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Effect of Diesel Contamination on PM Emissions

Final Report

February 2026

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Final Report

Effect of Diesel Contamination on PM Emissions

Project E-145

Submitted to:

Coordinating Research Council
1 Concourse Parkway, Ste 800
Atlanta, GA 30328
Attention: Amber Leland

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PETROLEUM PRODUCTS RESEARCH DEPARTMENT

Southwest Research Institute® Final Report
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FOREWORD

This report covers modeling efforts conducted by Southwest Research Institute (SwRI) for the Coordinating Research Council (CRC). The project, performed under CRC contract E-145, was conducted between November of 2024 and July of 2025. The internal SwRI proposal number is 08-99874. The SwRI project manager was Daniel Sanchez, assisted by Ken Childress, Robert Legg and Michelle Ratchford. Statistical analysis and support were provided by Dr. Travis Kostan.

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LIST OF ACRONYMS

ASTM	ASTM International
DBE	Double Bond Equivalent
CRC	Coordinating Research Council
DHA	Detailed Hydrocarbon Analysis
E10	Fuels containing 10 vol% ethanol
FID	Flame Ionization Detector
FBP	Final Boiling Point
GC	Gas Chromatograph or Chromatography
MSD	Mass Spectrometer Detector
PFI	Port Fuel Injection
PME	Particulate Matter Emissions
PMI	Particulate Matter Index
SIDI	Spark-Ignited Direct-Injection
SwRI	Southwest Research Institute
TID	Time Interval Deconvolution
ULS	Ultra Low Sulfur
VUV	Vacuum Ultraviolet Absorption Spectroscopy
VP443K	Vapor Pressure at 443K
YSI	Yield Sooting Index

1.0 EXECUTIVE SUMMARY

Particulate emissions from internal combustion engines are heavily influenced by higher boiling point unsaturated compounds found within the fuel with the highest emitters being the aromatic hydrocarbons with higher carbon number. It was the aim of this work to determine whether the diesel contamination that may occur in the distribution of gasoline has a significant impact on the particulate emissions as predicted by the PMI and PME indices. Secondarily, this work sought to identify if any of the ASTM test methods utilized in this study are sensitive to diesel fuel contamination and whether they have the potential to detect and quantify the level of contamination.

Gasoline sample sets with low and high PMI/PME values were blended with high aromatic diesel fuel at levels approximating the contamination levels expected to occur during distribution. The sample sets were analyzed using standardized ASTM test methods to measure several properties including those needed for determining the PMI and PME values. The PMI and PME values of the samples in each set were calculated and the results evaluated to determine the impact of the diesel contamination. The property results were also analyzed to assess the impact of the diesel contamination of the property itself in an aim to see if diesel fuel contamination could be inferred from the property itself.

The 2.0% diesel contamination in the Low PMI fuel raised the PMI 0.17 units and only raised the PMI 0.12 units in the High PMI fuel. The impact of the 2.0% diesel contamination on the PME, both PFI and SIDI, was only on order of 0.065 units. The lower-than-expected impact is likely due to the lack of sensitivity of the DHA to diesel contamination. In reviewing select DHA compounds it was observed that the variation of the compounds with respect to contamination level was less than the published repeatability of the method indicating that any influence of the diesel on the result was lost in the variability of the method. It's also important to note that the range of compounds detected by the DHA method only covers a portion of the full diesel compound range.

All of the test methods evaluated showed some level of sensitivity to diesel contamination. The change in PMI and PME values showed the least sensitivity to diesel contamination. The density method and all three distillation methods all showed a sensitivity to diesel contamination at varying levels, with the simulated distillation methods being the most sensitive. Without direct knowledge of the neat fuel or the potential contaminant, it would be rather difficult to quantify the level of contamination with certainty. . However, it could be possible to utilize the chromatograph generated from either simulated distillation method to estimate the amount of diesel fuel contamination if simplifying assumptions are made.

2.0 INTRODUCTION

Particulate emissions from internal combustion engines are heavily influenced by higher boiling point unsaturated compounds found within the fuel. The highest emitters are the aromatic hydrocarbons with higher carbon number [1]. The amount of higher carbon number aromatics found in gasoline is a function of the crude slate consumed at the refinery, the conditions under which the process units are operated, and the outside blend stocks used in the gasoline formulation and thus to a certain extent the PMI of the gasoline can be influenced at the refinery gate. Since gasoline is transported through common carrier pipelines and tankers subject to switch loading, there exists a possibility that higher boiling point compounds and aromatic compounds found in diesel and jet fuel could contaminate the gasoline and have an impact on the propensity of the fuel to generate higher particulate emissions.

It was the aim of this work to determine whether the diesel contamination that may occur in the distribution of gasoline has a significant impact on the particulate emissions as predicted by the PMI and PME indices. Secondarily, this work sought to identify if any of the ASTM test methods utilized in this study are sensitive to diesel fuel contamination and whether they have the potential to detect and quantify the level of contamination present in gasoline.

3.0 SCOPE OF WORK

Gasoline sample sets with low and high PMI/PME values were blended with high aromatic diesel fuel at levels approximating the contamination levels expected to occur during distribution. The sample sets were analyzed using standardized ASTM test methods to measure several properties, including those needed for determining the PMI and PME values. The PMI and PME values of the samples in each set were calculated using the corresponding measured properties obtained. Statistical analysis was performed on the data obtained from the standardized testing. Based on the statistical analysis the significance diesel contamination has on PMI and PME values was evaluated. The statistical analysis results were used to determine which standardized test methods are effective at detecting diesel contamination in gasoline samples. Recommendations for the criteria and detection threshold for each property found to be effective at detecting diesel contamination were made. The major tasks of this project are listed below with details of each task provided in the following sections.

Major Project Tasks:

- Blend the gasoline sample sets
- Perform analytical testing on sample sets
- Calculate the PMI and PME values for each sample
- Determine the impact diesel contamination had on PMI and PME values
- Identify the analytical test methods found to be effective at detecting diesel contamination in gasoline samples
- Recommend the criteria and detection threshold for the methods found to be effective at detecting diesel contamination in gasoline samples

3.1 Blend the gasoline sample sets

Gasoline and diesel fuel distributed in the market can have varying compositional characteristics due to several factors including manufacturer, region, and time of year. Two E10 gasolines and one #2 ULS diesel fuel were chosen for this project requiring the preparation of two gasoline sample sets. The two gasolines were chosen on the basis of their PMI values, one with a low PMI of 0.82 and the other a high PMI of 2.74. The focus of this project was to evaluate gasoline sample sets with diesel contamination levels similar to those expected to occur during distribution. For this project, five diesel contamination levels were chosen for evaluation, 0.0, 0.5, 1.0, 1.5, and 2.0 vol%. An overview of the sample set and contamination levels can be seen in Table 1.

TABLE 1. SAMPLE SET CONTAMINATION LEVEL OVERVIEW

	Diesel Contamination Level (Volume Percent)				
Blend #	**0.00 vol%**	**0.50 vol%**	**1.00 vol%**	**1.50 vol%***	**2.00 vol%**
1	Low PMI E10				
2		Low PMI E10 + #2 ULSD			
3			Low PMI E10 + #2 ULSD		
4				Low PMI E10 + #2 ULSD	
5					Low PMI E10 + #2 ULSD
6	High PMI E10				
7		High PMI E10 + #2 ULSD			
8			High PMI E10 + #2 ULSD		
9				High PMI E10 + #2 ULSD	
10					High PMI E10 + #2 ULSD

* - The 1.50 vol% blend was not selected to be used in the final analysis.

TABLE 2. SAMPLE SET BLENDING VOLUMES

	Component & Volume (mL) to Blend		
Blend #	**Low PMI E10**	**High PMI E10**	**#2 ULSD**
1	1000		0
2	995		5
3	990		10
4	985		15
5	980		20
6		1000	0
7		995	5
8		990	10
9		985	15
10		980	20

3.1.1 Sample Set Fuel Components

The low and high PMI E10 gasoline samples chosen for this project were received in partial 55-gallon drums. The 55-gallon drums as well as several new 2.5L aluminum containers were placed in cold storage and allowed to acclimate for 24 hours. The low and high PMI E10 gasoline drums were agitated before being unsealed. The low and high PMI E10 gasolines were then transferred to labeled new 2.5L aluminum containers using a new siphon drum pump for each drum. The filled 2.5L aluminum containers were kept in cold storage until the sample blending was to be performed.

The #2 ULS Diesel fuel used for this project was supplied by a major U.S. Refiner in four 1-quart glass Boston round containers. The diesel fuel containers were labeled and placed in our temperature-controlled diesel storage area until the sample blending was performed.

3.1.2 Sample Set Blending Process

The sample blending was performed by the lab over a three-day period as instructed. The lab was provided with blending instructions with efforts focused on maintaining uniform sample representation and minimizing the potential loss of lighter hydrocarbons from the gasoline component.

The first day of sample blending consisted of gathering the needed blending materials as well as the fuel components and placing them in our temperature-controlled diesel storage area to acclimate. This included new 1.1L aluminum containers, class-A graduated cylinders, #2 ULS Diesel, and the low & high PMI E10 gasolines. The class-A graduated cylinders were cleaned, dried, and covered with Parafilm before being placed on a utility cart with the other materials. The utility cart with all the fuel components and materials was placed in our temperature-controlled diesel storage area. The materials were allowed to acclimate 24 hours before the sample blending was performed.

The second day of sample blending was focused on blending the low and high PMI E10 gasolines with the #2 ULS Diesel fuel at the chosen contamination levels for the project, 0.0, 0.5, 1.0, 1.5, and 2.0 v%. The sample blending was performed in the same temperature-controlled diesel storage area where the fuel components and materials had been left to acclimate to on the first day. Using the appropriate class-A graduated cylinders the lab measured the volumes of each fuel component listed in Table 2 and combined them in a labeled 1.1L aluminum container. The labeled 1.1L aluminum containers were immediately fitted with a plug and capped after each sample was blended. Once all the sample blends were complete the sample filled 1.1L aluminum containers were brought into the lab and placed on a reciprocating shaker table for 5 minutes to mix the blended samples thoroughly. The blended sample containers and materials needed for the aliquoting of the sample sets were placed on a utility cart. The utility cart was moved to our gasoline cold storage area to acclimate for 24 hours.

The third day of the sample blending was focused on aliquoting the blended samples into containers designated for each analytical test method. The lab performed sample aliquoting in the same gasoline cold storage area as the blended samples and materials had been left to acclimate on the second day. For each blended sample, a set of acclimated containers was labeled with the corresponding sample information and the test method the aliquot would be designated for. Each set of containers was filled with the corresponding blended sample, leaving minimal headspace in each container. This was done as part of the efforts to minimize the potential loss of lighter hydrocarbons from the gasoline component as well as any changes to the sample that may occur from repeated sampling from a single container and a changing headspace volume. The containers the blended samples were aliquoted into were chosen to provide sufficient sample volume needed for the analytical testing while having minimal headspace. The chosen containers and the test methods they were designated for are listed in Table 3. The test method designated sample set aliquots were kept in our gasoline cold storage area until the analytical testing was scheduled to be performed.

TABLE 3. SAMPLE ALIQUOT CONTAINER OVERVIEW

Test Method	Container Volume (mL)	Container Description
ASTM D2887	40	Clear Glass Vial
ASTM D4052	40	Clear Glass Vial
ASTM D6730 -X1 FID-MSD	40	Clear Glass Vial
ASTM D7096	40	Clear Glass Vial
ASTM D8369	40	Clear Glass Vial
ASTM D86	250	Amber Glass Boston Round
Reserve	40	Clear Glass Vial
Reserve	500	Amber Glass Boston Round

3.2 Perform analytical testing on sample sets

The analytical testing for this project focused on measuring the boiling point distribution, API gravity, and hydrocarbon composition properties of the sample sets. All test methods chosen to measure the sample set properties are ASTM International active standards. Testing was performed using the standard method conditions unless noted in the following sections

The slate standardized test methods performed are listed below with a description of each method provided in the following sections.

- ASTM D4052 - Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
- ASTM D86 - Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure
- ASTM D2887 - Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
- ASTM D7096 - Determination of the Boiling Range Distribution of Gasoline by Wide-Bore Capillary Gas Chromatography
- ASTM D6730 - Determination of Individual Components in Spark Ignition Engine Fuels by 100-Metre Capillary (with Precolumn) High-Resolution Gas Chromatography
- ASTM D8369 - Detailed Hydrocarbon Analysis by High Resolution Gas

Chromatography with Vacuum Ultraviolet Absorption Spectroscopy (GC-VUV)

3.2.1 ASTM D4052 - Density, Relative Density, and API Gravity of Liquids by Digital Density Meter

ASTM D4052 test method is used to measure the density, relative density, and API gravity properties of liquid petroleum products. The test method does this by introducing a small volume of liquid sample into an instrument's oscillating U-tube. The instrument measures the change in the U-tubes oscillation frequency caused by the change in mass of the sample filled U-tube. The measured change in the U-tubes oscillation frequency is applied to a calibration curve to determine the density, relative density, and API gravity of the sample at standard temperature.

3.2.2 ASTM D86 - Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure

ASTM D86 test method is used to measure the boiling range characteristics of liquid petroleum distillate fuels. The test method uses a distillation apparatus to distill 100mL of sample fuel. The distillation is performed under the conditions designated for the group the sample fuel falls under. As the sample fuel is distilled the observed volume of sample condensate, residue, loss, and temperature are recorded. Once the distillation of the sample is completed, the observed temperatures can be corrected for the barometric pressure. The results are reported as percent evaporated or percent recovered along with the recorded temperature.

3.2.3 D2887 - Boiling Range Distribution of Petroleum Fractions by Gas Chromatography

ASTM D2887 test method is used to measure the boiling range distribution of liquid petroleum products and fractions. It is applicable to samples with a final boiling point of 538°C (1000°F). The test method uses a gas chromatography instrument equipped with a nonpolar packed or capillary column to perform a simulated true boiling point distillation of the sample. The sample is introduced onto the column and heated at a linear rate to elute the hydrocarbon components in order of increasing boiling point from the column. The detector's chromatographic response and resulting area are recorded throughout the sample analysis program.

