ORNL/TM-2016/83

Assessment of Gasoline Additive Containing Ditert-butoxypropanol

B.H. West
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April 2016

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ASSESSMENT OF GASOLINE ADDITIVE CONTAINING DITERT-BUTOXYPROPANOL

B.H. West
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Oak Ridge National Laboratory

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ABSTRACT

The Fuels, Engines, and Emissions Research Center completed analysis and testing of the CPS Powershot gasoline additive under the auspices of the Department of Energy's Technical Assistance for US Small Businesses in Vehicle Technologies. Gas chromatography-mass spectrometry (GC-MS) was used to quantify the makeup of the additive, finding a predominance of 2,3-Ditert-Butoxypropanol, also known as Glyceryl Di-Tert-Butyl Ether (GTBE). Blends of the additive at 2 and 4 volume percent were subjected to a number of standard ASTM tests, including Research Octane Number, Motor Octane Number, distillation, and vapor pressure. Results show a high boiling range and low vapor pressure for the additive, and a very modest octane boosting effect in gasoline with and without ethanol.

1. BACKGROUND

The efficiency of modern spark-ignition engines is limited by knock, especially with the widespread growth in the use of turbocharged, direct-injection engines. The use of high-octane fuels can enable more optimized combustion phasing, allowing for improved efficiency. Recently published data[1,2,3,4,5,6] highlight the potential fuel economy benefits of high-octane fuels that take advantage of ethanol's properties in a mid-level blend. Two paths to higher octane fuel include more intensive refinery operations, which can impact cost and yield, and increased ethanol blending, which raises concerns about infrastructure and vehicle compatibility. A third, less explored path could involve the use of an octane-boosting additive.

CPS Powershot is a registered oxygenated fuel additive, Glyceryl Di-Tert-Butyl Ether (GTBE), marketed as an octane booster. The ORNL effort explored the chemical makeup of the Powershot additive and further examined the effect of the additive on three relevant gasoline fuels.

[1] Leone, T., Olin, E., Anderson, J., Jung, H. et al., "Effects of Fuel Octane Rating and Ethanol Content on Knock, Fuel Economy, and CO2 for a Turbocharged DI Engine," *SAE Int. J. Fuels Lubr*. 7(1):9-28, 2014, doi:10.4271/2014-01-1228

[2] Splitter, D.A., and Szybist, J.P., "Experimental Investigation of Spark-Ignited Combustion with High-Octane Biofuels and EGR. 2. Fuel and EGR Effects on Knock-Limited Load and Speed," *Energy & Fuels*, 28(2): 1432-1445, 2014, doi:10.1021/ef401575e

[3] Jung, H., Leone, T., Shelby, M., Anderson, J. et al., "Fuel Economy and CO2 Emissions of Ethanol-Gasoline Blends in a Turbocharged DI Engine," *SAE Int. J. Engines* 6(1):422-434, 2013, doi:10.4271/2013-01-1321.

[4] Splitter, D. and Szybist, J., "Intermediate Alcohol-Gasoline Blends, Fuels for Enabling Increased Engine Efficiency and Powertrain Possibilities," *SAE Int. J. Fuels Lubr*. 7(1):2014, doi:10.4271/2014-01-1231.

[5] Thomas, John, Brian West, and Shean Huff, "Effects of High-Octane Ethanol Blends on Four Legacy Flex-Fuel Vehicles, and a Turbocharged GDI Vehicle," ORNL/TM-2015/116, March 2015

[6] Theiss, Tim, et al., "Summary of High-Octane Mid-Level Ethanol Blends Study," ORNL/TM-2016/42, 2016.

2. ANALYSIS AND TESTING OF CPS POWERSHOT ADDITIVE

2.1 ORNL ANALYSIS

Gas chromatography-mass spectrometry (GC-MS) was used to quantify the makeup of the CPS Powershot additive. A detailed description of the method and findings are in Appendix A of this report. In summary, ORNL chemists found that the additive is largely comprised of 3 isomers of the diether form of GTBE or 2,3-Ditert-Butoxypropanol. These isomers make up some 83% of the Powershot additive, with an additional 16% of olefinic impurities found, and 1% monoether isomers.

