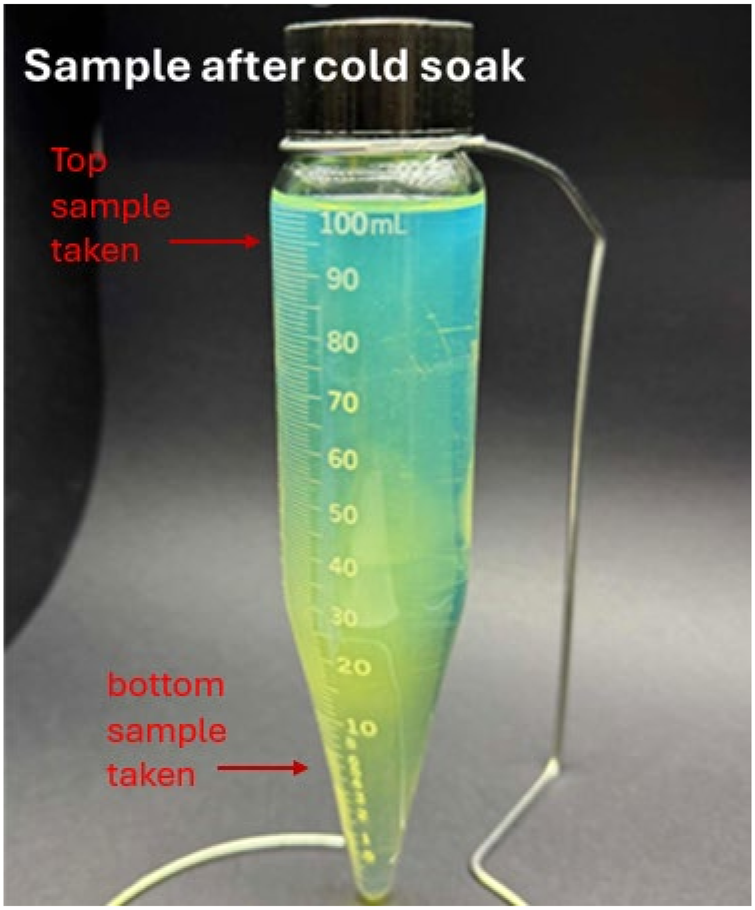


Figure 3. Centrifuge tube with top and bottom sampling points noted

Table 3. FTIR calibration solutions

Sample	Biodiesel vol%	Solvent	Set A	Set B
1	0.0	ULSD or RD	X	
2	0.3	ULSD or RD	X	
3	0.5	ULSD or RD	X	
4	1.0	ULSD or RD	X	
5	2.5	ULSD or RD	X	
6	5.0	ULSD or RD	X	
7	7.5	ULSD or RD	X	
8	10.0	ULSD or RD	X	X
9	12.5	ULSD or RD		X
10	15.0	ULSD or RD		X
11	17.5	ULSD or RD		X
12	20.0	ULSD or RD		X
13	25.0	ULSD or RD		X
14	30.0	ULSD or RD		X
15	50.0	ULSD or RD		X

Precipitate Analysis by Modified ASTM D6584

Samples exhibiting haze and precipitates were centrifuged for 10 minutes while cold using a Rotanta 460R centrifuge set to 0°C. The supernatant was decanted and then a wash of n-heptane (20 mL) was added to the tube to remove residual fuel residue. The tube was then centrifuged again at 0°C, and the heptane wash was decanted. The centrifuge tube was then dried under nitrogen purge for 15 minutes at room temperature. The centrifuge tube was weighed to provide a measure of the mass of precipitate that was formed. Analysis of the precipitate was performed using a modified ASTM D6584 methodology that was developed in-house at NLR for analysis of saturated monoglycerides and steryl glucosides which allows for simultaneous quantitation by a flame ionization detector (FID) and identification by MS, this is accomplished by splitting the column effluent into two different detectors using a Deans Switch Additionally, the hold time at the end of the method is extended to allow for the steryl glucosides to elute. The precipitate was derivatized by silylating with *N*-Methyl-*N*-(trimethylsilyl)trifluoroacetamide (MSTFA) to ensure volatility of components in the GC (as required by the D6584 method). A standard curve containing a mixture of saturated monoglycerides (monopalmitin, monostearin, and monoolein) and steryl glucosides (standard mixture from Caymen Chemical) was prepared and tricaprin and 1,2,4-butanetriol were used as internal standards.

Results

Fuel Properties

Hydrocarbon base fuels. Hydrocarbon fuel properties are shown in Table 4. RD 39724 and ULSD 39615 have lower CPs than RD 39616. ASTM D86 distillation curves were measured by an outside test laboratory and are shown in Figure 4. Note that the two RDs have a narrow boiling point range compared to USLD 39615 which is typical.

Table 4. ASTM D975 fuel properties of hydrocarbon fuels

Sample	Test Method	Renewable Diesel 39724
Flash Point (°C)	ENISO2719	94
Water and Sediment (mg/kg)	ENISO12937	35
Sediment (mg/kg)	EN12662	1
Kinematic Viscosity (mm^2/s)	ENISO3104	3.25
Ash (mass%)	ENISO6245	<0.001
Sulfur (mg/kg)	ENISO20846	<1
Cetane Number	EN15195	78.6
Aromaticity (wt%)	EN12916	0.2
Cloud Point (°C)	ASTM D2500	-16.6
LTFT/CFPP (°C)	EN116	-16
Carbon Residue (% mass	ENISO13070	<0.1
Lubricity (micron)	ENISO12156-1	568 at 60°C
Conductivity (pS/m)	ISO6297	147 at 21°C
NLR CP D5773		-16.2

Sample/Test Method	Renewable Diesel 39616	ULSD 39615
Flash Point (°C), D93	62	68
Water and Sediment (% vol), D2709	<0.010	0
Kinematic Viscosity, (mm^2/s at 40°C), D445	3.337	2.994
Ash (mass%), D482	<0.0100	<0.0100
Sulfur (ppm), D5453	<1.0	2.1
Copper Strip Corrosion (rating), D130	1A	1A
Cetane Number, D613	81.1	48.5
Aromaticity (% vol), D1319	0.2	22.4
Cloud Point (°C), D2500	5.7	-14
Carbon Residue (% mass), D524	0.02	0.05
Conductivity (pS/m), D2624	1 at 21°C	386
NLR CP (°C) D5773	5.0	-12.3

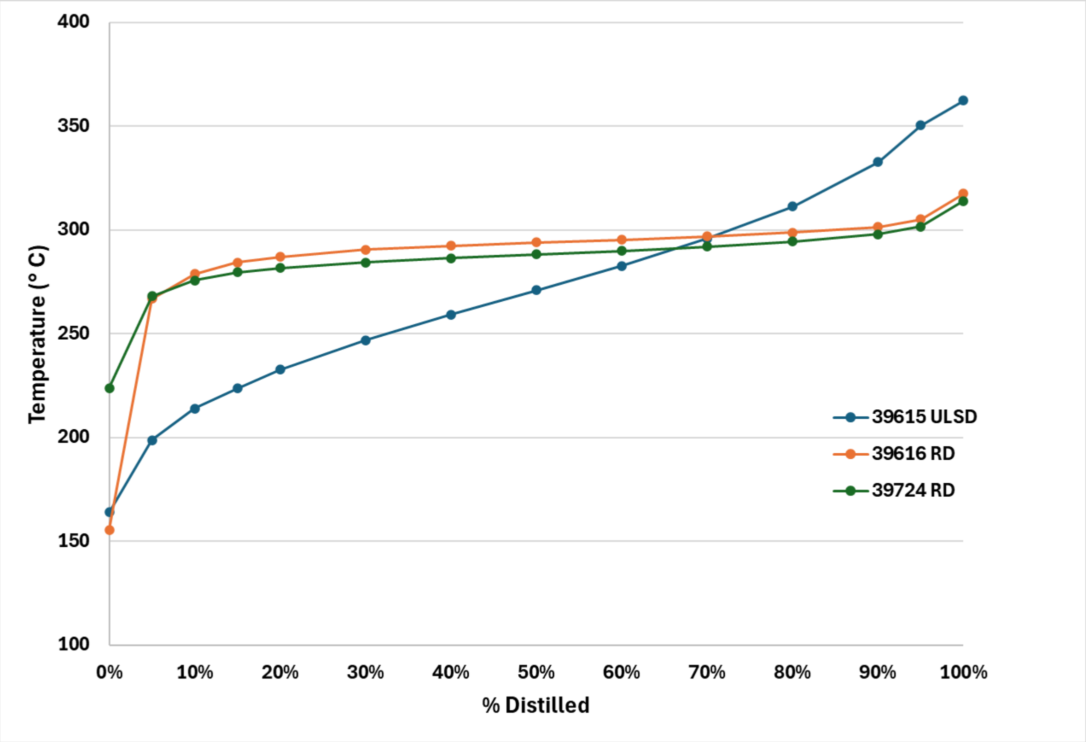


Figure 4. ASTM D86 curves for hydrocarbon base fuels

B100 base fuels. ASTM D6751 results are shown in Table 5. Base fuels were selected to come from two different feedstocks (a soy-based feedstock and an animal fat feedstock), and the fatty acid methyl ester (FAME) profiles are shown in Figure 5. Additionally, a fuel with a high cold soak filtration time (CSFT) was selected. While the target CSFT was to be above 200 seconds, the sample we obtained was at 199 seconds – which still meets ASTM D6751 grade 1B S15 LM.