3.2.4 ASTM D7096 - Determination of the Boiling Range Distribution of Gasoline by Wide-Bore Capillary Gas Chromatography

ASTM D7096 test method was developed to specifically cover the boiling range of gasoline samples and gasoline blending components. It is applicable to samples with a final boiling point of 280°C (536°F) or lower. The sample is injected into a heated inlet where it is vaporized and transported into a non-polar, wide-bore capillary gas chromatographic column. The column is heated at a specified rate to cause the samples to be eluted in boiling point order, such that n-pentane and lighter saturated hydrocarbons are resolved discreetly. Area slices are converted to volume using theoretical response factors and elution temperatures interpolated from a known mixture of hydrocarbons.

3.2.5 ASTM D6730-X1 - Determination of Individual Components in Spark Ignition Engine Fuels by 100-Metre Capillary (with Precolumn) High-Resolution Gas Chromatography

ASTM D6730 speciates individual hydrocarbon components with boiling ranges up to 225°C (437°F) of spark-ignition fuels and mixtures containing oxygenates. When the procedure in Appendix X1 is followed, the range extends to beyond 300°C (572°F); n-heptadecane (nC17) was successfully detected in gasoline samples spiked with diesel fuel in this project. The sample is injected into a heated inlet and then introduced onto a column at subambient temperatures. After sample separation, the column is connected to a splitter, and the effluent is split between the FID and MSD. The peak responses are quantified by response factors applied to the FID signal and components are identified by comparison to a reference chromatograph. The mass selective detector (MSD) assists in the identification of the compounds. Appendix X1 illustrates the configuration of the FID with the MSD and includes an extended component table.

3.2.6 ASTM D8369 - Detailed Hydrocarbon Analysis by High Resolution Gas Chromatography with Vacuum Ultraviolet Absorption Spectroscopy (GC-VUV)

ASTM D8369 utilizes vacuum ultraviolet absorption spectroscopy to identify the compound classes contained in a sample after separation by gas chromatography. The sample is injected into a heated inlet where it is volatilized and transferred to a 60-meter nonpolar column. The analysis software then uses Time Interval Deconvolution TID^{TM} to deconvolute the VUV signal into the representative class types (paraffin, olefin, aromatic, etc.). Individual compounds are spectrally verified and speciated by library matching; Compounds not in the library are identified by carbon number and class type. Figure 1 demonstrates the principle of TID. The acquired VUV signal is a spectral combination of the co-eluting compound’s response. When the spectrum does not match a reference spectrum in the VUV reference library, the software will search for a multi-analyte combined that provides the best fit.

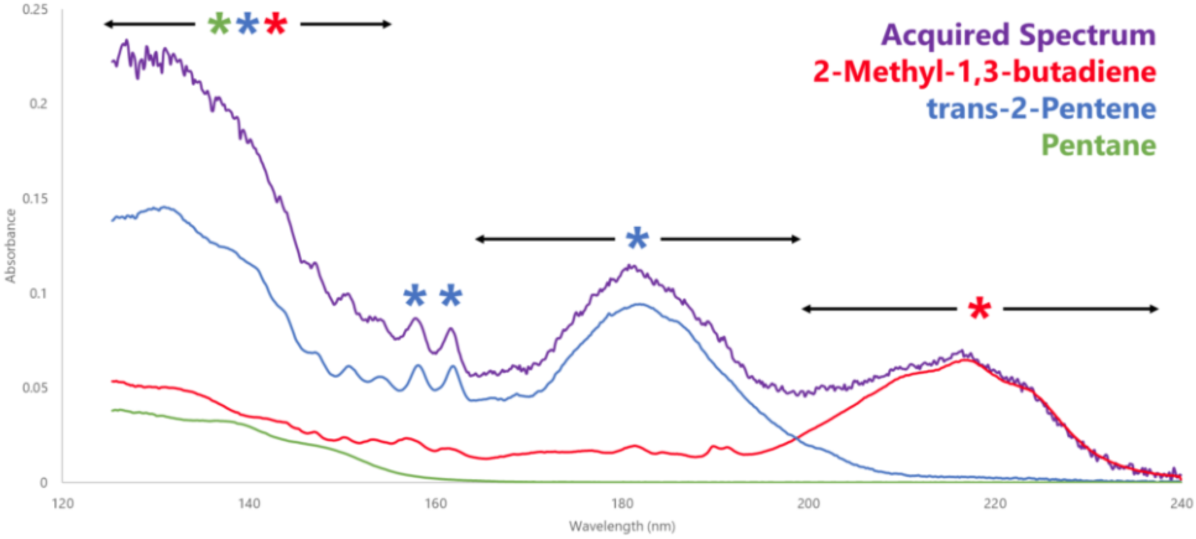

Figure 1. Because all our quantitation is first order (thanks to Beer's Law), the acquired spectrum is simply the sum of a linear combination of multiple contributing analyte spectra. The area under each contributing spectrum is the spectral response of its corresponding analyte.

FIGURE 1. VUV TIME INTERVAL DECONVULTION

3.3 Calculate the PMI and PME values for each sample

The PMI calculation developed by Aikawa, et al, [2] is a function of the Double Bond Equivalent (DBE), which is essentially the amount of unsaturation of the component molecule, and the vapor pressure of the compound at 443°K (VP443K).

$$PMI = \sum_i Wt_i * \left(\frac{1+DBE_i}{VP(443K)_i}\right)$$

In gasoline, aromatic compounds have the highest degree of unsaturation, especially the polyaromatic compounds. Thus, one can infer from the equation that aromatic compounds with low vapor pressure and corresponding high boiling points would be the largest contributors to the PMI. Knowing the aromatic fraction of the heavier boiling points could lead to a good predictor of the PM and PMI values.

The PME was developed by Crawford, et al., to enhance the PMI to account for the tendency of the PMI to be a biased indicator when used with fuels of varying ethanol content.[3] Instead of using 1+DBE as the estimator of the propensity of the compound to produce soot, the PME adopted the yTerm which is based upon the Yield Sooting Index (YSI) developed by the Pfefferle Lab Group at Yale University. Additional enhancements to the PMI include:

- A term to account for the impact of the engine technology on particulate emissions (N_{TECH});
- An adjustment for the influence of the fuel's energy density on the overall fuel economy which will impact the actual PM mass emitted per mile (43.4/LHV);

- An adjustment to the VP(443K) to account for the impact ethanol charge cooling has on the early vaporization leading to enrichment of the fuel droplets (α)
- An adjustment to the estimated PM to account for the error introduced from unidentified compounds in the DHA analysis (β)

The PME equation was further refined after a validation study using independent datasets on a variety of gasolines. [4] While functionally similar, the α and β terms were slightly modified to improve the correlation and extend the range of applicability.

PMI and PME were calculated from the ASTM D6730 DHA generated in this study. The PMI was also determined from the VUV software. In the VUV software, the PMI contribution from unknown compounds is determined by first identifying the compound class (paraffin, aromatic, olefin, etc.) and carbon number from the retention time and general shape of the spectral response. The VUV software then deconvolutes the unknown peaks into the respective hydrocarbon type contribution. From this information, the software applies a representative VP443 and DBE for the compound class and carbon number to calculate the PMI contribution from the compounds associated with that peak. In contrast, the ASTM D6730 software assigns one compound to each peak and has the potential to misidentify coeluting compounds.

TABLE 4. CALCULATED PM INDICIES

ASTM D8369 DHA-VUV PMI								
	Low PMI Fuel				High PMI Fuel			
Diesel (vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
PMI	0.740	0.740	0.750	0.760	2.400	2.380	2.420	2.480
ASTM D6730 DHA PMI & PME								
	Low PMI Fuel				High PMI Fuel			
Diesel (vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
PMI	0.820	0.880	0.880	0.990	2.470	2.570	2.500	2.590
PME (PFI)	1.110	1.150	1.130	1.160	2.220	2.320	2.250	2.300
PME (SIDI)	0.760	0.790	0.780	0.820	1.770	1.850	1.800	1.840

3.4 Determine the impact diesel contamination had on PMI and PME values

Up to 2.0% diesel contamination in gasoline had a minimal impact on the PMI values and even less impact on the PME values. At most a PMI increase of 0.17 was seen when 2.0% diesel was added to the Low PMI gasoline. The largest impact at the 2.0 % contamination on the PME (PFI) was 0.08. In some cases a general trend was observed, but it was not consistent across both fuels and all indices.

TABLE 5. IMPACT OF DIESEL CONTAMINATION ON PM INDICES

Δ PMI/PME (2.0 vol% Diesel Contamination – Neat Fuel)				
	Low PMI Fuel		High PMI Fuel	
Method	D6730	D8369	D6730	D8369
PMI	0.17	0.023	0.12	0.08
PME (PFI)	0.05	---	0.08	---
PME (SIDI)	0.06	---	0.07	---

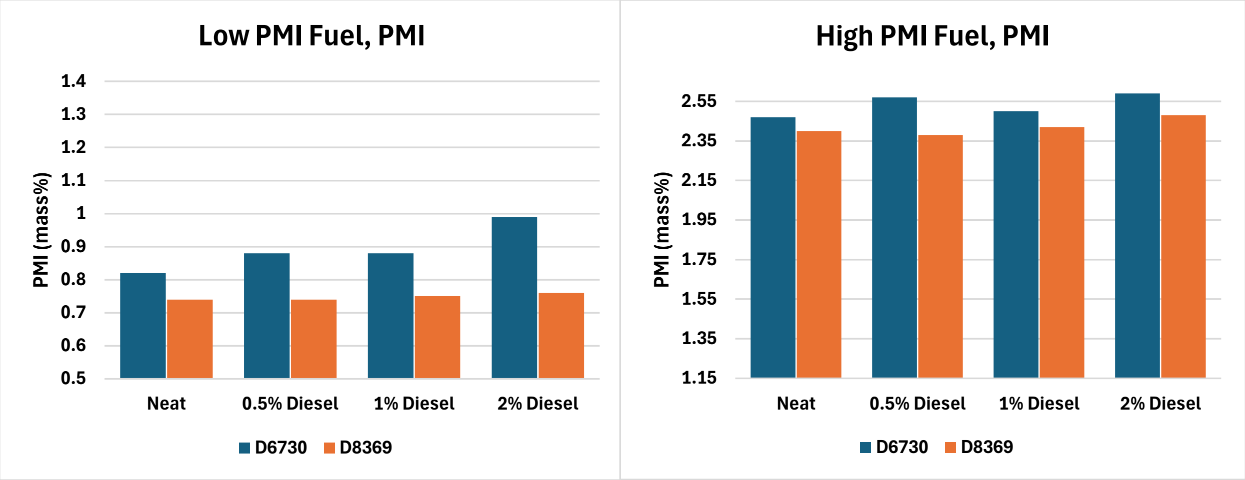

FIGURE 2. PMI DIESEL CONTAMINATION RESPONSE

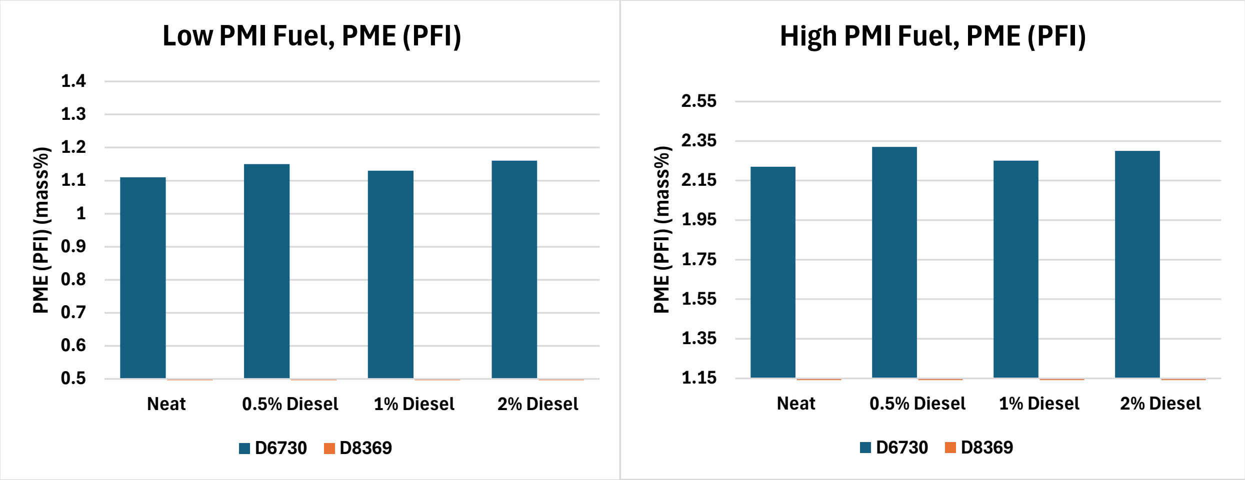

FIGURE 3. PME(PFI) DIESEL CONTAMINATION RESPONSE

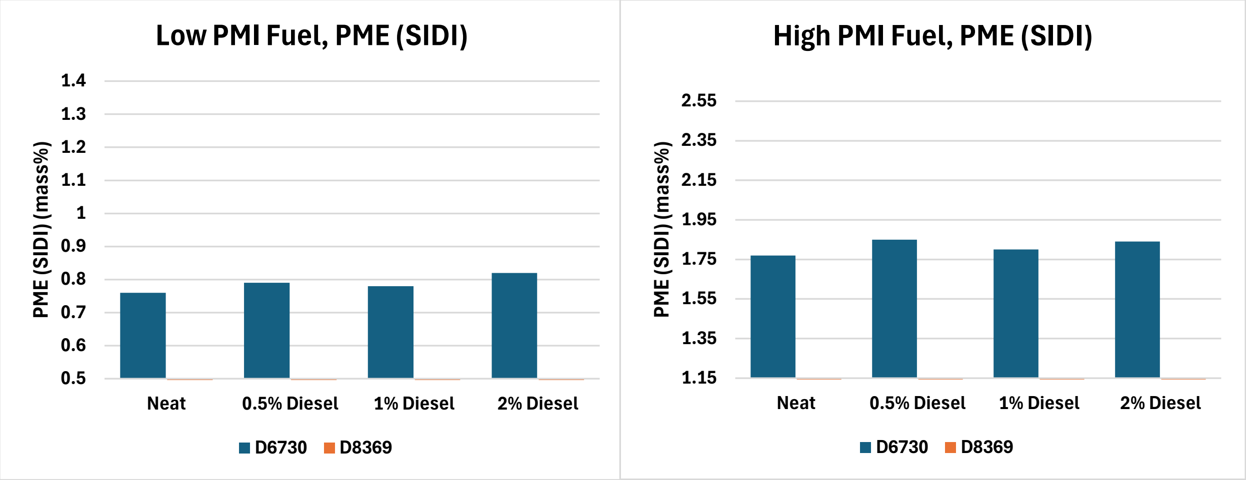

FIGURE 4. PME(SIDI) DIESEL CONTAMINATION RESPONSE

A contributing factor to the lack of discernable impact on the PM indices is the variability of the DHA methods. 1,2,4 Trimethylbenzene was the component with the largest PMI contribution in the Low PMI fuel and 2-Methylnaphthalene was the largest contributor to the High PMI fuel. Both compounds have a precision statement defined in ASTM D6730. What was observed was that the difference between all levels of contamination was less than the repeatability of the method indicating that the methods are poorly suited for detecting diesel fuel contamination below the 2.0% level. Since the PMI is dependent upon the DHA analysis then it follows that the PMI and PME will be poor predictors of diesel contamination. Another important factor is the fact that the D6730 method extends only to nC17, at best, when the "extended" Appendix X1 protocol is applied. Diesel fuel in the market can have a carbon number range approaching C30.