2.2 FUEL BLENDING AND ASTM TESTING

The antiknock index (AKI) noted on fuel dispensers in the US is based on two standard Octane Number tests, the ASTM D2699 Research Octane Number (RON) Test[1], and the ASTM D2700 Motor Octane Number (MON) Test[2]. Both tests are conducted in a special CFR test engine, but under different conditions. The AKI is the average of the RON and MON, given by (RON+MON)/2 and denoted on fuel dispensers as (R+M)/2.

Another important ASTM measurement for gasoline is the D86 Test Method for Distillation of Liquid Fuels[3]. The ASTM D4814 Standard Specification for Automotive Spark-Ignition Engine Fuel[4] provides the requirements for fuel for gasoline engines, including limits on the distillation temperatures (given by the D86 test).

The CPS Powershot additive was blended at 2 and 4 volume percent with three base stocks: 91 RON E0[5] gasoline, 72 RON E0 natural gasoline, and 93 RON E10. While CPS Powershot is EPA approved for use at 2 volume %, blends at 4 volume % were evaluated for research purposes. Both E0 and E10 fuels were tested to assess whether there was any synergistic effect of the CPS Powershot additive and ethanol. The low octane natural gasoline was tested because it is an abundant, low value, high-volatility gasoline that is commonly used as ethanol denaturant (as well as a diluent for heavy Canadian oil sands). Natural gasoline can also be upgraded in the refinery or potentially blended with high volumes of high-octane blendstocks to produce a marketable gasoline. Ethanol is known to provide a more significant octane boost to lower octane blendstocks[6]; thus it was deemed worthwhile to examine whether CPS Powershot had a similar effect on a low octane gasoline.

Standard ASTM tests were conducted at Southwest Research Institute, in San Antonio, TX. Selected results are discussed in this letter report; all test results are included in Appendix B.

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[1] ASTM D2699, "Standard Test Method for Research Octane Number of Spark-Ignition Engine Fuel," available at http://www.astm.org/Standards/D2699.htm

[2] ASTM D2700, "Standard Test Method for Motor Octane Number of Spark-Ignition Engine Fuel, " available at http://www.astm.org/Standards/D2700.htm

[3] ASTM D86, "Standard Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure," available at http://www.astm.org/Standards/D86.htm

[4] ASTM D4814, "Standard Specification for Automotive Spark-Ignition Engine Fuel," available at http://www.astm.org/Standards/D4814.htm

[5] When describing gasoline and ethanol blends, the industry frequently refers to gasoline/ethanol blends with Exx nomenclature, where the E denotes ethanol and the xx indicates the volume percent ethanol in the blend with the remainder being petroleum gasoline. As such, E0 is commonly used to denote ethanol-free gasoline.

[6] Szybist, J. and West, B., "The Impact of Low Octane Hydrocarbon Blending Streams on the Knock Limit of "E85"," *SAE Int. J. Fuels Lubr*. 6(1):2013, doi:10.4271/2013-01-0888

Octane Number Results

Octane Number test results are shown in Figures 1-3; RON test results are in Figure 1, MON test results are in Figure 2, and the AKI results are shown in Figure 3. The CPS Powershot provides a very modest octane boost at 2 and 4 volume percent blending. Results are also summarized in Table 1. Note that the repeatability of the Octane Number Tests was assessed with a repeat of the 91 RON E0 with 0 and 4% CPS Powershot additive. These repeat tests were conducted weeks apart and repeatability is excellent with variation of no more than 0.2 Octane Number.

Table 1. Octane Number Results for CPS Powershot Blends

Base Fuel	Base Fuel, no Additive			Base Fuel with 2 vol% CPS Powershot			Base Fuel with 4 vol% CPS Powershot		
	RON	MON	AKI	RON	MON	AKI	RON	MON	AKI
72 RON E0	72.4	70.8	71.6	72.4	71.5	72.0	73.1	72.5	72.8
91 RON E0, Run 1	91.0	84.8	87.9	91.4	85.1	88.3	91.8	85.4	88.6
91 RON E0, Run 2	90.9	84.6	87.8	NT[a]	NT	NT	92.0	85.2	88.6
93 RON E10	92.6	84.7	88.7	93	84.8	88.9	93.5	85.1	89.3