Table 5. ASTM D6751 fuel properties

Sample	**40347 (Low CP Fuel)**	**40349 (High CP Fuel)**	**High CSFT B100 (40348)**
Test			
Sulfur (% mass), D5453	<1	6.603	<0.0005
Cold Soak Filterability (seconds), D7501	79.96	153	199
Monoglyceride Content (% mass), D6584	0.373	0.381	0.236
Metals (ppm), EN14538	0.3	0.62	<0.1*
Flash Point (°C), D93	129	147.5	159.0
Water and Sediment (% vol), D2709	ND	<0.01	0.2
Kinematic Viscosity, (mm^2/s at 40°C), D445	4.019	4.848	4.0643
Sulfated Ash (mass%), D874	<0.005	<0.001	<0.005
Copper Strip Corrosion (rating), D130	1A	1A	1A
Cetane Number, D613	47.2	61.3	46.5
Cloud Point (°C), D2500	-1	13.1	2.0
Carbon Residue (% mass), D4530	0.000	0.02	<0.01
Acid Number (mg KOH/g)< D664	0.07	0.218	0.20
Free Glycerin (% mass), D6584	0.002	0.003	<0.005
Total Glycerin (% mass), D6584	0.105	0.182	0.08
Phosphorus Content (% mass), D4951	0.0000	0.00001	<5
Distillation Temperature (°C), D1160	350	354	356
Oxidation Stability (hours, min), EN15751	4.95	19.61	6.5
NLR CP D5773	0.8	13.4	0.7
CSFBT (CAN/CGSB-3.0 no. 142.0-2024)	1.25	2.9	10.04

ND = none detected

***** ASTM D7111

Figure 5. Fatty acid profile of B100 base fuels.

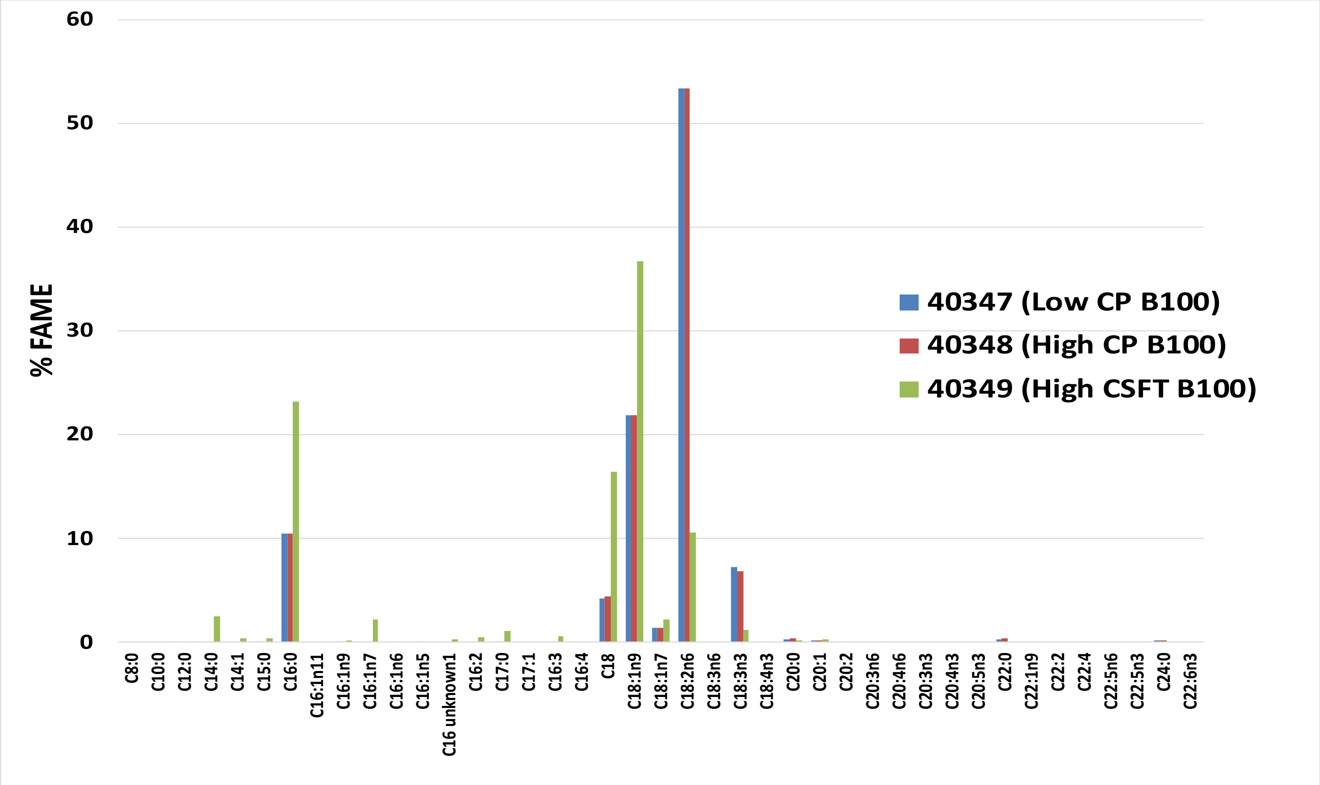


Figure 6. Fatty acid profile of B100 base fuels.

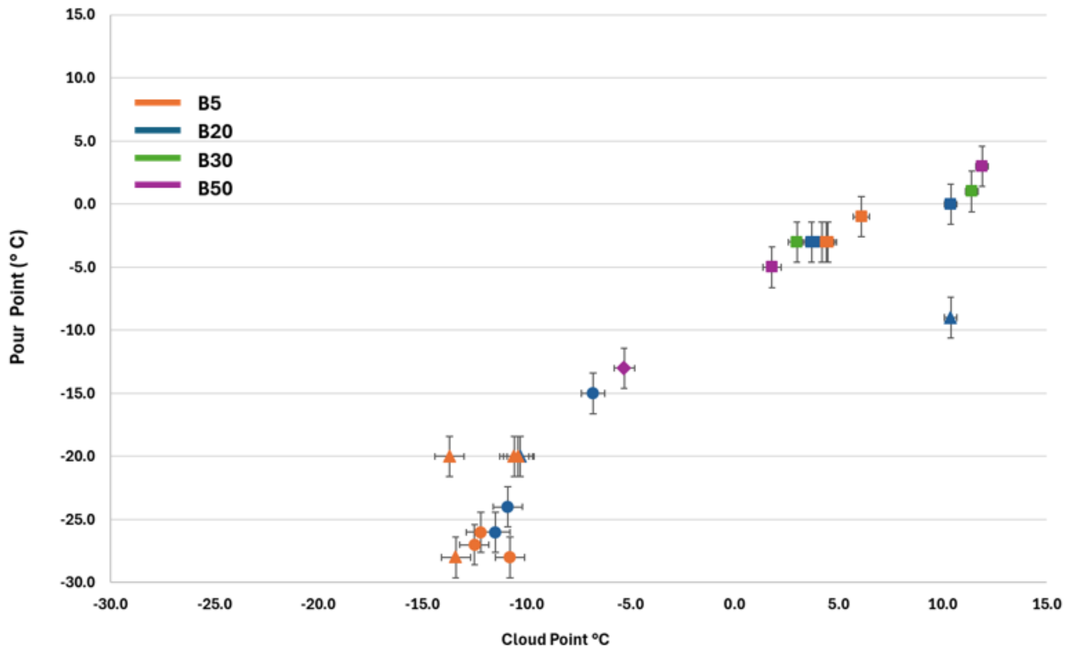
Fuel Blend Properties

Cloud point and pour point. Cloud point and pour point were measured by ASTM D5773 and D5949 respectively. ASTM D5773 states repeatability between 0.3°C and 0.9°C depending on the actual cloud point temperature (See Table 1 Precision and Bias for Biodiesel and biodiesel blends in ASTM D5773). For the Pour point, the stated precision and bias determined in ASTM D5949 was determined using a 1°C and 3°C instrument test interval. Our instrument is operated at 2°C intervals, therefore two random samples were selected and run three times over three different days. Table 6 contains the results for the triplicate analysis.