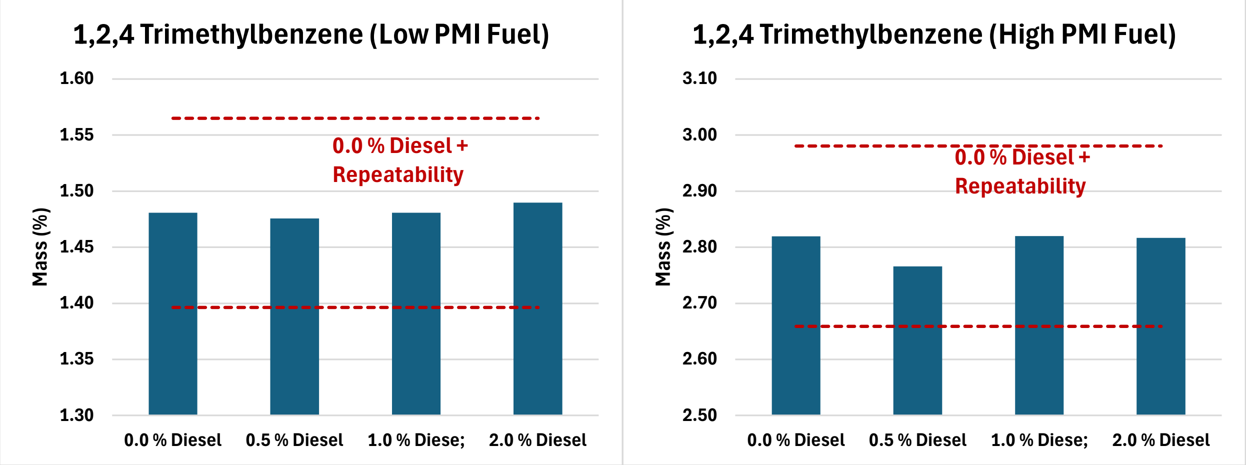

FIGURE 5. PMI CONTRIBUTION FROM 1,2,4 TRIMETHYLBENZENE

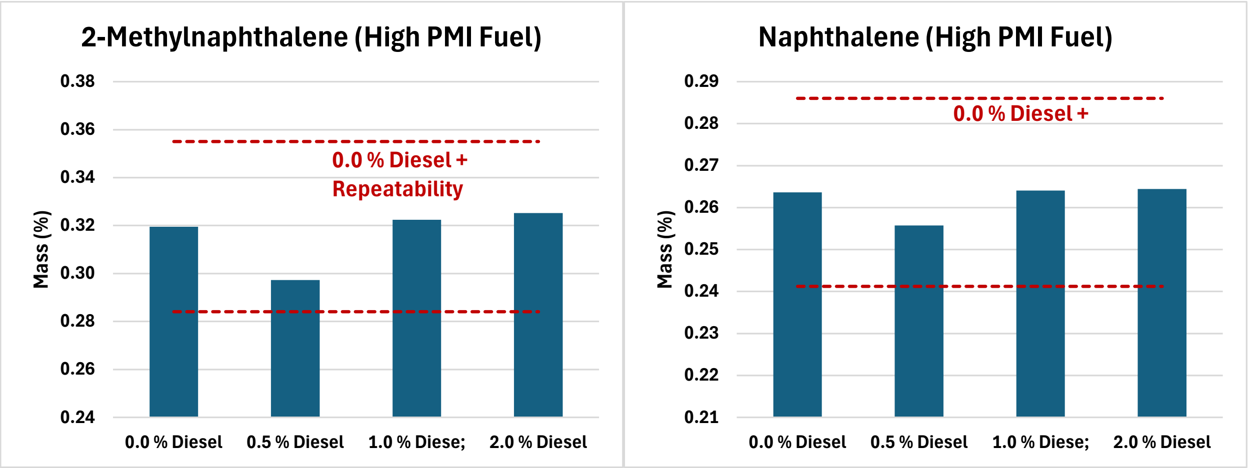

FIGURE 6. PMI CONTRIBUTION FROM SELECT PAHS

ASTM D8369 does not yet have a full precision statement in the method; however, the individual components follow the same trend as ASTM D6730. It was interesting to note that the individual components measured by the VUV method were higher than the same component as measured by DHA, yet the PMI values calculated by the VUV software were lower than those values obtained using the PMI calculated from the ASTM D6730 DHA data.

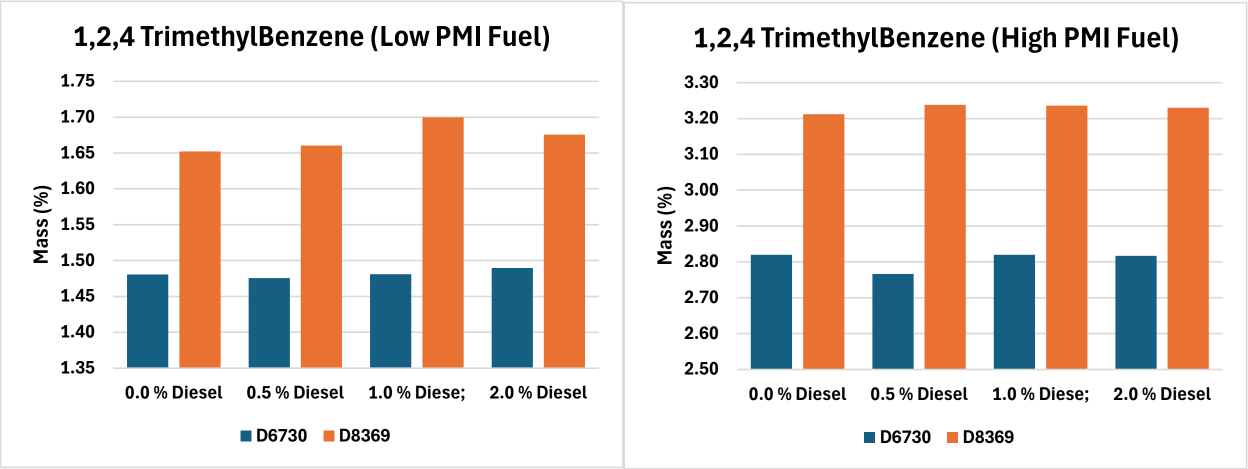

FIGURE 7. DHA METHOD COMPARISON FOR 1,2,4 TRIMETHYLBENZENE

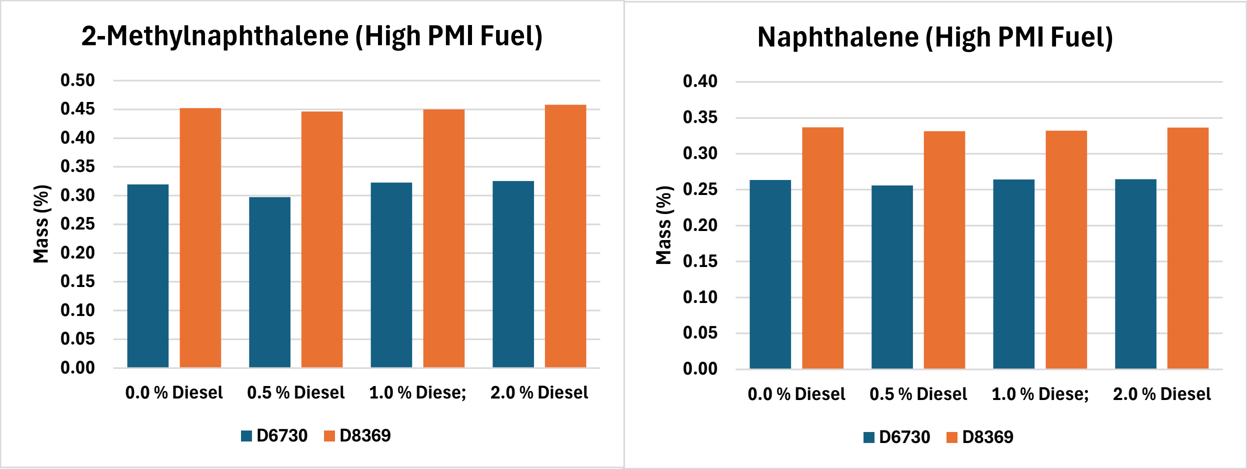

FIGURE 8. DHA METHOD COMPARISON FOR SELECT PAHS

3.5 Identify the analytical test methods found to be effective at detecting diesel contamination in gasoline samples

Diesel contamination had an influence on the measured properties of all the methods utilized within this study; however, the usefulness of that influence as a tool to determine the amount of diesel contamination in a gasoline sample will be limited.

Density, as measured by ASTM D4052, is arguably the most sensitive parameter impacted by contamination, especially when the density of the contaminant is significantly different than the density of pristine product. The method's tight repeatability of 0.00045 g/ml for gasoline samples could infer that the method can detect diesel contamination in gasoline as low as 0.3 vol%. This is supported by the density data generated in the study as highlighted in Table 6. In all cases, the increase in density from the addition of diesel fuel increased the density more than the repeatability of the method.

TABLE 6. EFFECT OF DIESEL CONTAMINATION ON DENSITY

ASTM D4052 Density @ 15°C results (g/ml)				
Diesel	Low PMI Fuel		High PMI Fuel	
(vol%)		Δ		Δ
0.0	0.7299	---	0.7647	---
0.5	0.7307	0.0008	0.7657	0.0010
1.0	0.7315	0.0016	0.7661	0.0014
2.0	0.7328	0.0029	0.7672	0.0025

While ASTM D4052 is sensitive to the effects of diesel contamination in gasoline, it is almost useless as a tool for quantifying the level of diesel contamination in gasoline due to the wide range of initial gasoline and diesel densities. The initial density of the gasoline would have to be known as well as the density of the contaminant to quantify the level of contamination. Since the density measurement is also sensitive to volatile loss, it would be difficult to separate any increase in density due to contamination from the increase in density to sample handling issues.

The detailed hydrocarbon analysis, both D6730 and D8369, do have the potential to identify diesel contamination in gasoline if the gasoline composition is known, however, the precision of the method will make it impractical to quantify low levels of contamination. The contamination will most likely be seen as an increase in the heavier components; however, since the identifiable compounds are limited to those compounds found in gasoline it will be almost impossible to separate what portion of the increase is due to diesel contamination and what portion was due to the method variability associated with the aromatics normally present in the gasoline. For the fuels used in this project, n-alkanes above C13 were clear diesel markers. However, the neat fuel composition would still need to be known to apply this metric unequivocally to a market gasoline.

TABLE 7. EFFECT OF DIESEL CONTAMINATION ON DHA AROMATICS

ASTM D6730 Aromatics by Carbon # - DHA (mass%)								
	Low PMI Fuel				High PMI Fuel			
Diesel (Vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
C6	0.968	0.952	0.96	0.959	0.769	0.766	0.771	0.769
C7	4.161	4.115	4.126	4.146	6.945	6.873	6.965	6.945
C8	6.219	6.191	6.179	6.216	10.613	10.468	10.618	10.613
C9	4.427	4.498	4.425	4.455	8.205	8.11	8.213	8.205
C10	1.561	1.71	1.622	1.629	5.035	5.041	5.052	5.035
C11	0.304	0.428	0.352	0.385	2.495	2.514	2.514	2.495
C12	0.116	0.19	0.17	0.24	1.059	1.206	1.089	1.059
C13	0.008	0.008	0.016	0.035	0.076	0.11	0.077	0.076
C14	---	---	0.001	0.011	---	---	0.011	0.008
C15	---	---	---	---	---	---	---	---
Total	17.764	18.092	17.851	18.077	35.206	35.096	35.311	35.206

Since PMI is strongly related to the aromatic content of the fuel, the following tables will focus on the changes in aromatic content as the result of the blending of gasoline with diesel fuel. Table 7 shows the impact of diesel contamination on the aromatic content as a function of the number of carbon atoms in the compound. While there appears to be a slight trend between the neat, 1.0% and 2.0% contamination levels, the 0.5% contamination level does not follow that trend. This is due to the 0.5% level being analyzed later than the neat and 1.0% and 2.0%. This demonstrates that although the method could be sensitive to contamination, the variability inherent in the method will overshadow any sensitivity of the method to quantify diesel contamination.