[a]Not Tested

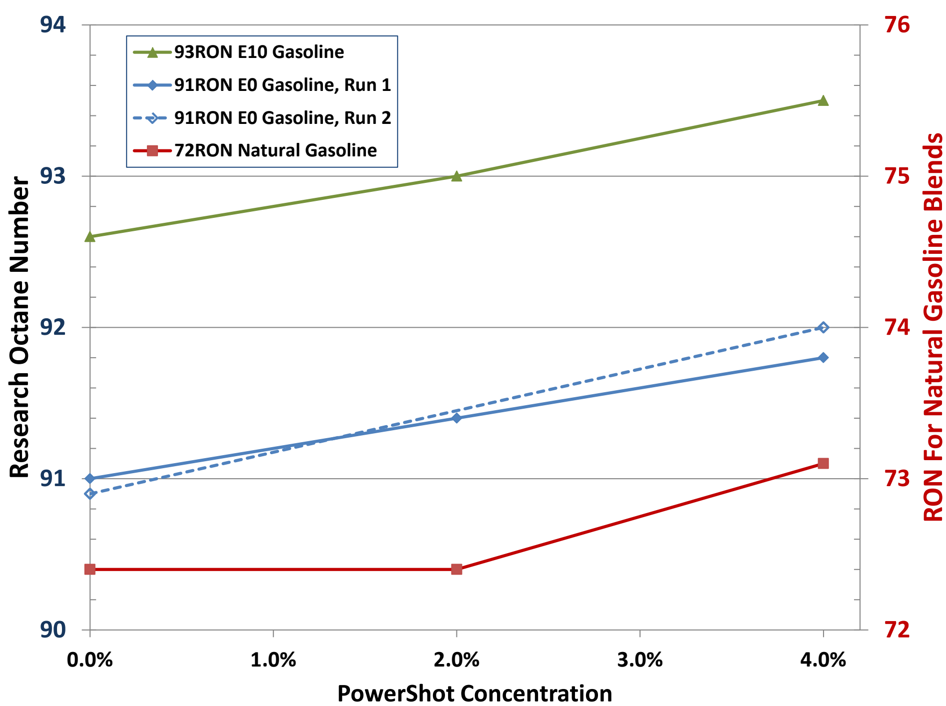


Figure 1. Research Octane Number (RON) for CPS Powershot blends

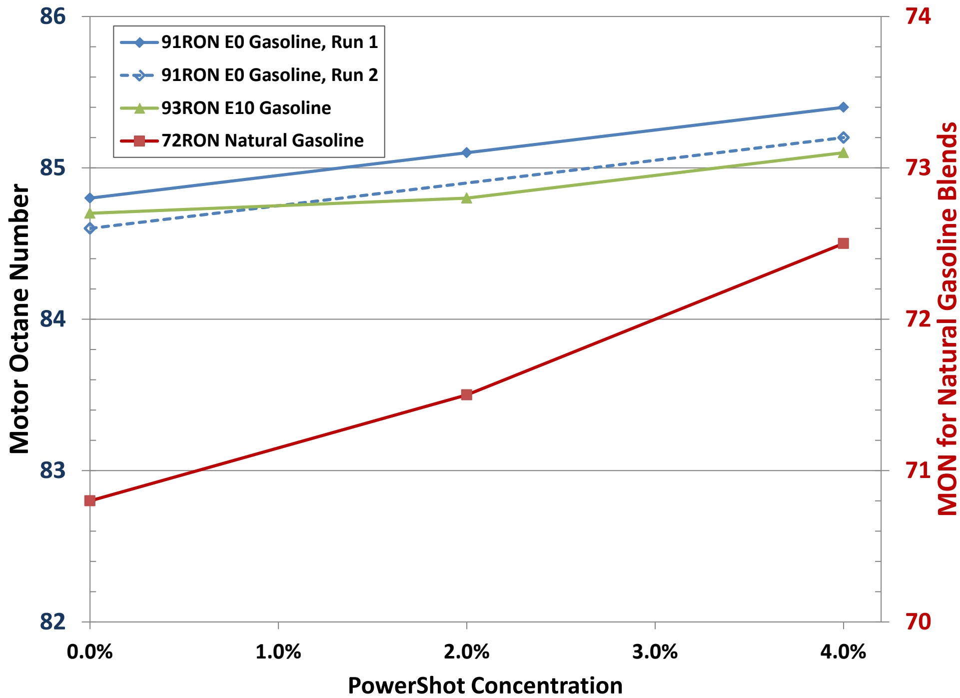


Figure 2. Motor Octane Number (MON) for CPS Powershot blends

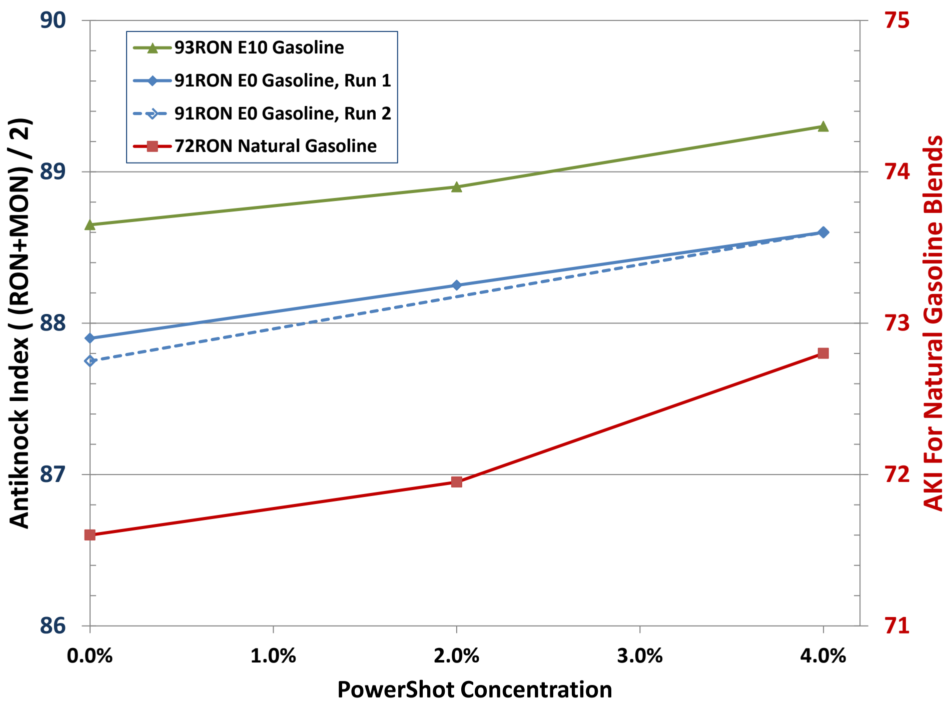


Figure 3. Antiknock Index (AKI) for CPS Powershot blends

2.2.1 DISTILLATION AND RVP RESULTS

The ASTM D4814 specification establishes limits on distillation temperature of spark ignition engine fuels. The temperature at which 50% of the sample is recovered is denoted T50. Similarly, T90 indicates the temperature at which 90% has been recovered. Upper limits within D4814 include a maximum T50 of 250°F, maximum T90 of 374°F, and a final boiling point (FBP) of 437°F. Boiling point information for 2,3-Ditert-butoxypropanol could not be found in the literature, but given its high molecular weight, there was concern about its suitability as a gasoline additive. As such, a neat sample of CPS Powershot was subjected to the ASTM D86 distillation test to determine its boiling range. Additionally, the same fuel blends tested for octane number were analyzed with D86. Results of these distillations are shown in Figure 4.