Table 6. Repeatability measurements for pour point

	Pour Point (°C)		
Sample	**Replicate 1**	**Replicate 2**	**Replicate 3**
B20 40349 + 39724	-9	-10	-10
B20 40347 + 39615	-25	-20	-23

Cloud point and pour point were measured for all 23 samples, Figure 6 shows the parity plot of the cloud point versus the pour point. Error bars are based on repeatability stated in ASTM D4959 which is considered more robust than repeatability measurements performed at NLR. Table S1 in the supplementary data section includes the recorded cloud and pour points. Figures S1 and S2 display the plotted values individually for the cloud and pour point respectively. Cloud point values are roughly 10°C higher than pour point values. Higher levels of biodiesel blending, and higher biodiesel cloud point, result in higher blend cloud point as expected.



● 39615 = ULSD
■ 39616 = RD 1 High CP
▲ 39724 = RD 2 Low CP
◆ 50/50 blend 39615/39616

Figure 7. Parity plot of cloud and pour points for the 23 blends utilized for cold soaking

Distillation curves. Distillation curves for all 23 samples were measured by ASTM D86 by an outside test laboratory. Figure 7 shows the measured distillation curves. Table S2 contains the tabular data for the samples. As expected, blends in ULSD 39615 had a broader boiling point curve compared to blends prepared in RD. Overall, blends containing less biodiesel had a lower boiling point distribution, with the ULSD blends having a higher final boiling point. It should also be noted that the scope of D86 includes blends up to 20% biodiesel. Blends containing higher levels of biodiesel were measured, and data was provided solely for comparison.

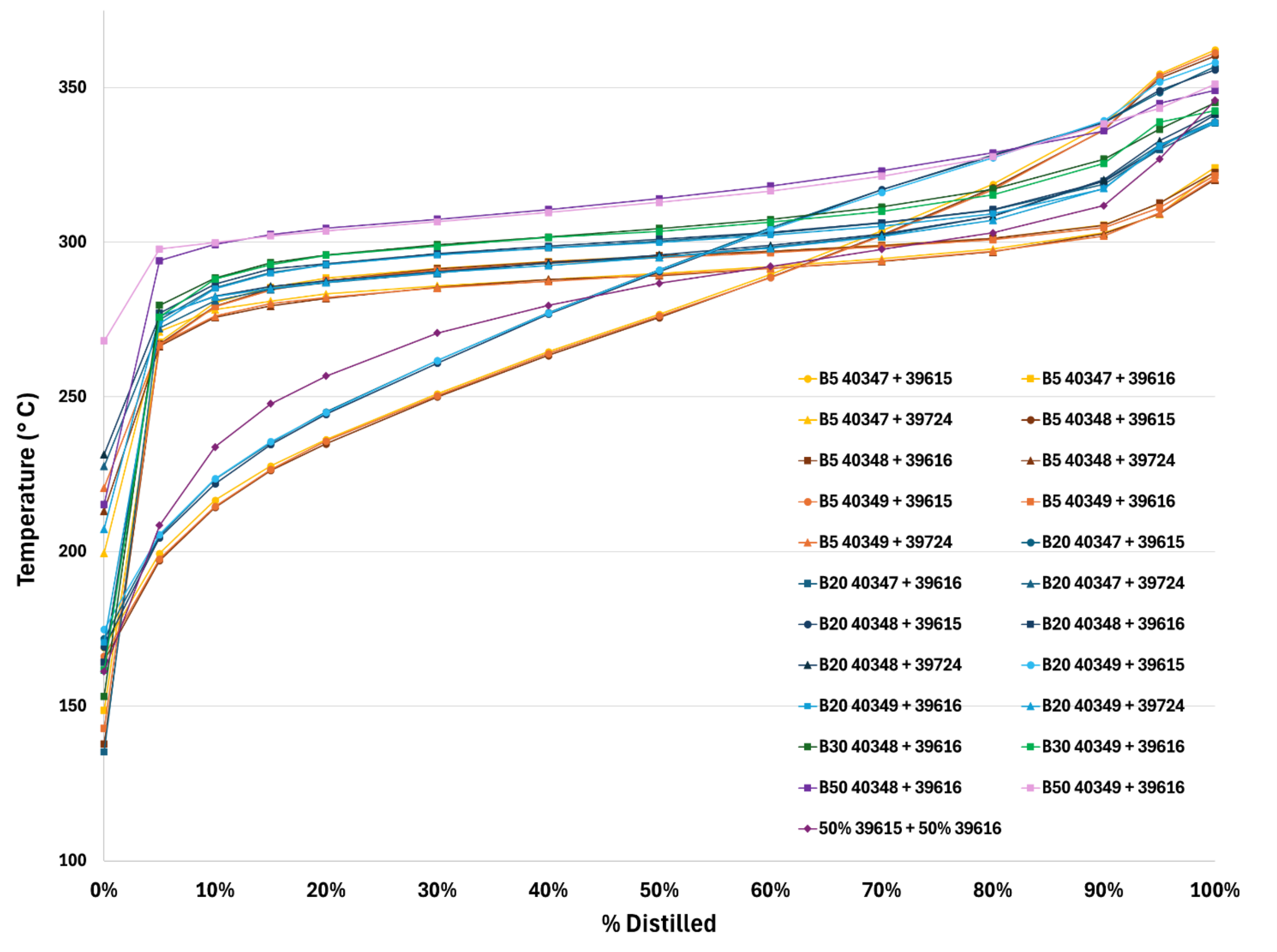


Figure 8. D86 Distillation curves for 23 samples utilized for cold soaking

Fuel Cold Soaking

Instrument Haze Rating readings. The Haze Clarity Phz meter was calibrated daily prior to measurements using a Haze standard provided by the manufacturer. Measurements were carried out in accordance with ASTM D8184. Table 7 contains the Instrument Haze Rating readings for all 23 samples at the three soak temperatures studied. In several instances, the Instrument Haze Rating reading was lower after the sample had been sitting at room temperature (highlighted boxes) indicating that some precipitate dissolved back into solution after warming. In those cases, the sample was visibly less hazy after warming to room temperature over the 24-hour period. Figure 8 shows before and after photos of one of the samples which became less hazy after warming to RT.