This notion is further supported when looking at the individual aromatic species. Table 8 compares the increase in select aromatic compounds for the High PMI Fuel. The aromatic compounds in the low PMI fuel were below the valid concentration range of the precision statement in ASTM D6730, so they are not included in this review. It is evident from the results in the table that the incremental increase in the aromatic content due to the addition of the diesel fuel was below both the repeatability and reproducibility levels cited in the method. On an individual component basis, it is even harder to spot a generic increase in concentration level due to the addition of diesel fuel further supporting the notion that the inherent variability in the method would make this method a poor candidate for trying to identify diesel contamination.

TABLE 8. ASTM D6730 SELECT AROMATICS PRECISION

ASTM D6730 Selected Aromatics Precision									
	High PMI Fuel								
	Neat fuel			0.5 % Diesel		1.0 % Diesel		2.0 % Diesel	
Carbon #	wt%	r	R	wt%	Δ	wt%	Δ	wt%	Δ
1-Methyl-3-n-propylbenzene									
C10	0.462	0.030	0.062	0.457	0.005	0.462	0.000	0.463	0.000
1,3-Dimethyl-5-ethylbenzene									
C10	0.359	0.022	0.038	0.358	0.001	0.359	0.000	0.358	0.001
1,2,4,5-Tetramethylbenzene									
C10	0.412	0.034	0.066	0.405	0.007	0.414	0.002	0.416	0.003
4-Methylindan									
C10	0.264	0.036	0.055	0.261	0.003	0.266	0.002	0.269	0.005
Naphthalene									
C10	0.264	0.022	0.045	0.256	0.008	0.264	0.001	0.264	0.001
2-Methylnaphthalene									
C11	0.320	0.035	0.071	0.297	0.022	0.322	0.003	0.325	0.006
1-Methylnaphthalene									
C11	0.169	0.019	0.036	0.156	0.014	0.170	0.001	0.170	0.001
1t-Butyl-4-ethylbenzene									
C12	0.078	0.009	0.022	0.078	0.001	0.080	0.002	0.080	0.002
1,3-Di-n-propylbenzene									
C12	0.113	0.016	0.027	0.110	0.003	0.115	0.001	0.116	0.003

ASTM D8369 currently only has an interim repeatability statement, so a more detailed review of the precision is not possible for this method. Table 9 shows the impact of diesel contamination on the aromatic content as a function of the compound's carbon number. There is no real trend of increasing aromatic content versus percent diesel fuel contamination for the VUV method.

TABLE 9. EFFECT OF DIESEL CONTAMINATION ON VUV DHA AROMATICS

ASTM D8369 Aromatics by Carbon # -VUV DHA (mass%)								
	Low PMI Fuel				High PMI Fuel			
Diesel (Vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
C6	1.040	1.068	1.044	1.036	0.832	0.863	0.830	0.824
C7	4.349	4.436	4.423	4.352	7.175	7.419	7.163	7.124
C8	6.327	5.919	6.472	6.373	11.010	10.121	11.097	11.019
C9	4.877	4.876	5.003	4.933	9.268	9.313	9.351	9.322
C10	1.382	1.344	1.411	1.411	5.407	5.273	5.415	5.501
C11	0.077	0.076	0.092	0.104	2.990	3.103	3.107	3.194
C12	0.007	0.002	0.007	0.004	0.853	0.669	0.737	0.825
C13	---	---	---	---	0.153	0.122	0.144	0.192
C14	---	---	---	---	---	---	---	---
C15	---	---	---	---	---	---	---	---
Total	18.06	17.72	18.45	18.21	37.69	36.88	37.84	38.00

All the distillation methods showed some level of sensitivity to diesel fuel contamination. Figure 9 compares how each method responded to the different contamination levels for both the Low and High PMI fuels. As expected, the simulated distillation methods showed the greatest response since the temperatures are calculated from all components in the fuel.

TABLE 10. EFFECT OF DIESEL CONTAMINATION ON ASTM D86

ASTM D86 Atmospheric Distillation % Evaporated (°C)								
	Low PMI Fuel				High PMI Fuel			
	R	Δ @0.5%	Δ @1.0%	Δ @2.0%	R	Δ @0.5%	Δ @1.0%	Δ @2.0%
90%	5.98	1.0	0.7	3.7	5.96	2.4	3.5	4.1
95%	7.55	1.5	3.4	6.7	8.73	3.3	4.0	8.4
96%		2.0	4.0	8.4			5.3	10.5
97%		2.8	5.8	11.7			7.9	13.7
98%		5.7	8.9	17.4			11.3	19.9
FBP	7.10	4.8	7.6	15.5	7.10	4.8	12.5	26.2

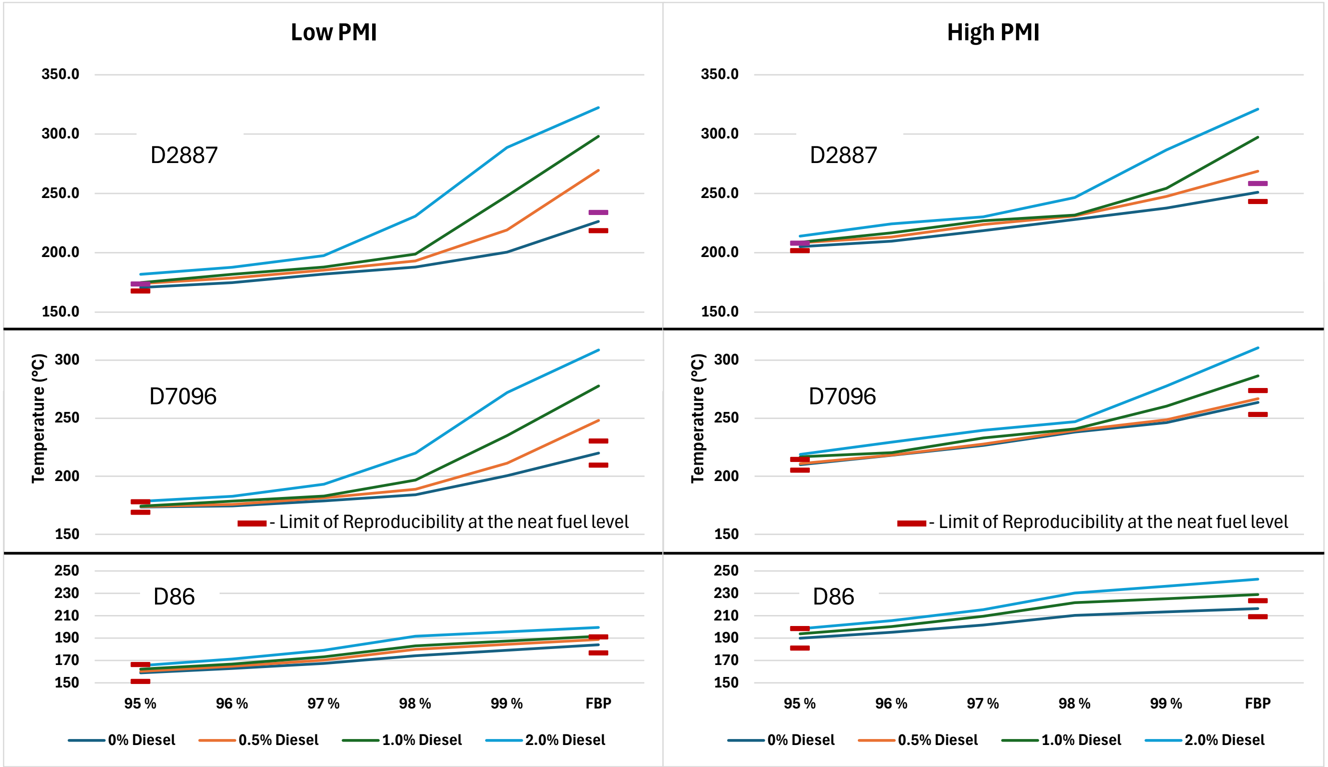

FIGURE 9. DIESEL FUEL CONTAMINATION IMPACT ON DISTILLATION

ASTM D86 was the least sensitive of the three distillation methods to diesel fuel contamination. Table 10 shows that the Final Boiling Point (FBP) was the only point in the distillation curve where the increase in boiling point exceeded the reproducibility of the method for the 1.0% and 2.0% contamination levels. Precision is not defined for the intermediate distillation points between 95% and FBP but from the table it can be observed that the earlier distillation points become decreasingly sensitive where the 96 and 97% levels only seem to be sensitive at the 2.0% and the sensitivity drops off at the 95% point.

Contamination, if detectable, should manifest as both an increase in the residue and an increase in the temperature at the tail end of the distillation. Table 10 highlights the impact of diesel fuel contamination on the temperature; however, the recovery, residue, and loss did not appear to be impacted. It would be rather difficult to translate the increase in final boiling point temperature into percentage contamination without additional information on both the neat fuel and contaminant. To further cloud the issue, the seasonal change in both gasoline and diesel has a significant impact on the final boiling points of both products, making a generalized assumption difficult.

Both simulated distillation methods showed good sensitivity to diesel contamination at all levels. Since it was developed for heavier petroleum fractions, D2887 does not have a precision statement in the range of the samples used in this study. Although not strictly applicable it can still be used as a guide for determining the response of the method to diesel fuel contamination. It is interesting to note that the precision of D7096 is similar to the precision of D2887. Table 11 and Table 12 show that both simulated distillation methods are sensitive to diesel contamination at all three levels in the 95 to FBP range.

TABLE 11. EFFECT OF DIESEL CONTAMINATION ON ASTM D2887

ASTM D2887 Simulated Distillation % Off (°C)								
	Low PMI Fuel				High PMI Fuel			
	R	Δ @0.5%	Δ @1.0%	Δ @2.0%	R	Δ @0.5%	Δ @1.0%	Δ @2.0%
90%	2.97	2.2	2.0	3.9	3.07	2.5	3.6	5.1
95%	3.01	3.3	4.1	11.1	3.17	3.3	3.7	8.9
96%		3.8	7.0	12.9		3.5	7.0	14.7
97%		3.3	5.9	15.6		5.1	8.3	11.5
98%		5.2	10.9	42.8		3.1	3.7	18.5
99%		18.7	47.4	88.2		9.9	16.7	49.1
FBP	7.63	43.1	71.7	95.9	7.63	17.9	46.4	70.2

TABLE 12. EFFECT OF DIESEL CONTAMINATION ON ASTM D7096

ASTM D7096 Gasoline Simulated Distillation (°C)								
	Low PMI Fuel				High PMI Fuel			
	R	Δ @0.5%	Δ @1.0%	Δ @2.0%	R	Δ @0.5%	Δ @1.0%	Δ @2.0%
90%	3.7	4.2	9.0	15.0	3.7	0.2	2.8	7.1
95%	4.6	0.3	0.7	4.8	4.6	0.9	6.8	8.9
96%		1.3	4.2	8.4		0.2	2.2	11.3
97%		2.5	4.1	14.2		1.1	6.4	13.0
98%		4.7	12.7	35.9		1.3	2.5	8.9
99%		10.8	34.7	71.7		2.5	14.2	31.6
FBP	10.3	28.0	57.8	88.7	10.3	3.2	22.8	47.0

3.6 Recommend the criteria and detection threshold for the methods found to be effective at detecting diesel contamination in gasoline samples

All the methods evaluated in the study demonstrated some level of sensitivity to diesel fuel contamination; however, without direct knowledge of the neat fuel or the potential contaminant, it would be rather difficult to quantify the level of contamination with certainty. Looking beyond the methods, it might be possible to use information from the simulated distillation methods to estimate the amount of diesel that might be present. Figure 10 shows the combined chromatography signal from the Neat High PMI fuel and the diesel fuel used in this study. There is considerable overlap in the 6 to 9 minute region, but looking beyond 11 minutes in the middle of the diesel chromatograph, there were peaks that were wholly from the diesel fuel.

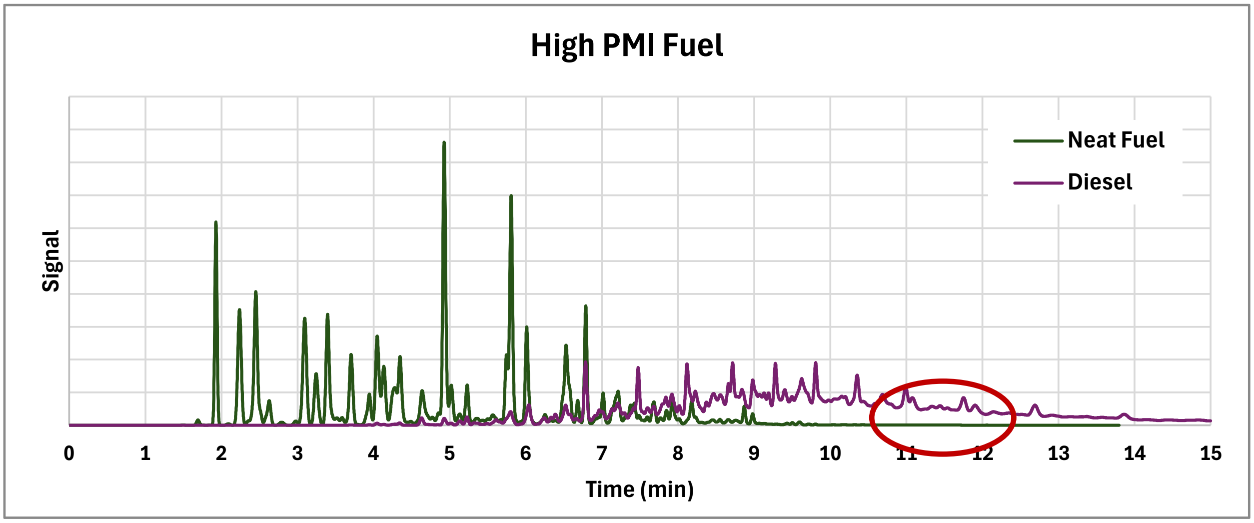

FIGURE 10. D7096 NEAT GASOLINE AND DIESEL CHROMATOGRAPHS

Figure 11 is an expanded view of the region highlighted in the red circle. You can clearly see peaks associated with the diesel fuel only. These peaks could potentially be used as markers for estimating the amount of distillate contamination.

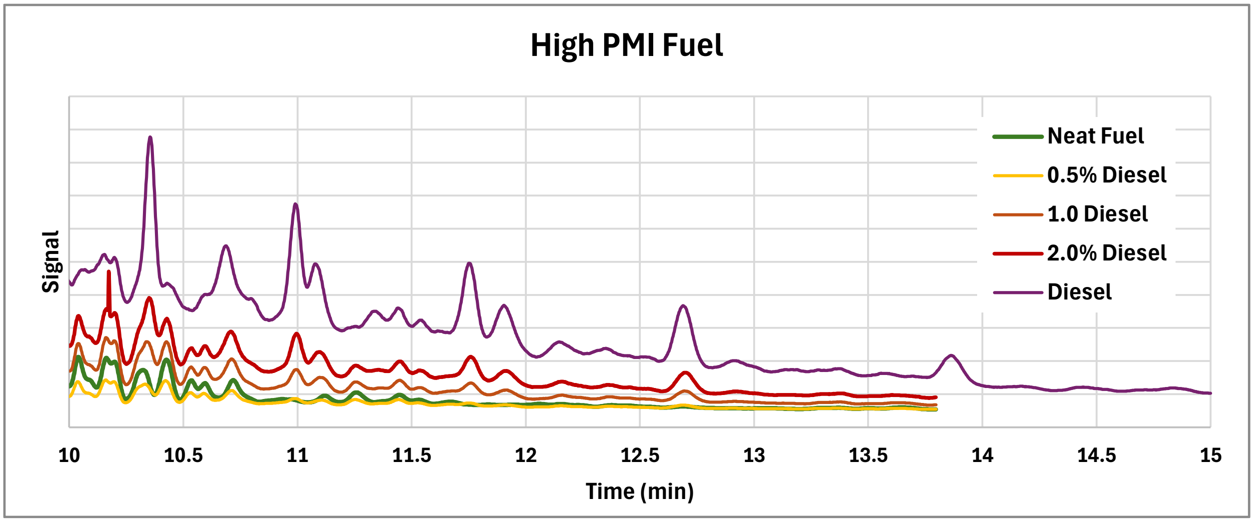

FIGURE 11. D7096 DIESEL CONTAMINATION REGION

One approach would be to measure the area under the chromatograph in a region known to be free from gasoline, apply both the relative response factors and a proportionality factor to account for the portion of distillate that is coeluting with the gasoline and take ratio of the adjusted distillate area to the total area under the chromatograph. For this approach to be viable, additional information would need to be gathered, such the variability of the region of interest amongst different market fuels to develop a representative proportionality factor. Additionally, a survey of pristine gasolines in the market, that is those fuels that have not been subject to potential contamination, would be needed to identify a reasonable start time to begin the measurement of where diesel contamination begins.

Additionally, some method modifications may be required. For D7096 the run time should be extended to capture all potential diesel peaks. An extended calibration mixture should be used to extend the relative response factor validation, alternatively, the theoretical relative response factors could be used if the measured relative response factors are within 10% of the theoretical values.

4.0 CONCLUSIONS

Low levels of diesel fuel contamination did not appear to have a noticeable impact on the PMI or PME calculations as determined either by ASTM D 6730 FID DHA or by ASTM D8369 VUV DHA. The variability of the methods themselves precluded any discrimination at the component level which in turn impacted the PM indices. It was observed that 78% of the compounds eluting past n-Pentadecane in the results from ASTM D6730 were listed as "unidentified" which contributed to the lack of response to the diesel contamination. ASTM D8369 VUV DHA may not be able to detect low concentrations of heavier compounds (approximately < 0.005% mass aromatics) using the standard ASTM D8369 conditions. Also, both methods lack sufficient carbon number range to capture the bulk of diesel fuel components. As the methods are currently written, neither method appears to be a good tool for detecting the effects or concentration of diesel contamination in gasoline.

ASTM D4052 Density and the distillation methods did show a detectable level of response to the different levels of diesel contamination. The simulated distillation methods had the best response particularly in the distillation tail. Even though there was a response, without a priori knowledge of the neat fuel and potential contaminant, it would be difficult to develop a standard protocol for determining the level of diesel fuel contamination from the data obtained in the standard method report. However, it could be possible to utilize the information contained in the chromatography from the simulated distillation methods to estimate the level of diesel fuel contamination. Any signal in the region that should be free from gasoline can be viewed as a diesel fuel contribution. The area in the diesel fuel range could be scaled to estimate the area's contribution from the diesel contamination and compared to the total area to get a reasonable effort of the level of contamination.

5.0 REFERENCES

[1] Iizuka, M., Kirii, A., Takeda, H., Watanabe, H., "Effect of Fuel Properties on Particulate Matter Emissions From a Direct Injection Gasoline Vehicle," *JSAE Review*, 28(3)

[2] Aikawa, K., Sakurai, T., and Jetter, J., "Development of a Predictive Model for Gasoline Vehicle Particulate Matter Emissions," *SAE Int. J. Fuels Lubr.* 3(2):610-622, 2010, doi:10.4271/2010-01-2115.

[3] CRC RW-107-2 (2021), "An Improved Index for Particulate Matter Emissions (PME)". CRC Project RW-107-2. March 2021.

[4] CRC RW-107-3a (2023), "Validation of the New PM Index Formula: Phase 2". CRC Project RW-107-3a. September 2023.

APPENDIX A

DETAILED ANALYTICAL DATA

TABLE 13. ASTM D4052 DENSITY DATA

ASTM D4052 Density, Relative Density, and API								
	Low PMI Fuel				High PMI Fuel			
Diesel (vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
API (°)	62.30	62.07	61.87	61.53	53.47	53.24	53.13	52.86
Sp. Gravity @ 60°F	0.7302	0.7310	0.7318	0.7330	0.7650	0.7660	0.7664	0.7675
Density @ 15°C, g/ml	0.7299	0.7307	0.7315	0.7328	0.7647	0.7657	0.7661	0.7672

TABLE 14. ASTM D525 OXIDATION STABILITY DATA

ASTM D525 Oxidation Stability of Gasoline		
	Low PMI Fuel	High PMI Fuel
Run Length (min)	1440	1440
Induction Period (min)	748	Not Observed
Maximum Pressure (psi)	164.1	156.8
Time to Maximum Pressure (min)	381	286
Minimum Pressure (psi)	63.0	70.7
Time to Minimum Pressure (min)	1289	1440
Press Drop (psi)	101.1	86.1
Observation (report)	Break	Slow Oxidizing Fuel

TABLE 15. ASTM D86 DISTILLATION DATA

ASTM D86 Distillation at Atmospheric Pressure								
	Low PMI Fuel				High PMI Fuel			
Diesel (vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
IBP (°C)	35.6	38.1	36.7	36.2	40.8	43.6	38.9	41.3
1% Evap. (°C)	41.6	42.2	41.6	41.2	47.2	---	47.3	47.5
2% Evap. (°C)	46.0	46.4	46.0	46.1	51.7	---	51.7	51.7
3% Evap. (°C)	47.9	48.4	48.1	48.3	53.7	---	53.8	53.8
4% Evap. (°C)	49.5	49.8	49.7	50.0	54.9	---	55.2	55.3
5% Evap. (°C)	50.8	50.9	50.8	51.1	55.9	56.1	56.1	56.3
6% Evap. (°C)	51.7	51.9	51.9	52.1	56.8	---	56.8	57.3
7% Evap. (°C)	52.5	52.6	52.7	53.0	57.5	---	57.5	57.9
8% Evap. (°C)	53.2	53.3	53.4	53.6	58.1	---	58.2	58.5
9% Evap. (°C)	53.8	54.0	54.0	54.3	58.6	---	58.7	59.0
10% Evap. (°C)	54.5	54.5	54.5	55.0	59.1	58.9	59.2	59.5
11% Evap. (°C)	55.0	55.1	55.0	55.5	59.6	---	59.5	60.0
12% Evap. (°C)	55.5	55.6	55.3	56.1	60.0	---	60.0	60.4
13% Evap. (°C)	55.9	56.1	55.8	56.5	60.4	---	60.4	60.8
14% Evap. (°C)	56.3	56.4	56.3	57.0	60.9	---	60.7	61.2
15% Evap. (°C)	56.7	56.8	56.8	57.4	61.3	61.3	61.1	61.6
16% Evap. (°C)	57.0	57.1	57.2	57.7	61.8	---	61.5	61.9
17% Evap. (°C)	57.4	57.6	57.5	58.1	62.2	---	61.8	62.2
18% Evap. (°C)	57.9	58.2	57.9	58.6	62.5	---	62.2	62.6
19% Evap. (°C)	58.3	58.5	58.3	59.0	62.8	---	62.7	63.0
20% Evap. (°C)	58.7	58.9	58.8	59.4	63.2	63.3	63.1	63.5
21% Evap. (°C)	59.1	59.3	59.3	59.8	63.6	---	63.5	63.9
22% Evap. (°C)	59.4	59.6	59.7	60.3	64.0	---	63.9	64.2
23% Evap. (°C)	59.8	60.0	60.1	60.6	64.4	---	64.2	64.7
24% Evap. (°C)	60.2	60.5	60.4	61.0	64.8	---	64.6	65.0
25% Evap. (°C)	60.6	60.8	60.8	61.4	65.1	---	65.0	65.3
26% Evap. (°C)	61.0	61.2	61.2	61.6	65.4	---	65.3	65.6
27% Evap. (°C)	61.3	61.6	61.6	62.1	65.7	---	65.6	66.0
28% Evap. (°C)	61.8	62.0	61.9	62.4	66.1	---	66.0	66.4
29% Evap. (°C)	62.1	62.3	62.2	62.6	66.4	---	66.3	66.7
30% Evap. (°C)	62.5	62.7	62.7	63.0	66.8	66.9	66.6	67.0
31% Evap. (°C)	62.8	63.0	63.0	63.4	67.1	---	66.9	67.3
32% Evap. (°C)	63.1	63.3	63.3	63.8	67.4	---	67.3	67.6
33% Evap. (°C)	63.5	63.7	63.6	64.1	67.7	---	67.7	67.8

34% Evap. (°C)	63.8	64.1	64.0	64.6	68.1	---	68.0	68.2
35% Evap. (°C)	64.1	64.4	64.3	64.8	68.4	---	68.7	68.8
36% Evap. (°C)	64.4	64.8	64.7	65.1	68.7	---	69.2	69.4
37% Evap. (°C)	64.7	65.1	65.0	65.6	69.2	---	70.3	70.3
38% Evap. (°C)	65.1	65.4	65.3	65.9	70.1	---	71.8	71.8
39% Evap. (°C)	65.5	65.6	65.7	66.2	71.5	---	73.7	74.1
40% Evap. (°C)	65.8	66.0	66.1	66.5	73.7	74.3	76.5	77.2
41% Evap. (°C)	66.1	66.5	66.3	66.8	76.1	---	79.6	80.5
42% Evap. (°C)	66.4	66.7	66.5	67.1	79.0	---	82.8	83.9
43% Evap. (°C)	66.7	67.3	66.8	67.5	82.2	---	86.2	87.5
44% Evap. (°C)	66.9	68.0	67.3	68.0	85.4	---	89.5	90.6
45% Evap. (°C)	67.4	68.3	68.2	68.8	88.5	---	92.5	93.5
46% Evap. (°C)	68.3	69.4	69.7	70.1	91.4	---	95.2	96.3
47% Evap. (°C)	70.0	70.9	71.8	72.1	94.3	---	97.7	98.8
48% Evap. (°C)	72.5	73.6	74.5	74.8	96.9	---	100.0	101.2
49% Evap. (°C)	75.6	76.4	78.0	78.0	99.3	---	102.3	103.3
50% Evap. (°C)	78.8	80.0	81.5	81.2	101.6	102.6	104.3	105.2
51% Evap. (°C)	82.2	83.1	84.4	84.3	103.6	---	106.2	106.9
52% Evap. (°C)	85.2	86.0	87.3	87.3	105.6	---	107.9	108.6
53% Evap. (°C)	87.9	88.8	89.8	89.8	107.5	---	109.4	110.3
54% Evap. (°C)	90.4	91.0	91.9	91.9	109.1	---	110.9	111.8
55% Evap. (°C)	92.4	93.0	93.6	93.9	110.7	---	112.4	113.4
56% Evap. (°C)	94.1	94.9	95.4	95.7	112.2	---	113.9	114.9
57% Evap. (°C)	95.7	96.4	96.8	97.0	113.7	---	115.4	116.3
58% Evap. (°C)	97.2	97.8	98.2	98.5	115.2	---	116.8	117.7
59% Evap. (°C)	98.6	99.1	99.5	99.8	116.7	---	118.2	119.1
60% Evap. (°C)	99.9	100.4	100.6	101.2	118.3	118.3	119.6	120.6
61% Evap. (°C)	101.2	101.6	101.5	102.6	119.8	---	121.2	122.2
62% Evap. (°C)	102.4	102.8	102.5	103.8	121.3	---	122.7	123.8
63% Evap. (°C)	103.5	104.0	103.8	104.8	122.8	---	124.2	125.3
64% Evap. (°C)	104.6	105.1	105.3	105.3	124.2	---	125.8	126.8
65% Evap. (°C)	105.7	106.3	106.6	106.0	125.7	---	127.2	128.3
66% Evap. (°C)	106.7	107.3	107.8	107.8	127.4	---	128.7	129.8
67% Evap. (°C)	107.7	108.4	108.8	109.5	128.9	---	130.2	131.3
68% Evap. (°C)	108.8	109.6	109.9	110.8	130.4	---	131.9	132.9
69% Evap. (°C)	109.8	110.7	111.2	111.9	131.9	---	133.4	134.6
70% Evap. (°C)	111.0	111.9	112.5	113.1	133.1	134.2	135.0	136.2
71% Evap. (°C)	112.3	113.3	113.8	114.5	134.6	---	136.5	137.7
72% Evap. (°C)	113.6	114.5	115.0	115.7	136.4	---	138.1	139.4
73% Evap. (°C)	114.8	115.8	116.2	117.1	138.3	---	139.9	141.1
74% Evap. (°C)	116.1	117.1	117.4	118.4	140.2	---	141.7	142.7
75% Evap. (°C)	117.4	118.3	118.8	119.8	142.0	---	143.2	144.5