Table 7. Instrument Haze Rating **readings for all samples at the three soak temperatures**

		20 °C		10 °C		Based on CP		
Sample	**Cloud Point (°C)**	**24-hour soak**	**24-hours at RT**	**24-hour soak**	**24-hours at RT**	**24-hour soak**	**24-hours at RT**	**Temperature of 3rd soak**
B5 40347 + 39615	-12.5	1.0	1.0	1.0	1.0	1.0	1.0	-9 °C
B5 40347 + 39616	4.5	1.0	1.0	1.0	1.0	1.0	1.0	7 °C
B5 40347 + 39724	-13.4	1.0	1.0	1.0	1.0	1.1	1.0	-9 °C
B20 40347 + 39615	-11.5	1.0	1.0	1.0	1.0	1.3	1.0	-9 °C
B20 40347 + 39616	4.2	1.0	1.0	1.0	1.0	1.0	1.0	7 °C
B20 40347 + 39724	-10.3	1.0	1.0	1.0	1.0	1.7	1.0	-9 °C
B5 40348 + 39615	-12.2	1.0	1.0	1.0	1.0	1.0	1.0	-9 °C
B5 40348 + 39616	4.4	1.0	1.0	1.0	1.0	1.0	1.0	7 °C
B5 40348 + 39724	-13.7	1.0	1.0	1.0	1.0	1.0	1.0	-9 °C
B20 40348 + 39615	-10.9	1.0	1.2	1.0	1.2	1.5	1.1	-9 °C
B20 40348 + 39616	3.7	1.2	1.2	1.0	1.1	1.0	1.1	7 °C
B20 40348 + 39724	-10.6	1.4	1.5	1.0	1.4	1.1	1.3	-9 °C
B30 40348 + 39616	3.0	1.4	1.5	1.0	1.4	1.0	1.3	7 °C
B50 40348 + 39616	1.8	1.8	1.9	1.3	1.9	1.0	1.6	7 °C
B5 40349 + 39615	-10.8	1.0	1.0	1.0	1.0	1.0	1.0	-9 °C
B5 40349 + 39616	6.1	1.0	1.0	1.0	1.0	1.0	1.1	7 °C
B5 40349 + 39724	-10.4	1.0	1.0	1.0	1.0	1.0	1.0	-9 °C
B20 40349 + 39615	-6.8	1.0	1.0	1.0	1.3	1.8	1.1	-3 °C
B20 40349 + 39616	10.4	1.0	1.2	--	--	1.6	1.8	13 °C
B20 40349 + 39724	10.4	1.0	1.0	--	--	1.1	1.7	13 °C
B30 40349 + 39616	11.4	1.0	1.4	--	--	1.1	1.7	13 °C
B50 40349 + 39616	11.9	1.0	1.2	--	--	2.5	2.3	13 °C
50% 39615 + 50% 39616	-5.3	1.0	1.0	1.0	1.0	1.0	1.0	-3 °C
39615	-12.3	1.0	1.0	1.2	1.0	N/A	N/A	N/A
39616	5.0	1.0	1.0	1.0	1.0	N/A	N/A	N/A
39724	-16.2	1.0	1.0	1.0	1.0	N/A	N/A	N/A

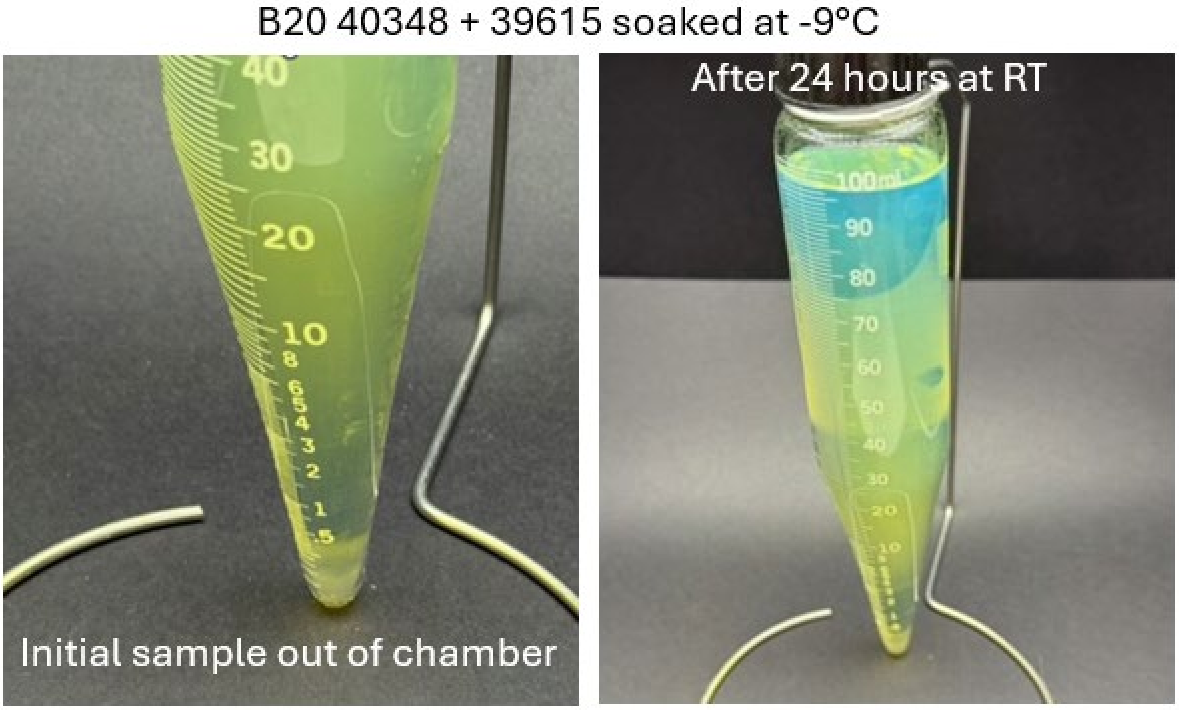


Figure 9. B20 40348 + 39615 after soaking at -9°C and after warming up to room temperature

Samples that contained visible precipitate are listed in Table 8 along with the soak temperature where the precipitate was isolated, the respective initial cloud point of the sample, and the mass of collected precipitate that was recorded. There were a total of 17 samples that contained visible precipitate and an attempt to isolate enough material for GC analysis was attempted. Samples made with B100 40348 had the most instances of precipitate formed in the blends. B100 40348, which had a CSFT near the threshold (200 seconds) shows a higher propensity to form precipitates in blends with RD. Additionally, even B100 40349, the sample within acceptable CSFT range also shows evidence of precipitate formation in blends with RD and ULSD. As expected, the formation of precipitates was most heavily influenced by the B100 used for blending rather than the base hydrocarbon fuel used as precipitates were noted in both RD and ULSD samples. In general, Haze readings less than or equal to 2 are considered acceptable. The manufacturer states that readings are accurate to one significant figure, therefore samples with readings of less than 2.5 should be considered a reading of 2. No samples in Table 8 were above this threshold and would be considered acceptable. It should be pointed out that all samples in Table 8 were those that were held just above the cloud point of the fuel blend.

Table 7. List of samples containing precipitate, the soak temperature where precipitate was isolated and the representative initial cloud point

Sample	Soak Temperature (°C)	Cloud Point (°C)	Precipitate Weight (mg)	Haze Reading
B20 40348 in 39615	10	-10.9	Not enough to isolate	1.2
B20 40348 in 39616	10	3.7	Not enough to isolate	1.1
B20 40348 in 39724	10	-10.6	Not enough to isolate	1.4
B30 40348 in 39616	10	3.0	Not enough to isolate	1.4
B50 40348 in 39616	10	1.8	Not enough to isolate	1.9
B20 40349 in 39615	10	-6.8	2.21	1.3
B20 40349 in 39616	13	10.4	2.57	1.8
B20 40349 in 39724	13	10.4	3.48	1.7
B30 40349 in 39616	13	11.4	6.07	1.7
B50 40349 in 39616	13	11.9	6.06	2.3
B20 40348 in 39616	7	3.7	Not enough to isolate	1.1
B30 40348 in 39616	7	3.0	Not enough to isolate	1.3
B50 40348 in 39616	7	1.8	1.74	1.6
B20 40349 in 39615	-3	-6.8	2.16	1.8
B20 40347 in 39724	-9	-10.3	Not enough to isolate	1.1
B20 40348 in 39615	-9	-10.9	Not enough to isolate	1.1
B20 40348 in 39724	-9	-10.6	Not enough to isolate	1.3

Top and bottom FTIR analysis. Top and bottom aliquots removed from the centrifuge tubes were analyzed by ASTM D7371 utilizing a Thermo Fischer FTIR. Two sets of calibration standards were prepared in both the low aromatic fuel (using RD 39724) and the ULSD 39615 to give a total of four calibration standard sets. Standards were prepared as outlined in Table 3. B5 top and bottom samples were analyzed using the low biodiesel content curve (from B0 to B10), and all other samples were analyzed on a high biodiesel content curve (from B10 to B50). Tables S3 and S4 show the measured results for the top versus the bottom for each sample set. ASTM D7371 repeatability criteria are listed as 0.24% at 1.00% biodiesel concentration. 0.25% at 2.00%, 0.30% at 5.00%, 0.37% at 10.00%, and 0.53% at 20.00% respectively (repeatability above 20.00% was not determined in ASTM D7371). Based on these data, there is not a significant difference between the top and bottom for any of the samples tested indicating that biodiesel settling to the bottom of the tube did not occur at any of the soak temperatures studied over the 24-hour soak period. Figure S3 in the Supplementary material shows the parity plot of the top versus the bottom for all of the samples measured. All samples fall along the parity line and show a slope of 1.