76% Evap. (°C)	118.8	119.7	120.2	121.2	143.7	---	144.9	146.3
77% Evap. (°C)	120.1	121.2	121.7	122.8	145.4	---	146.8	148.1
78% Evap. (°C)	121.5	122.5	123.1	124.4	147.2	---	148.6	149.9
79% Evap. (°C)	123.0	124.1	124.6	125.9	149.0	---	150.5	151.6
80% Evap. (°C)	124.4	125.6	126.1	127.8	150.7	151.6	152.3	153.6
81% Evap. (°C)	125.9	127.3	127.9	129.3	152.4	---	154.2	155.5
82% Evap. (°C)	127.5	128.8	129.6	131.2	154.3	---	156.1	157.4
83% Evap. (°C)	128.0	130.7	131.4	133.1	156.1	---	158.0	159.4
84% Evap. (°C)	129.1	132.4	133.2	135.0	158.1	---	159.9	161.5
85% Evap. (°C)	132.7	134.4	135.1	137.1	160.3	---	161.6	163.6
86% Evap. (°C)	135.6	136.6	137.3	138.9	162.4	---	163.1	165.0
87% Evap. (°C)	138.0	138.8	139.5	141.4	164.3	---	165.2	166.4
88% Evap. (°C)	140.3	141.2	142.0	143.9	166.2	---	168.4	169.1
89% Evap. (°C)	142.7	143.6	144.2	146.4	168.3	---	171.5	172.1
90% Evap. (°C)	145.2	146.2	145.9	148.9	171.4	---	174.9	175.5
91% Evap. (°C)	147.7	148.6	148.2	151.8	175.1	173.8	177.9	179.1
92% Evap. (°C)	150.3	151.2	151.4	154.5	178.4	---	181.3	183.3
93% Evap. (°C)	152.5	151.9	155.1	156.3	181.9	---	185.0	187.8
94% Evap. (°C)	155.1	156.5	158.5	160.5	185.6	---	189.2	192.4
95% Evap. (°C)	158.8	160.3	162.2	165.5	189.9	193.2	193.9	198.3
96% Evap. (°C)	162.8	164.8	166.8	171.2	195.1	---	200.4	205.6
97% Evap. (°C)	167.4	170.2	173.2	179.1	201.7	---	209.6	215.4
98% Evap. (°C)	174.2	179.9	183.1	191.6	210.4	---	221.7	230.3
FBP (°C)	184.0	188.8	191.6	199.5	216.4	221.2	228.9	242.6
Recovered (%)	98.6	98.1	98.4	98.2	98.7	98.3	98.9	98.7
Residue (%)	0.8	1.0	0.9	0.9	0.8	1.1	0.8	0.8
Loss (%)	0.6	0.9	0.7	0.9	0.5	0.6	0.3	0.5
DI	1,010.1	1,018.5	1,026.1	1,031.0	1,193.0	1,201.9	1,213.9	1,220.9
Pressure (mmHg)	746.7	739.4	746.7	746.7	746.7	740.0	746.7	746.7

TABLE 16. ASTM D2887 SIMULATION DISTILLATION DATA

ASTM D2887 Boiling Range of Petroleum Fractions								
	Low PMI Fuel				High PMI Fuel			
Diesel (vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
IBP (°C)	22.6	22.8	22.7	22.5	25.4	27.3	25.5	25.4
1% Off (°C)	23.6	23.4	23.7	23.6	26.6	28.1	26.6	26.5
2% Off (°C)	25.7	27.3	25.9	25.7	27.9	28.9	28.0	27.9
3% Off (°C)	27.3	28.4	27.4	27.2	28.7	29.3	28.8	28.7
4% Off (°C)	28.2	28.8	28.3	28.1	29.3	29.6	29.4	29.3
5% Off (°C)	28.8	29.1	28.9	28.7	29.8	29.9	29.9	29.9
6% Off (°C)	29.3	29.4	29.4	29.2	30.3	30.2	30.4	30.3
7% Off (°C)	29.7	29.6	29.8	29.7	30.8	30.6	30.9	30.8
8% Off (°C)	30.1	29.9	30.2	30.1	31.3	31.0	31.4	31.3
9% Off (°C)	30.5	30.3	30.6	30.5	31.8	31.6	31.9	31.9
10% Off (°C)	31.0	30.6	31.1	31.0	32.5	32.2	32.8	32.8
11% Off (°C)	31.5	31.1	31.5	31.4	33.4	33.3	33.7	33.7
12% Off (°C)	31.9	31.5	32.1	31.9	34.2	33.9	34.6	34.5
13% Off (°C)	32.5	32.1	32.8	32.8	35.0	34.5	35.4	35.3
14% Off (°C)	33.4	33.1	33.6	33.7	35.9	35.0	36.4	36.4
15% Off (°C)	34.1	33.6	34.3	34.4	37.3	35.8	38.1	38.0
16% Off (°C)	34.8	34.2	35.0	35.1	39.3	37.4	40.9	41.1
17% Off (°C)	35.6	34.7	35.9	36.0	47.1	39.8	49.5	49.6
18% Off (°C)	36.5	35.4	36.9	37.1	50.9	51.3	51.8	51.7
19% Off (°C)	37.7	36.3	38.2	38.4	52.6	53.0	53.3	53.3
20% Off (°C)	39.2	37.6	39.9	40.4	54.0	54.0	54.7	54.7
21% Off (°C)	42.6	38.9	46.2	47.5	55.4	55.0	56.2	56.3
22% Off (°C)	49.5	43.1	50.3	50.4	57.1	56.4	58.3	58.4
23% Off (°C)	51.4	51.6	51.9	52.1	59.4	59.0	60.8	60.9
24% Off (°C)	52.8	52.8	53.3	53.4	61.9	61.1	63.4	63.5
25% Off (°C)	54.0	53.7	54.5	54.7	64.4	65.4	65.6	65.7
26% Off (°C)	55.3	54.6	55.8	56.1	66.3	67.3	67.3	67.4
27% Off (°C)	56.8	55.7	57.6	57.9	67.9	68.5	68.9	69.0
28% Off (°C)	58.8	57.7	59.7	60.2	69.2	69.2	69.8	70.0
29% Off (°C)	61.1	59.9	62.0	62.5	70.5	69.9	72.1	72.3
30% Off (°C)	63.3	62.1	64.2	64.5	72.7	73.1	73.5	73.6
31% Off (°C)	65.2	65.8	66.0	66.2	73.8	74.2	74.5	74.7
32% Off (°C)	66.8	67.3	67.4	67.7	75.0	75.0	77.2	78.3
33% Off (°C)	68.1	68.4	68.7	68.9	78.9	79.0	80.5	80.9
34% Off (°C)	69.1	69.1	69.4	69.5	81.2	81.6	82.6	83.1
35% Off (°C)	69.7	69.5	70.1	70.5	83.3	83.9	84.5	84.9

36% Off (°C)	70.7	70.1	71.6	72.2	85.1	85.9	86.2	86.5
37% Off (°C)	72.4	71.7	73.1	73.4	86.7	87.3	87.6	87.9
38% Off (°C)	73.6	73.7	74.1	74.4	88.0	88.6	88.9	89.2
39% Off (°C)	74.6	74.6	75.1	75.6	89.3	90.0	90.3	90.6
40% Off (°C)	75.7	75.3	77.1	78.6	90.7	91.5	91.8	92.3
41% Off (°C)	78.8	77.0	79.9	80.6	92.3	93.5	93.6	94.2
42% Off (°C)	80.7	80.5	81.7	82.6	94.1	95.4	96.1	97.3
43% Off (°C)	82.7	82.7	83.8	84.4	97.1	98.8	98.7	98.9
44% Off (°C)	84.5	84.8	85.3	85.8	98.9	99.5	99.4	99.7
45% Off (°C)	85.9	86.4	86.6	87.0	99.6	100.9	101.2	102.1
46% Off (°C)	87.0	87.4	87.6	88.0	101.9	103.5	103.3	104.7
47% Off (°C)	88.0	88.2	88.5	88.9	104.2	106.9	106.7	108.4
48% Off (°C)	88.9	89.1	89.5	90.0	107.8	111.0	109.7	110.1
49% Off (°C)	90.0	90.1	90.8	91.5	110.0	111.9	110.7	111.0
50% Off (°C)	91.3	91.5	92.3	93.1	110.9	112.5	111.4	111.6
51% Off (°C)	92.9	93.7	93.9	94.6	111.5	113.0	112.0	112.1
52% Off (°C)	94.5	95.2	95.3	95.9	112.1	113.5	112.5	112.6
53% Off (°C)	95.8	96.3	96.6	97.2	112.6	113.9	112.9	113.1
54% Off (°C)	97.1	97.4	97.9	98.5	113.0	114.2	113.3	113.5
55% Off (°C)	98.4	98.8	98.8	99.1	113.5	114.5	113.8	113.9
56% Off (°C)	99.0	99.4	99.3	99.6	113.9	115.0	114.2	114.9
57% Off (°C)	99.5	99.9	99.8	100.0	114.4	117.1	115.9	116.7
58% Off (°C)	100.0	100.3	100.3	101.1	116.2	118.8	117.5	118.2
59% Off (°C)	100.5	102.2	101.9	102.6	117.8	120.2	119.0	120.3
60% Off (°C)	102.3	103.4	103.0	103.6	119.2	125.9	123.3	126.5
61% Off (°C)	103.2	105.1	104.5	105.9	124.7	128.1	127.1	128.4
62% Off (°C)	105.2	107.0	106.6	108.5	127.3	135.9	132.0	135.4
63% Off (°C)	107.2	110.5	109.4	110.2	133.0	139.5	136.7	137.9
64% Off (°C)	109.8	111.6	110.5	111.0	137.1	140.9	138.5	139.2
65% Off (°C)	110.8	112.3	111.3	111.6	138.8	141.8	139.7	140.3
66% Off (°C)	111.4	112.8	111.8	112.1	139.9	142.5	140.6	141.1
67% Off (°C)	112.0	113.2	112.3	112.6	140.8	143.0	141.4	141.7
68% Off (°C)	112.5	113.6	112.8	113.0	141.5	143.4	142.0	142.3
69% Off (°C)	112.9	114.0	113.2	113.4	142.1	143.8	142.5	142.8
70% Off (°C)	113.3	114.3	113.6	114.1	142.6	144.1	143.0	143.2
71% Off (°C)	113.7	115.6	114.5	115.9	143.0	144.4	143.4	144.2
72% Off (°C)	114.8	117.4	116.3	117.5	143.5	145.2	144.9	145.9
73% Off (°C)	116.6	119.3	117.9	119.1	145.1	147.1	146.3	146.9
74% Off (°C)	118.2	121.6	119.6	122.4	146.5	148.0	147.2	147.6
75% Off (°C)	120.1	124.7	123.1	126.5	147.3	148.5	147.8	150.7
76% Off (°C)	123.7	127.6	126.8	127.6	147.9	151.3	152.3	157.9
77% Off (°C)	126.9	129.6	127.9	132.4	152.5	158.1	160.0	162.0

78% Off (°C)	128.1	136.9	133.6	137.0	160.4	162.7	162.5	163.5
79% Off (°C)	134.2	139.9	137.4	139.1	162.7	164.0	163.8	164.4
80% Off (°C)	137.7	141.6	139.4	140.4	163.9	164.8	164.7	165.8
81% Off (°C)	139.5	142.3	140.5	141.2	164.8	166.0	166.2	167.7
82% Off (°C)	140.6	142.9	141.3	141.8	166.4	167.9	168.3	169.8
83% Off (°C)	141.4	143.3	141.9	143.2	168.5	170.5	170.1	170.8
84% Off (°C)	142.0	144.2	143.5	145.4	170.2	171.5	171.0	171.4
85% Off (°C)	143.6	146.4	145.5	146.5	171.0	172.1	171.6	173.9
86% Off (°C)	145.7	147.5	146.6	148.9	171.7	172.7	174.7	176.4
87% Off (°C)	146.7	148.9	149.3	153.3	174.9	177.0	176.8	182.1
88% Off (°C)	149.5	152.7	153.6	160.9	177.1	181.2	182.6	184.2
89% Off (°C)	153.8	160.8	161.1	163.1	182.8	184.6	184.6	187.9
90% Off (°C)	161.2	163.4	163.2	165.1	184.8	187.3	188.4	189.9
91% Off (°C)	163.3	164.9	165.2	167.6	188.6	190.4	190.3	195.6
92% Off (°C)	165.2	167.2	167.6	169.8	190.5	194.7	196.2	199.6
93% Off (°C)	167.7	170.1	169.8	170.7	196.5	198.6	200.5	203.3
94% Off (°C)	169.8	171.2	170.7	174.9	201.1	203.7	204.3	207.6
95% Off (°C)	170.8	174.1	174.9	181.9	205.1	208.4	208.8	214.0
96% Off (°C)	174.9	178.7	181.9	187.8	209.7	213.2	216.7	224.4
97% Off (°C)	182.0	185.3	187.9	197.6	218.7	223.8	227.0	230.2
98% Off (°C)	188.0	193.2	198.9	230.8	228.0	231.1	231.7	246.5
99% Off (°C)	200.5	219.2	247.9	288.7	237.6	247.5	254.3	286.7
FBC (°C)	226.4	269.5	298.1	322.3	250.9	268.8	297.3	321.1