Precipitate Analysis

Samples that contained precipitate were centrifuged in a Rotanda centrifuge set to 0°C in order to isolate the precipitate for GC analysis. After being centrifuged for 10 minutes, the fuel was decanted from the centrifuge tube. 30 mL of cold n-heptane (stored overnight in the freezer) was added to each tube and the tube was centrifuged at 0°C for 10 minutes a second time. The n-heptane was decanted and the precipitate in the tube was allowed to dry overnight under ambient laboratory conditions. The tubes were then weighed to obtain a precipitate weight. In some cases, precipitate was very difficult to isolate due to small amounts being present in the tube and not packing down to a tight pellet when centrifuged. Some loss of precipitate could be possible when decanting both the fuel and n-heptane after the centrifuge step, but care was taken to avoid this. Any tube where the weight was less than 0.5 mg was not analyzed by the GC analysis (These are noted in Table 8 as "not enough precipitate to isolate"). To obtain higher masses of precipitate, it would be recommended to use a larger volume of sample (in this case, all samples were 100 mL) to generate more precipitate. Additionally, a different method of isolating the crystals, perhaps by filtration, may be better for isolating crystals; especially for those samples where the precipitate appeared very fine.

Once the precipitate was isolated, it was analyzed by a modified ASTM D6584 where the effluent from the column was split between a flame ionization detector and a mass spectrometer. Samples were prepared for GC analysis by dissolving the precipitate in 100 uL each of butanetriol and tricaprin internal standard solutions (which are supplied in pyridine). 100 uL of MSTFA was then added to the vial, and it was allowed to stand for 20 minutes at room temperature as prescribed by the method. After the 20-minute period, 8 mL of n-heptane was added to the vial, and the solution was mixed by inverting the vials several times to ensure homogenization. Table 9 contains the area percent of the identified components in the samples. Blend samples prepared from B100 40349 contained almost exclusively monopalmitin and monostearin, though a few other minor monoglycerides were present (see Figure 9 for overlay chromatograms of 40349 samples). All 40349 blend samples analyzed contained a small amount of steryl glucosides (< 1%). For the one sample of 40348 (B50 40348 in 39616) that had enough precipitate present for analysis, there were significantly larger amounts of steryl glucosides present (Table 10). Figure 10 shows an overlay of the steryl glucosides region of the chromatogram for comparison.

Table 9. Area % of compounds in precipitate samples

	Area % of sample					
Compound ID	**B20 40349 in 39615 (-3°C)**	**B20 40349 in 39615 (10°C)**	**B20 40349 in 39616 (13°C)**	**B20 40349 in 39724 (13°C)**	**B30 40349 in 39616 (13°C)**	**B50 40349 in 39616 (13°C)**
Monomyristin	2.0	1.6	2.0	1.9	1.8	1.4
1-Monopentadecanoin	ND	ND	ND	0.6	ND	ND
Monopalmitin	53.2	50.3	50.2	48.2	49.6	48.4
1-Heptadecanoin	ND	ND	ND	2.6	2.2	2.2
Monoolein	ND	ND	ND	2.4	ND	ND
Monostearin	44.7	48.1	45.1	44.2	46.4	48.0

Table 10. Area % of compounds in B50 40348 in 39616

	Area % of Sample
Compound ID	**B50 40348 in 39616**
Monopalmitin	16.8
Monostearin	18.1
Steryl Glucoside 1	9.4
Steryl Glucoside 2	7.7
Steryl Glucoside 3	17.5
Steryl Glucoside 4	5.0
Steryl Glucoside 5	8.7
Steryl Glucoside 6	11.8
Steryl Glucoside 7	5.0

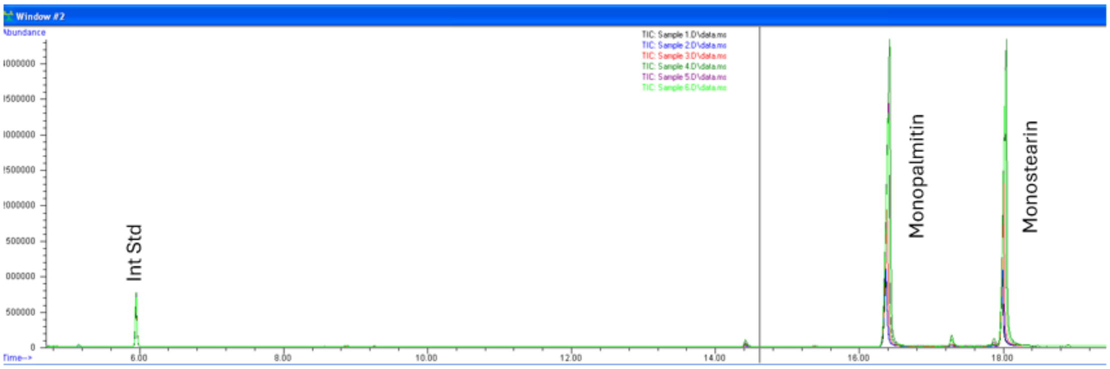


Figure 9. GC chromatogram overlay of samples analyzed

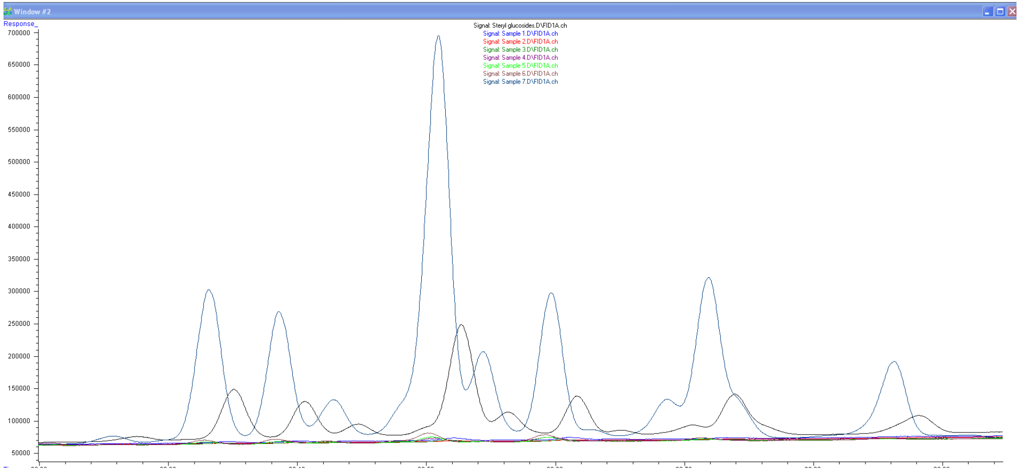


Figure 10. Steryl glucosides region of the GC chromatogram

This analysis suggests that there are likelylarger amounts of steryl glucosides present in B100 40348 versus B100 40349. This could also be a reason for the difference in consistency between the isolated precipitates. In most cases, we could not isolateisolate precipitates from 40348 due to their very fine nature while precipitate from 40349 was more easily isolated. Exact identification of each steryl glucoside present was difficult as the standard solution from Caymen chemical is a mixture of several different components and the NIST library for silyated components of these is sparce. However, the compounds elute in a tight window between di- and tri- glycerides making their identification as steryl glucosides obvious.

Conclusions and Recommendations

All base fuels met the applicable ASTM standards for the products and grades. One biodiesel was purposely selected to have a high CSFT to evaluate its effect on component solubility in RD compared to ULSD (but still meeting ASTM D6751 requirements). Blend samples were analyzed for cloud point and pour point, and results were as expected. As expected, for D86, blends in ULSD had a broader boiling point curve compared to blends prepared in RD. Overall, blends containing less biodiesel had a lower boiling point distribution, with the ULSD blends having a higher final boiling point. It should also be noted that the scope of D86 includes blends up to 20% biodiesel. Blends containing higher levels of biodiesel were measured, and data was provided solely for comparison. Instrument Haze Rating readings were completed immediately after cold soaking and after 24 hours of standing at room temperature. In several instances, the Instrument Haze Rating readings were lower after the sample had been sitting at room temperature indicating that some precipitate dissolved back into solution after warming. In those cases, the sample was visibly less hazy after warming to room temperature over the 24-hour period. FTIR analysis for biodiesel content of top and bottom samples showed no evidence for settling or separation of the biodiesel.