TABLE 17. ASTM D7096 GASOLINE SIMULATED DISTILLATION DATA

ASTM D7096 Boiling Range of Gasoline								
	Low PMI Fuel				High PMI Fuel			
Diesel (vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
IBP (°C)	-1.9	-2.1	-1.7	-1.8	10.1	10.2	10.2	10.2
1% Vol (°C)	-0.8	-1.1	-0.7	-0.7	10.5	10.6	10.5	10.5
2% Vol (°C)	2.8	1.2	9.4	8.2	10.9	11	10.9	10.9
3% Vol (°C)	10.6	10.6	10.7	10.7	11.1	11.2	11.1	11.1
4% Vol (°C)	11	10.9	11	11	11.3	11.4	11.3	11.3
5% Vol (°C)	11.2	11.2	11.2	11.2	11.5	11.6	11.5	11.6
6% Vol (°C)	11.4	11.4	11.4	11.4	11.7	11.8	11.7	11.7
7% Vol (°C)	11.6	11.5	11.6	11.6	11.9	12	11.9	11.9
8% Vol (°C)	11.7	11.7	11.7	11.8	12.1	12.2	12.1	12.1
9% Vol (°C)	11.9	11.9	12	12	12.3	12.4	12.3	12.4
10% Vol (°C)	12.1	12.1	12.2	12.2	12.7	12.8	12.8	12.8
11% Vol (°C)	12.3	12.3	12.4	12.4	25.6	25.3	25.8	26
12% Vol (°C)	12.6	12.6	12.7	12.8	26.8	26.7	26.9	26.9
13% Vol (°C)	13.5	13.3	24.9	25.4	27.4	27.3	27.5	27.5
14% Vol (°C)	26.4	26.2	26.6	26.7	27.9	27.8	27.9	28.1
15% Vol (°C)	27	26.9	27.2	27.2	28.3	28.3	28.5	28.6
16% Vol (°C)	27.5	27.4	27.6	27.7	29	29.2	30.1	32.9
17% Vol (°C)	27.9	27.8	28.1	28.1	34.6	34.7	35	35.1
18% Vol (°C)	28.3	28.2	28.4	28.5	35.3	35.4	35.5	35.6
19% Vol (°C)	28.8	28.8	29.2	29.3	35.7	35.8	35.9	36
20% Vol (°C)	32.2	33	34	34.3	36.1	36.1	36.2	36.3
21% Vol (°C)	34.8	34.9	35.2	35.3	36.4	36.5	36.7	36.8
22% Vol (°C)	35.5	35.5	35.7	35.7	37	37.2	37.6	38.2
23% Vol (°C)	35.9	35.9	36.1	36.1	39.7	41.5	42.2	42.7
24% Vol (°C)	36.2	36.2	36.4	36.5	43.1	48.1	55.9	58.4
25% Vol (°C)	36.7	36.7	37	37.1	58.7	59	59.2	59.4
26% Vol (°C)	37.4	37.7	38.2	38.4	59.4	59.6	59.7	59.9
27% Vol (°C)	38.9	40.5	41.2	41.5	59.9	60.1	60.2	60.3
28% Vol (°C)	41.9	42.3	42.7	42.9	60.4	60.5	60.6	60.7
29% Vol (°C)	43	43.8	49.3	55.6	60.8	61	61.4	63.4
30% Vol (°C)	57.2	58.5	58.9	59	63.5	63.9	64.1	64.4
31% Vol (°C)	59.1	59.3	59.5	59.6	64.4	64.6	64.9	65.3
32% Vol (°C)	59.6	59.7	59.9	60	65.3	67.6	67.9	68.1
33% Vol (°C)	60.1	60.2	60.4	60.4	68.1	68.3	68.4	68.5
34% Vol (°C)	60.4	60.6	60.7	60.8	68.5	68.6	68.7	68.9
35% Vol (°C)	60.9	61.2	62.1	63.6	68.9	69	69.3	69.6

36% Vol (°C)	63.6	64.1	64.3	64.5	69.5	69.8	70.7	73.5
37% Vol (°C)	64.5	64.8	65	65.4	72.7	75.5	79	79.9
38% Vol (°C)	65.3	67.5	67.8	68.1	79.7	80.1	80.4	80.7
39% Vol (°C)	68	68.2	68.4	68.5	80.6	80.8	81	81.3
40% Vol (°C)	68.4	68.6	68.7	68.8	81.2	81.5	85.8	86.9
41% Vol (°C)	68.8	68.9	69.1	69.3	86.7	87.1	87.6	89.1
42% Vol (°C)	69.2	69.4	69.7	70	88.4	89.2	89.6	89.8
43% Vol (°C)	69.9	70.4	70.9	72	89.7	89.8	90	90.3
44% Vol (°C)	71.5	73.5	74.6	76.3	90.2	90.3	90.5	90.8
45% Vol (°C)	75.7	78.8	79.5	79.9	90.6	90.8	91.3	91.9
46% Vol (°C)	79.8	80.2	80.5	80.7	91.6	91.8	92.3	92.6
47% Vol (°C)	80.6	80.8	80.9	81.2	92.4	92.5	92.9	93.6
48% Vol (°C)	81.1	81.4	82.1	86.3	93.2	93.4	95.3	95.9
49% Vol (°C)	85.7	86.7	87.1	87.5	95.6	95.8	96.4	96.9
50% Vol (°C)	87.3	87.8	88.9	89.5	96.6	96.8	97.4	97.9
51% Vol (°C)	89.3	89.6	89.8	90	97.7	97.8	98.2	98.5
52% Vol (°C)	89.9	90.1	90.3	90.5	98.3	98.4	98.7	99.2
53% Vol (°C)	90.3	90.5	90.7	91	98.8	98.9	102.5	104.2
54% Vol (°C)	90.8	91	91.2	91.5	103.7	103.9	104.6	105.6
55% Vol (°C)	91.3	91.5	91.8	92.1	104.8	105	107.5	109.8
56% Vol (°C)	91.9	92.2	92.4	92.8	108.8	109.2	110.1	110.2
57% Vol (°C)	92.6	92.8	93.2	94.9	110.1	110.1	110.3	110.4
58% Vol (°C)	93.5	95	95.6	96	110.3	110.3	110.4	110.5
59% Vol (°C)	95.8	96	96.3	96.6	110.5	110.5	110.6	110.7
60% Vol (°C)	96.4	96.5	96.8	97	110.6	110.6	110.9	111.1
61% Vol (°C)	96.8	97	97.2	97.5	111	110.9	111.3	111.6
62% Vol (°C)	97.3	97.5	97.7	98.1	111.4	111.4	111.9	113.6
63% Vol (°C)	97.8	98	98.2	98.5	112.2	112.4	114.7	116.6
64% Vol (°C)	98.3	98.4	98.6	98.8	115.1	115.4	119.9	124.5
65% Vol (°C)	98.6	98.7	99	100.1	121.2	122.6	125.2	126.1
66% Vol (°C)	99.1	99.6	101.5	104.1	125.5	125.7	127.8	131.7
67% Vol (°C)	103.2	103.9	104.3	104.6	128.8	129.5	133.1	136.4
68% Vol (°C)	104.3	104.4	104.8	105.6	134.2	135.2	136.6	137.1
69% Vol (°C)	104.9	105.2	106.6	108.9	136.8	136.8	137.2	137.7
70% Vol (°C)	107.3	108.6	109.2	109.9	137.4	137.5	137.7	137.9
71% Vol (°C)	109.3	109.7	110.1	110.3	137.8	137.8	138	138.1
72% Vol (°C)	110.1	110.2	110.3	110.5	138	138	138.2	138.3
73% Vol (°C)	110.4	110.4	110.5	110.8	138.2	138.2	138.3	138.5
74% Vol (°C)	110.6	110.6	110.9	111.3	138.4	138.4	138.6	139.1
75% Vol (°C)	111	111	111.4	112.1	138.7	138.8	139.5	144
76% Vol (°C)	111.5	111.7	112.5	115.2	142.2	143.5	144.1	144.6
77% Vol (°C)	112.8	114.3	115.7	120.1	144.3	144.4	144.8	145.7

78% Vol (°C)	116.1	119.2	120.6	124	144.9	145.1	147	157
79% Vol (°C)	120.9	122.3	124.5	125.8	151.4	152.4	158.8	160.5
80% Vol (°C)	124.8	125.3	125.9	128.6	159.3	159.8	160.8	161.7
81% Vol (°C)	126.1	127.3	129.5	133.9	161	161.2	161.9	163.4
82% Vol (°C)	130.1	132.1	135	137	162.3	162.5	163.8	168.6
83% Vol (°C)	135.8	136.6	137.2	137.8	164.4	166.2	169.1	173.1
84% Vol (°C)	137.3	137.5	137.8	138.1	170.8	172.5	173.2	173.8
85% Vol (°C)	137.9	138	138.2	138.4	173.4	173.5	173.8	174.2
86% Vol (°C)	138.2	138.3	138.5	139.4	174	174.1	174.3	176.3
87% Vol (°C)	138.5	138.8	139.9	144.1	174.4	174.5	177.2	178.9
88% Vol (°C)	140.9	143.4	144.2	145.2	178.2	178.5	179.2	182.2
89% Vol (°C)	144.3	144.6	145.4	153.6	181.2	181.5	182.4	183.7
90% Vol (°C)	145.7	149.9	154.7	160.7	182.8	183	185.6	189.9
91% Vol (°C)	156.3	159.5	160.9	162.7	187.9	188.5	190.5	196.6
92% Vol (°C)	161.1	161.8	163	168.1	191.9	193	198.7	201.9
93% Vol (°C)	163.3	164.5	168.5	173.3	199.9	200.3	203.8	208.4
94% Vol (°C)	169	172.2	173.4	174.3	206.1	206.7	209	213.3
95% Vol (°C)	173.6	173.9	174.3	178.4	210	210.9	216.8	218.9
96% Vol (°C)	174.4	175.7	178.6	182.8	218.1	218.3	220.3	229.4
97% Vol (°C)	178.9	181.4	183	193.1	226.6	227.7	233	239.6
98% Vol (°C)	184.1	188.8	196.8	220	238.2	239.5	240.7	247.1
99% Vol (°C)	200.5	211.3	235.2	272.2	246.3	248.8	260.5	277.9
FBC (°C)	220.1	248.1	277.9	308.8	263.7	266.9	286.5	310.7

TABLE 18. DIESEL FUEL SIMULATED DISTILLATION DATA

ASTM D2887 Boiling Range of Petroleum Fractions		
	Diesel Fuel	
Method	D2887	D7096M
IBP (°C)	103.0	104.8
1% Off (°C)	118.6	123.2
2% Off (°C)	140.5	137.5
3% Off (°C)	151.0	146.1
4% Off (°C)	159.7	158.8
5% Off (°C)	165.8	167.6
6% Off (°C)	169.9	173.6
7% Off (°C)	174.4	174.7
8% Off (°C)	177.2	178.4
9% Off (°C)	182.1	182.1
10% Off (°C)	185.6	185.9
11% Off (°C)	189.7	191.7
12% Off (°C)	193.6	193.3
13% Off (°C)	196.8	198.6
14% Off (°C)	198.4	203.3
15% Off (°C)	201.1	206.1
16% Off (°C)	203.9	208.8
17% Off (°C)	206.4	212.1
18% Off (°C)	209.3	215.6
19% Off (°C)	211.8	216.7
20% Off (°C)	214.4	218.4
21% Off (°C)	216.6	220.3
22% Off (°C)	218.2	223.4
23% Off (°C)	220.0	226.1
24% Off (°C)	222.3	228.0
25% Off (°C)	224.8	230.1
26% Off (°C)	226.9	232.3
27% Off (°C)	228.8	234.0
28% Off (°C)	230.7	235.3
29% Off (°C)	232.3	236.5
30% Off (°C)	234.2	238.5
31% Off (°C)	236.3	240.2
32% Off (°C)	237.7	243.0
33% Off (°C)	238.8	244.5
34% Off (°C)	240.3	246.2
35% Off (°C)	242.4	248.2

36% Off (°C)	244.7	250.2
37% Off (°C)	247.0	252.4
38% Off (°C)	249.1	253.6
39% Off (°C)	251.0	255.1
40% Off (°C)	252.7	257.2
41% Off (°C)	254.5	259.1
42% Off (°C)	255.9	261.3
43% Off (°C)	257.0	263.3
44% Off (°C)	258.5	264.7
45% Off (°C)	260.4	266.2
46% Off (°C)	262.3	268.1
47% Off (°C)	264.5	270.1
48% Off (°C)	266.3	271.1
49% Off (°C)	268.0	272.9
50% Off (°C)	269.9	275.1
51% Off (°C)	271.9	277.3
52% Off (°C)	273.4	279.4
53% Off (°C)	274.6	281.3
54% Off (°C)	276.4	283.3
55% Off (°C)	278.5	285.6
56% Off (°C)	280.4	286.9
57% Off (°C)	282.3	288.2
58% Off (°C)	284.1	289.9
59% Off (°C)	286.0	291.8
60% Off (°C)	288.0	293.4
61% Off (°C)	289.5	294.8
62% Off (°C)	290.7	296.6
63% Off (°C)	292.7	298.7
64% Off (°C)	294.9	300.2
65% Off (°C)	296.9	301.5
66% Off (°C)	298.5	302.9
67% Off (°C)	300.2	305.0
68% Off (°C)	302.1	307.1
69% Off (°C)	303.8	309.1
70% Off (°C)	305.1	311.0
71% Off (°C)	306.2	313.2
72% Off (°C)	307.8	315.4
73% Off (°C)	309.8	316.6
74% Off (°C)	311.6	317.9
75% Off (°C)	313.4	319.2
76% Off (°C)	315.4	321.1
77% Off (°C)	317.5	322.9