There was a total of 17 samples that contained visible precipitate and an attempt to isolate enough material for GC analysis was attempted. Samples made with B100 40348 had the most instances of precipitate formed in the blends. B100 40348, which had a CSFT near the threshold (200 seconds) shows a higher propensity to form precipitates in blends with RD. Additionally, B100 40349, the sample with lower SCFT results also shows evidence of precipitate formation in blends with RD. Precipitate analysis showed that monopalmitin and monostearin were the main components contained in precipitates from B100 40349 blends. There were small amounts of other monoglycerides present as well as minimal amounts of steryl glucosides. On the contrary, precipitate analysis from B100 40348 blends showed that there were larger amounts of steryl glucosides present when compared to those from 40349.

In future work, it may be beneficial to investigate utilizing larger sample volumes for precipitate isolation. Additionally, a different method for isolating precipitate could be beneficial. Difficulty in isolating the very fine precipitate formed from blends prepared with B100 40348 could be due in part to the fact that there was more steryl glucosides present in the precipitate from these samples.. A future study could be used to link Haze readings to CSFT which could be an indicator for when issues could be observed in the field.

References

1. Smagala, T.; Christensen, E.; Christison, K.; Mohler, R.; Gjersing, E.; McCormick, R. Hydrocarbon Renewable and Synthetic Diesel Fuel Blendstocks: Composition and Properties. *Energy and Fuels* **2013,** *27* (1), 237-246.

2. Graboski, M.; McCormick, R. Combustion of Fat and Vegetable Oil Derived Fuels in Diesel Engines. *Prog Energy and Comb Sci* **1998,** *24,* 125-164.

3. Tang, H.; De Guzman, R.; Salley, S.; Ng, K. *J. Am. Oil Chem. Soc.* **2008,** *85,* 1173-1182.

4. Moreau, R.; Scott, K.; Haas, M. *J. Am. Oil Chem. Soc.* **2008,** *85,* 761-770.

5. Chupka, G.; Fouts, L.; Lennon, J.; Alleman, T.; Daniels, D.; McCormick, R. Saturated monoglyceride effects on low-temperature performance of biodiesel blends. *Fuel Processing Technology* **2014,** *118,* 302-309.

6. Selvidge, C.; Blumenshine, S.; Campbell, K.; Dowell, C.; Stolis, J. *Proceedings of the 10th International Conference on Stability, Handling, and Use of Liquid Fuels*, Tucson, AZ, 2007.

7. Poirier, M.-A.; Lai, P.; Lawlor, L. The Effect of Biodiesel Fuels on the Low Temperature Operability of North American Heavy Duty Diesel Trucks. *SAE Technical Paper No. 2008-01-2380* **2008**.

8. Coordinating Research Council. *Biodiesel Blend Low-Temperature Performance Validation CRC Report No. 650;*, 2008.

9. Coordinating Research Council. *Biodiesel Low Temperature Performance Validation CRC Report No. 656;*, 2010.

10. NLR Laboratory Anlytical Procedure “Determination of Total Lipids as Fatty Acid Methyl Esters “, www. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://docs.nlr.gov/docs/fy24osti/87501.pdf, accessed April 17, 2026.

Supplementary Data

Table S1. Cloud and pour points for the 23 blends utilized in cold soaking

Sample	Pour Point (° C)	Cloud Point (° C)
B5 40347 + 39615	-27	-12.5
B5 40347 + 39616	-3	4.5
B5 40347 + 39724	-28	-13.4
B20 40347 + 39615	-26	-11.5
B20 40347 + 39616	-3	4.2
B20 40347 + 39724	-20	-10.3
B5 40348 + 39615	-26	-12.2
B5 40348 + 39616	-3	4.4
B5 40348 + 39724	-20	-13.7
B20 40348 + 39615	-24	-10.9
B20 40348 + 39616	-3	3.7
B20 40348 + 39724	-20	-10.6
B30 40348 + 39616	-3	3
B50 40348 + 39616	-5	1.8
B5 40349 + 39615	-28	-10.8
B5 40349 + 39616	-1	6.1
B5 40349 + 39724	-20	-10.4
B20 40349 + 39615	-15	-6.8
B20 40349 + 39616	0	10.4
B20 40349 + 39724	-9	10.4
B30 40349 + 39616	1	11.4
B50 40349 + 39616	3	11.9
50% 39615 + 50% 39616	-13	-5.3

Table S2. Tabular D86 data for blend samples utilized for cold soaking

°C	B5 40347 + 39615	B5 40347 + 39616	B5 40347 + 39724	B5 40348 + 39615	B5 40348 + 39616	B5 40348 + 39724	B5 40349 + 39615	B5 40349 + 39616	B5 40349 + 39724	B20 40347 + 39615	B20 40347 + 39616	
0%	169.1	148.6	199.6	164.8	137.8	213.2	166.2	142.8	220.7	171.8	135.3	
5%	199.4	267.8	271.2	197.1	267.1	266.4	197.6	266.6	267.1	205.1	274.9	
10%	216.6	280.6	278.2	214.3	279.3	275.7	214.6	279.2	276.2	223.3	285.3	
15%	227.7	285.4	281.0	226.2	285.1	279.4	226.6	284.6	280.2	235.2	290.2	
20%	236.2	288.4	283.3	234.9	287.7	281.9	235.8	287.7	282.2	245.2	292.7	
30%	251.0	291.6	285.9	250.0	291.4	285.4	250.4	291.0	285.2	261.8	296.1	
40%	264.6	293.8	288.1	263.4	293.6	288.0	264.0	293.2	287.4	277.2	298.2	
50%	276.7	295.6	290.0	275.7	295.6	289.2	276.2	294.9	289.5	291.1	300.4	
60%	289.6	297.1	292.1	288.7	297.1	291.5	288.6	296.6	291.5	304.7	303.0	
70%	303.6	299.1	294.7	302.3	298.9	293.8	302.0	298.6	294.0	317.1	306.2	
80%	318.7	301.3	297.8	317.6	301.3	296.9	317.0	300.8	297.1	327.9	310.4	
90%	338.2	305.6	303.1	336.3	305.4	302.8	336.5	304.8	302.1	338.6	318.8	
95%	354.4	312.4	309.1	353.1	312.7	309.2	353.8	311.2	309.5	348.4	330.0	
100%	362.2	324.2	322.9	360.3	322.6	320.2	361.3	321.6	320.7	356.7	338.6	
Recovered (mL)	97.7	97.7	98.1	97.9	97.4	97.8	98.1	97.7	97.7	98.2	97.8	
Residue (mL)	1.3	1.4	1.5	1.1	1.6	1.4	1.0	1.4	1.4	1.2	1.5	
Loss (mL)	1.0	0.9	0.4	1.0	1.0	0.8	0.9	0.9	0.9	0.6	0.7	

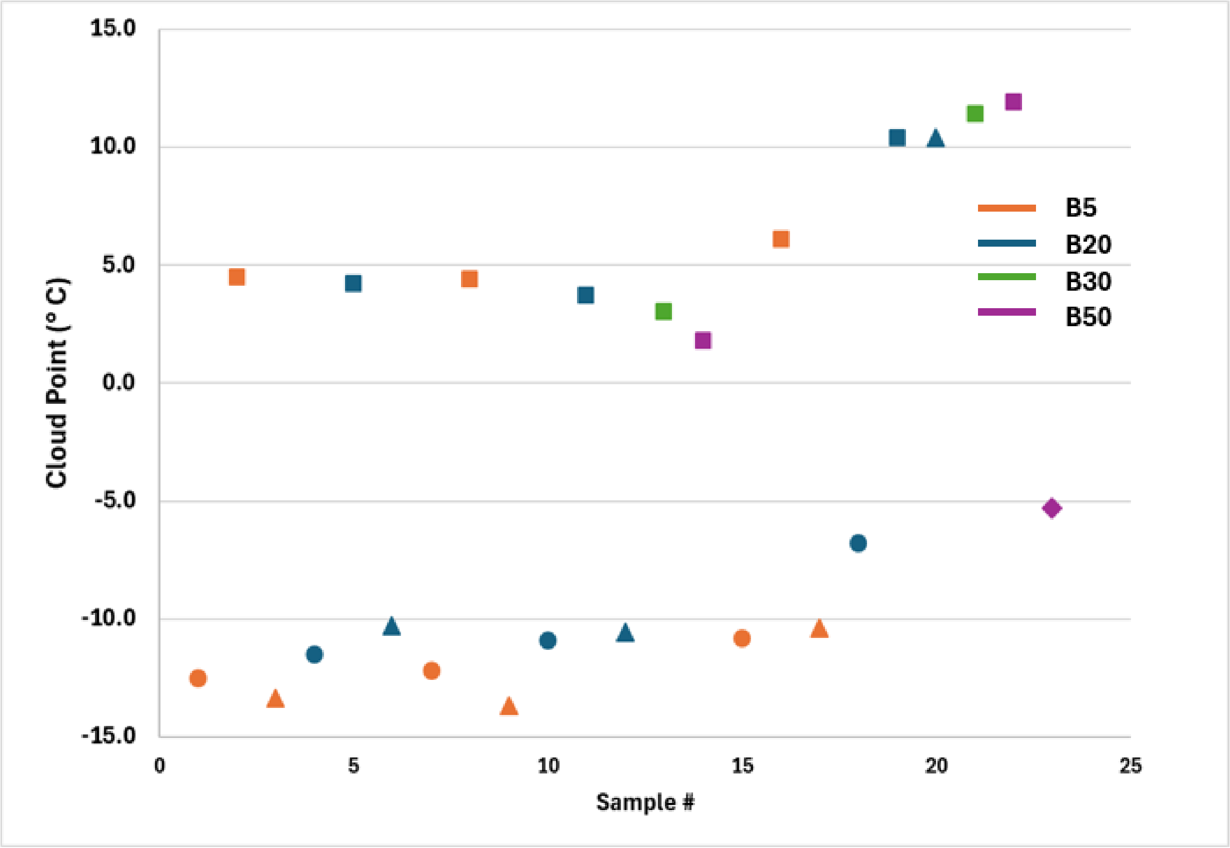
˚C	B20 40347 + 39724	B20 40348 + 39615	B20 40348 + 39616	B20 40348 + 39724	B20 40349 + 39615	B20 40349 + 39616	B20 40349 + 39724	B30 40348 + 39616	B30 40349 + 39616	B50 40348 + 39616	B50 40349 + 39616	50% 39615 + 50% 39616
0%	227.6	169.2	164.3	231.4	174.8	170.7	207.3	153.2	161.7	215.3	268.1	161.3
5%	272.2	204.5	277.1	276.2	205.6	273.8	276.3	279.6	275.8	294.1	297.8	208.4
10%	281.2	221.9	286.6	282.6	223.6	285.0	282.4	288.4	288.1	299.3	299.9	233.8
15%	284.8	234.7	291.4	285.8	235.5	289.9	285.1	293.4	292.8	302.6	302.1	247.8
20%	286.9	244.4	293.0	287.5	244.9	292.8	287.1	295.9	295.8	304.6	303.7	256.8
30%	290.1	260.9	296.4	290.6	261.8	295.9	290.3	299.2	298.7	307.4	306.7	270.7
40%	293.3	276.8	298.7	293.2	277.1	298.2	292.5	301.7	301.6	310.6	309.6	279.6
50%	295.1	290.6	301.0	295.9	291.0	299.9	295.2	304.5	303.5	314.1	312.9	286.7
60%	298.4	304.2	303.3	299.0	304.2	302.4	298.1	307.4	306.5	318.2	316.6	292.2
70%	302.2	317.0	306.3	302.7	316.1	305.2	301.9	311.4	310.0	323.1	321.4	297.7
80%	308.4	328.2	310.6	308.4	327.3	309.3	307.2	317.2	315.3	328.9	327.6	303.1
90%	319.8	338.8	319.7	320.3	339.3	317.3	317.4	326.9	325.4	336.0	338.3	311.9
95%	331.6	349.1	330.5	332.8	351.9	331.3	331.1	336.6	338.9	344.9	343.3	326.9
100%	339.3	355.8	341.3	341.8	358.2	338.6	339.1	345.2	342.6	349.1	351.1	345.9
Recovered (mL)	97.9	98.0	97.8	97.8	97.9	97.5	97.9	97.8	97.5	98.1	98.0	96.1
Residue (mL)	1.3	1.2	1.6	1.4	1.2	1.4	1.2	1.4	1.4	1.4	1.1	0.8
Loss (mL)	0.8	0.8	0.6	0.8	0.9	1.1	0.9	0.8	1.1	0.5	0.9	3.1

Table S3. Measured biodiesel content between top and bottom aliquots by ASTM D7371 for RD samples

Sample (RD Curve)	Bottom (mass %)	Top (Mass %)
39615-39616 50-50 10C	0.85	0.85
39615-39616 50-50 20C	0.86	0.85
39615-39616 50-50 -3C	0.87	0.90
39616 B0 10C	0.01	0.03
39616 B0 20C	0.00	0.00
39724 B0 10C	0.11	0.08
39724 B0 20C	-0.21	-0.19
40347 in 39616 B20 10C	25.01	24.99
40347 in 39616 B20 20C	24.83	24.78
40347 in 39616 B20 7C	25.01	25.00
40347 in 39616 B5 10C	5.56	5.50
40347 in 39616 B5 20C	5.21	5.38
40347 in 39616 B5 7C	5.70	5.68
40347 in 39724 B20 10C	18.63	18.55
40347 in 39724 B20 20C	18.99	19.06
40347 in 39724 B20 -9C	18.60	18.65
40347 in 39724 B5 10C	4.92	5.02
40347 in 39724 B5 20C	5.11	5.15
40347 in 39724 B5 -9C	5.03	4.97
40348 in 39616 B20 10C	25.03	24.96
40348 in 39616 B20 20C	24.78	24.69
40348 in 39616 B20 7C	25.03	24.88
40348 in 39616 B30 10C	35.01	34.99
40348 in 39616 B30 20C	34.92	34.94
40348 in 39616 B30 7C	35.03	35.02
40348 in 39616 B5 10C	5.50	5.58
40348 in 39616 B5 20C	5.27	5.41
40348 in 39616 B5 7C	5.73	5.68
40348 in 39616 B50 10C	55.14	55.18
40348 in 39616 B50 20C	54.94	55.01
40348 in 39616 B50 7C	55.16	55.22
40348 in 39724 B20 10C	18.65	18.64
40348 in 39724 B20 20C	18.95	19.00
40348 in 39724 B20 -9C	18.48	18.57
40348 in 39724 B5 10C	5.01	5.06
40348 in 39724 B5 20C	5.14	5.10
40348 in 39724 B5 -9C	5.01	5.04
40349 in 39616 B20 13C	24.89	24.92
40349 in 39616 B20 20C	25.96	24.65
40349 in 39616 B30 13C	34.83	34.82
40349 in 39616 B30 20C	34.65	34.56
40349 in 39616 B5 10C	5.88	5.74
40349 in 39616 B5 20C.	5.38	5.31
40349 in 39616 B5 7C.	5.82	5.81
40349 in 39616 B50 13C.	54.90	54.94
40349 in 39616 B50 20C	54.75	54.78
40349 in 39724 B20 13C	18.57	18.68
40349 in 39724 B20 20C	18.70	18.61
40349 in 39724 B5 10C	5.10	5.15
40349 in 39724 B5 20C	5.20	5.26
40349 in 39724 B5 -9C	5.14	5.07