78% Off (°C)	319.0	324.8
79% Off (°C)	320.6	326.9
80% Off (°C)	322.7	328.7
81% Off (°C)	324.9	330.3
82% Off (°C)	327.1	332.6
83% Off (°C)	329.3	335.2
84% Off (°C)	331.6	337.9
85% Off (°C)	333.4	340.7
86% Off (°C)	336.0	343.7
87% Off (°C)	339.0	346.2
88% Off (°C)	342.0	350.3
89% Off (°C)	344.8	354.7
90% Off (°C)	347.0	359.2
91% Off (°C)	350.3	363.9
92% Off (°C)	354.1	369.0
93% Off (°C)	357.8	376.5
94% Off (°C)	361.7	385.3
95% Off (°C)	366.4	394.0
96% Off (°C)	371.4	407.1
97% Off (°C)	378.1	423.5
98% Off (°C)	386.3	448.5
98% Off (°C)	399.5	488.5
FBC (°C)	411.4	526.8

TABLE 19. ASTM D8369 GC-VUV DATA

ASTM D8369 DHA by GC-VUV (mass%)								
	Low PMI Fuel				High PMI Fuel			
Diesel (vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
Carbon Number	**Paraffin Content**							
C3	0.06	0.06	0.05	0.06				
C4	1.38	1.39	1.25	1.32	0.16	0.16	0.15	0.15
C5	4.40	4.46	4.26	4.32	4.61	4.65	4.52	4.51
C6	4.09	4.14	4.09	4.07	3.83	3.91	3.83	3.81
C7	2.64	2.65	2.66	2.63	2.14	2.17	2.15	2.13
C8	0.92	0.85	0.95	0.86	1.13	1.11	1.10	1.16
C9	0.44	0.42	0.44	0.44	0.45	0.46	0.42	0.47
C10	0.17	0.18	0.21	0.20	0.17	0.17	0.18	0.19
C11	0.01	0.01		0.04	0.05	0.06	0.07	0.07
C12			0.01	0.02			0.03	0.04
C13			0.01	0.03			0.02	0.03
C14								0.00
C15				0.01				0.01
C16				0.01				0.01
C17				0.00				
Total	14.11	14.15	13.93	14.01	12.54	12.68	12.47	12.60
	Iso-paraffin Content							
C3								
C4	0.20	0.21	0.19	0.19	0.01	0.01	0.01	0.00
C5	5.70	5.77	5.46	5.58	4.68	4.66	4.56	4.54
C6	7.00	7.07	6.97	6.97	6.45	6.57	6.44	6.39
C7	7.85	7.79	7.90	7.81	5.52	5.66	5.54	5.55
C8	9.23	9.23	9.43	9.17	4.12	4.28	4.31	4.36
C9	1.91	2.16	2.29	2.18	1.25	1.16	1.50	1.42
C10	0.98	0.96	1.12	1.12	0.70	0.63	0.67	0.57
C11	0.15	0.17	0.19	0.23	0.08	0.05	0.11	0.15
C12	0.04	0.03	0.07	0.02	0.02	0.01	0.04	0.04
C13				0.01	0.03	0.01	0.01	0.01
C14				0.02			0.00	0.01
C15				0.00				0.01
C16								
C17				0.00				0.01
Total	33.08	33.38	33.62	33.29	22.85	23.04	23.18	23.06
	Olefin Content							
C3								

C4	0.11	0.11	0.09	0.10	0.01	0.01	0.00	0.01
C5	3.94	3.96	3.82	3.87	2.01	2.03	1.97	1.97
C6	4.32	4.29	4.23	4.23	1.98	2.00	1.96	1.97
C7	2.53	2.36	2.63	2.57	1.09	1.04	1.02	1.11
C8	1.61	1.71	1.48	1.72	0.40	0.31	0.57	0.43
C9	0.28	0.25	0.36	0.25	0.03	0.08	0.10	0.04
C10	0.27	0.24	0.22	0.29	0.05	0.07	0.06	0.05
C11				0.00				0.00
C12	0.01	0.01	0.02	0.02	0.00	0.01		
C13				0.00	0.01	0.01	0.01	0.01
C14	0.01			0.01				
C15								
C16								
C17								
Total	13.10	12.92	12.85	13.06	5.58	5.55	5.69	5.59
	Naphthene Content							
C3								
C4								
C5	0.42	0.43	0.40	0.42	0.49	0.50	0.48	0.47
C6	3.26	3.32	3.26	3.24	4.01	4.09	3.97	3.93
C7	3.69	3.85	3.71	3.65	3.26	3.32	3.23	3.35
C8	2.22	2.11	2.04	2.45	2.71	2.56	2.29	2.02
C9	0.42	0.24	0.33	0.26	0.24	0.24	0.21	0.31
C10	0.30	0.20	0.26	0.22	0.06	0.10	0.13	0.20
C11	0.10	0.07	0.02	0.04	0.07	0.06	0.04	0.03
C12	0.00			0.01		0.01		
C13								
C14								
C15								
C16								
C17								
Total	10.40	10.21	10.02	10.28	10.85	10.89	10.35	10.32
	Aromatic Content							
C6	1.04	1.07	1.04	1.04	0.83	0.86	0.83	0.82
C7	4.35	4.44	4.42	4.35	7.18	7.42	7.16	7.12
C8	6.33	5.92	6.47	6.37	11.01	10.12	11.10	11.02
C9	4.88	4.88	5.00	4.93	9.27	9.31	9.35	9.32
C10	1.38	1.34	1.41	1.41	5.41	5.27	5.41	5.50
C11	0.08	0.08	0.09	0.10	2.99	3.10	3.11	3.19
C12	0.01	0.00	0.01	0.00	0.85	0.67	0.74	0.82
C13					0.15	0.12	0.14	0.19
C14								

C15								
C16								
C17								
Total	18.06	17.72	18.45	18.21	37.69	36.88	37.84	38.00
	Oxygenate Content							
C1								
C2	11.26	11.62	11.13	11.14	10.50	10.96	10.47	10.43
C3								
C4								
Total	11.26	11.62	11.13	11.14	10.50	10.96	10.47	10.43
	All Hydrocarbon Types							
C1								
C2	11.26	11.62	11.13	11.14	10.50	10.96	10.47	10.43
C3	0.06	0.06	0.05	0.06				
C4	1.69	1.70	1.53	1.61	0.18	0.17	0.16	0.16
C5	14.46	14.61	13.95	14.19	11.78	11.84	11.53	11.50
C6	19.72	19.89	19.59	19.53	17.10	17.43	17.03	16.92
C7	21.06	21.08	21.32	21.02	19.19	19.62	19.10	19.27
C8	20.31	19.82	20.37	20.56	19.36	18.38	19.36	18.99
C9	7.92	7.94	8.43	8.07	11.24	11.25	11.58	11.56
C10	3.10	2.91	3.22	3.23	6.39	6.24	6.45	6.52
C11	0.34	0.32	0.31	0.42	3.20	3.27	3.32	3.44
C12	0.07	0.04	0.10	0.06	0.88	0.70	0.80	0.91
C13			0.01	0.03	0.18	0.14	0.18	0.24
C14	0.01			0.03			0.00	0.02
C15				0.01				0.02
C16				0.01				
C17				0.01				0.01
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 20. ASTM D6730 DHA DATA

ASTM D6730 DHA by 100-metre Column								
	Low PMI Fuel				High PMI Fuel			
Diesel (vol%)	0.0	0.5	1.0	2.0	0.0	0.5	1.0	2.0
Carbon Number	**Paraffin Content**							
C3	0.05	0.05	0.05	0.04	0.00			
C4	1.30	1.24	1.27	1.20	0.16	0.15	0.16	0.15
C5	4.63	4.47	4.60	4.49	4.94	4.80	4.90	4.83
C6	3.85	3.76	3.83	3.81	3.62	3.56	3.62	3.59
C7	2.55	2.52	2.53	2.54	2.08	2.06	2.09	2.08
C8	1.06	1.06	1.06	1.06	1.02	1.00	1.02	1.02
C9	0.39	0.39	0.39	0.40	0.41	0.41	0.41	0.42
C10	0.16	0.17	0.17	0.18	0.16	0.17	0.17	0.18
C11	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.08
C12	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05
C13	0.00	0.01	0.01	0.02	0.03	0.03	0.04	0.05
C14	0.00	0.01	0.01	0.02	0.01	0.02	0.02	0.03
C15		0.00	0.01	0.02		0.01	0.01	0.02
C16		0.00	0.01	0.01	0.00	0.01	0.01	0.01
C17			0.00	0.01			0.01	0.01
Total	14.05	13.75	14.00	13.90	12.52	12.33	12.56	12.51
	Iso-paraffin Content							
C3								
C4	0.19	0.18	0.19	0.18	0.01	0.01	0.01	0.01
C5	5.94	5.72	5.89	5.75	4.97	4.77	4.90	4.82
C6	6.56	6.34	6.52	6.47	6.11	5.96	6.10	6.04
C7	7.32	7.25	7.28	7.28	5.15	5.15	5.15	5.13
C8	9.14	9.10	9.05	9.09	4.37	4.44	4.39	4.38
C9	3.16	3.20	3.15	3.18	2.48	2.51	2.47	2.48
C10	1.28	1.43	1.30	1.31	1.02	1.04	0.99	1.03
C11	1.08	1.19	1.12	1.10	0.48	0.56	0.48	0.49
C12	0.05	0.08	0.06	0.06	0.10	0.11	0.10	0.11
C13	0.01	0.03	0.03	0.04	0.19	0.21	0.19	0.21
C14								
C15								
C16								
C17								
Total	34.74	34.53	34.58	34.46	24.88	24.76	24.79	24.70
	Olefin Content							
C3								

C4	0.12	0.13	0.11	0.11	0.02	0.02	0.02	0.02
C5	4.18	4.03	4.14	4.05	2.23	2.17	2.21	2.19
C6	3.73	3.75	3.71	3.70	1.84	1.88	1.78	1.83
C7	2.43	2.51	2.42	2.43	1.21	1.39	1.20	1.21
C8	1.53	1.55	1.55	1.57	0.93	0.98	0.92	0.94
C9	0.62	0.68	0.62	0.63	0.36	0.36	0.36	0.37
C10	0.23	0.26	0.23	0.24	0.17	0.19	0.19	0.17
C11	0.02	0.03	0.03	0.03	0.04	0.05	0.04	0.04
C12	0.00	0.01	0.00	0.00	0.01	0.02	0.01	0.01
C13								
C14								
C15								
C16								
C17								
Total	12.86	12.95	12.83	12.76	6.81	7.05	6.74	6.78
	Naphthene Content							
C3								
C4								
C5	0.39	0.38	0.39	0.38	0.46	0.45	0.46	0.45
C6	2.84	2.79	2.83	2.82	3.49	3.48	3.49	3.47
C7	3.36	3.36	3.35	3.36	3.07	3.10	3.08	3.07
C8	1.39	1.64	1.43	1.42	1.34	1.41	1.31	1.34
C9	0.71	0.74	0.70	0.72	0.65	0.67	0.65	0.66
C10	0.18	0.23	0.18	0.19	0.16	0.23	0.16	0.17
C11								
C12								
C13	0.00		0.00	0.00	0.01	0.02	0.01	0.02
C14								
C15								
C16								
C17								
Total	8.88	9.14	8.88	8.89	9.20	9.35	9.17	9.19
	Aromatic Content							
C6	0.97	0.95	0.96	0.96	0.77	0.77	0.77	0.77
C7	4.16	4.12	4.13	4.15	6.95	6.87	6.97	6.94
C8	6.22	6.19	6.18	6.22	10.61	10.47	10.62	10.59
C9	4.43	4.50	4.42	4.46	8.21	8.11	8.21	8.20
C10	1.56	1.71	1.62	1.63	5.03	5.04	5.05	5.06
C11	0.30	0.43	0.35	0.39	2.50	2.51	2.51	2.55
C12	0.12	0.19	0.17	0.24	1.06	1.21	1.09	1.17
C13	0.01	0.01	0.02	0.04	0.08	0.11	0.08	0.09
C14			0.00	0.01	0.01	0.01	0.01	0.02

C15								
C16								
C17								
Total	17.76	18.09	17.85	18.08	35.21	35.10	35.31	35.38
	Oxygenate Content							
C1								
C2	11.03	10.63	11.01	10.98	10.51	10.19	10.48	10.37
C3								
C4	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00
Total	11.03	10.64	11.02	10.98	10.52	10.20	10.48	10.38
	All Hydrocarbon Types							
C1	0.00		0.00	0.00	0.00			
C2	11.03	10.63	11.01	10.98	10.51	10.19	10.48	10.37
C3	0.05	0.05	0.05	0.04	0.00			
C4	1.61	1.56	1.57	1.49	0.19	0.19	0.18	0.18
C5	15.14	14.61	15.02	14.68	12.59	12.19	12.48	12.29
C6	17.95	17.58	17.85	17.76	15.82	15.64	15.76	15.70
C7	19.83	19.75	19.71	19.75	18.46	18.57	18.48	18.44
C8	19.34	19.54	19.26	19.36	18.28	18.29	18.25	18.27
C9	9.30	9.52	9.29	9.38	12.12	12.06	12.11	12.13
C10	3.42	3.81	3.51	3.55	6.55	6.67	6.57	6.61
C11	1.45	1.70	1.54	1.57	3.07	3.20	3.10	3.16
C12	0.18	0.30	0.25	0.33	1.21	1.37	1.25	1.34
C13	0.03	0.05	0.06	0.10	0.30	0.37	0.32	0.37
C14	0.00	0.01	0.01	0.03	0.02	0.03	0.03	0.04
C15		0.00	0.01	0.02		0.01	0.01	0.02
C16		0.00	0.01	0.01	0.00	0.01	0.01	0.01
C17			0.00	0.01			0.01	0.01
Sub Total	99.31	99.10	99.16	99.07	99.13	98.79	99.04	98.93
Unknown	0.69	0.90	0.84	0.93	0.87	1.21	0.96	1.07
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

APPENDIX B

DHA Reports

APPENDIX C

Simulated Distillation Reports