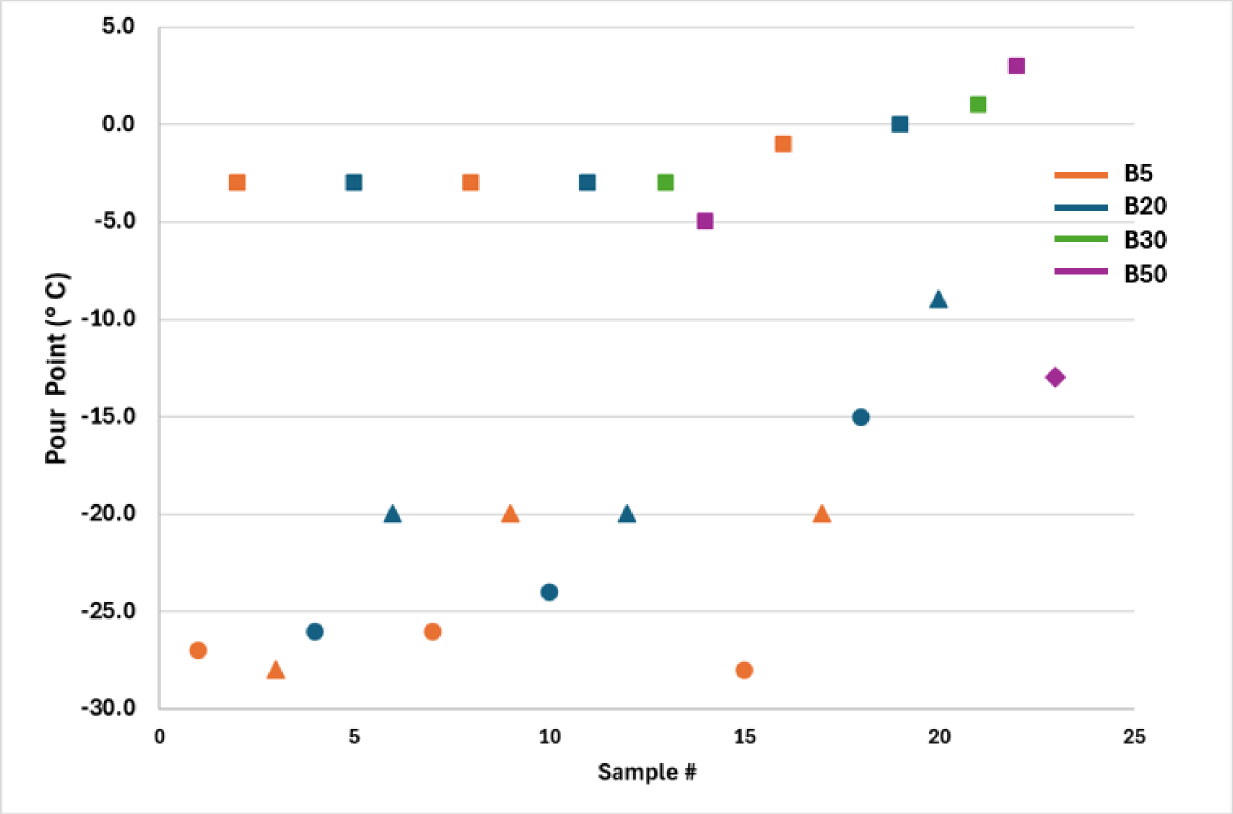
Table S4. Measured biodiesel content between top and bottom aliquots by ASTM D7371 for ULSD samples

Sample (ULSD Curve)	Top (Mass%)	Bottom (Mass %)
39615 B0 10C	0.20	0.13
39615 B0 20C	0.11	0.16
40347 in 39615 B20 10C	20.64	20.60
40347 in 39615 B20 20C	20.70	20.76
40347 in 39615 B20 -9C	20.67	20.67
40347 in 39615 B5 10C	5.29	5.34
40347 in 39615 B5 20C	5.22	5.22
40347 in 39615 B5 -9C	5.29	5.24
40348 in 39615 B20 10C	20.62	20.65
40348 in 39615 B20 20C	20.71	20.73
40348 in 39615 B20 -9C	20.39	20.61
40348 in 39615 B5 10C	5.27	5.29
40348 in 39615 B5 20C	5.15	5.12
40348 in 39615 B5 -9C	5.22	5.23
40349 in 39615 B20 10C	20.53	20.52
40349 in 39615 B20 20C	20.61	20.69
40349 in 39615 B20 -3C	20.51	20.52
40349 in 39615 B5 10C	5.25	5.36
40349 in 39615 B5 20C	5.29	5.33
40349 in 39615 B5 -9C	5.21	5.22



- ● 39615 = ULSD
- ■ 39616 = RD 1 High CP
- ▲ 39724 = RD 2 Low CP
- ◆ 50/50 blend 39615/39616

Figure S1. Cloud point for blend sample cold soaking



● 39615 = ULSD
■ 39616 = RD 1 High CP
▲ 39724 = RD 2 Low CP
◆ 50/50 blend 39615/39616

Figure S2. Pour point for blend sample cold soaking

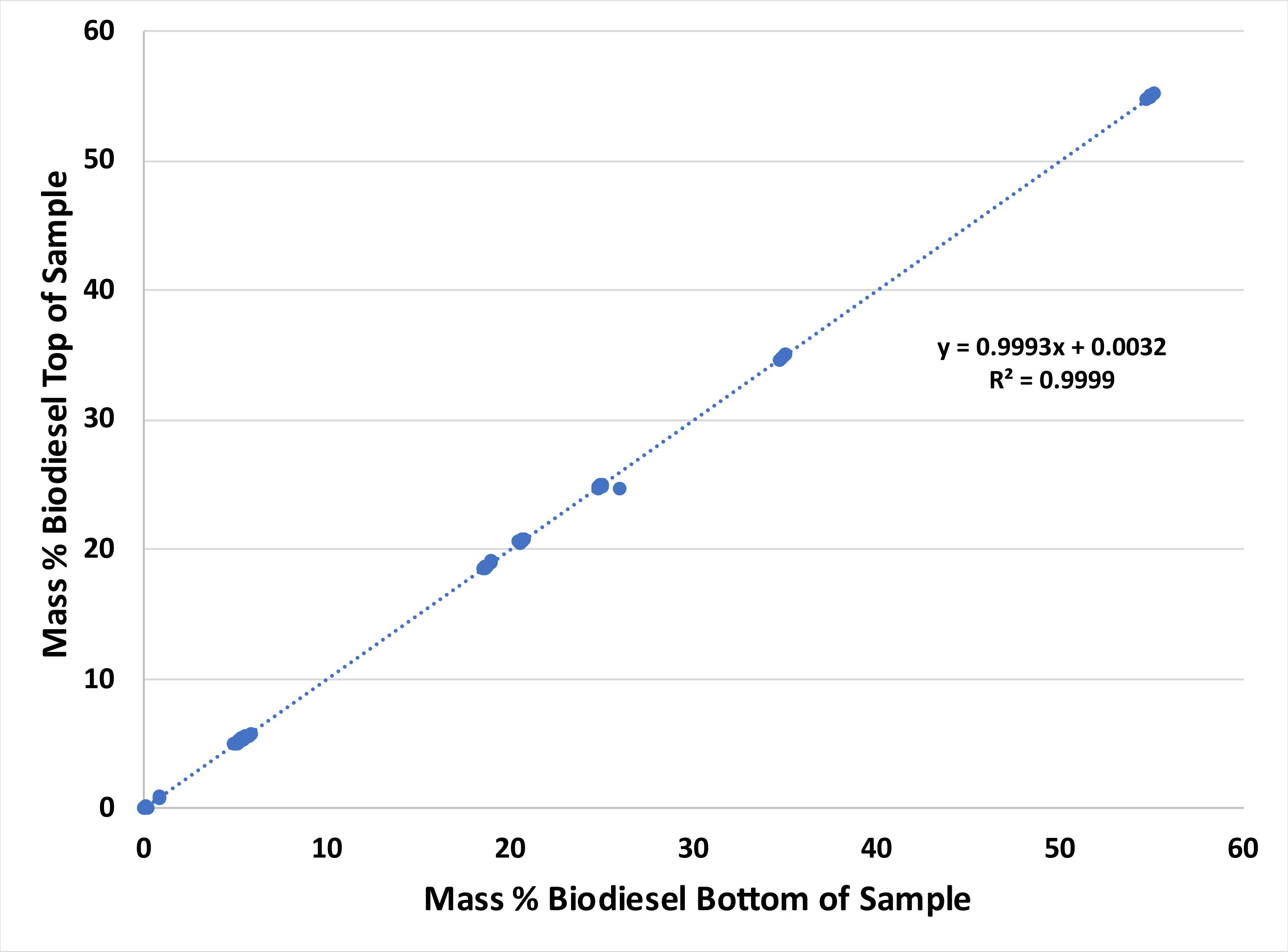


Figure S3. Parity plot of top versus bottom samples from ASTM D7371 measurement