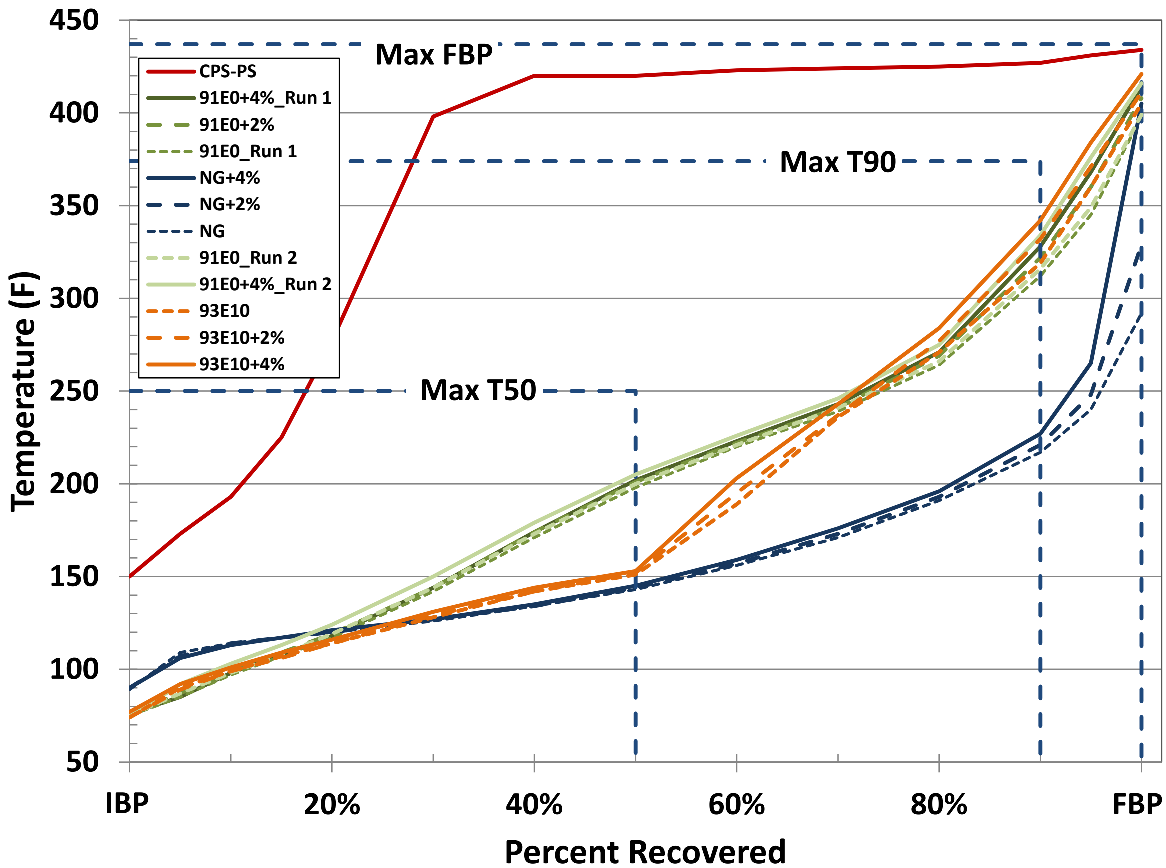


Figure 4. ASTM D86 Distillation for CPS Powershot blends. Max T50, Max T90, and Max FBP denote distillation limits for ASTM D4814.

The CPS Powershot D86 shows an FBP of 434°F, just below the D4814 maximum for gasoline blends. Note in Figure 4 that the 2 volume % and 4 volume % CPS Powershot blends have higher T90 and FBP than the neat blendstocks, as expected. The most dramatic change is in the very light and volatile natural gasoline sample. These results imply that the CPS Powershot components are vaporizing at the end of the distillation near their boiling point. Ethanol is well known for its tendency to increase vapor pressure of E10 gasoline blends, despite its lower vapor pressure in neat form. No such behavior is noted in the D86 for the CPS Powershot blends. Similarly, the Reid Vapor Pressure (RVP, ASTM D5191[1]) results show that in all cases, addition of the CPS Powershot lowered the RVP slightly. Table 2 summarizes the results of the RVP tests for all samples.

Table 2. Reid Vapor Pressure Results (psi)

Base Fuel	Base Fuel, no Additive	Base Fuel with 2 vol% CPS Powershot	Base Fuel with 4 vol% CPS Powershot
72 RON E0	10.79	10.55	10.5
91 RON E0, Run 1	13.75	13.65	13.63
91 RON E0, Run 2	13.72	Not Tested	13.68
93 RON E10	14.74	14.51	14.48

3. SUMMARY

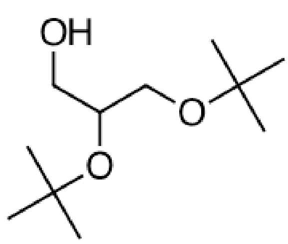
The CPS Powershot fuel additive was provided to ORNL for analysis and testing. ORNL GC/MS analysis shows that 3 isomers of the diether form of glyceryl tert-butyl ether make up the majority of the additive. The neat CPS Powershot fuel additive was subjected to a number of standard tests and blended at 2 and 4 volume percent with three relevant gasoline blendstocks; these blends were also subjected to a number of standard fuel tests. Results show that the additive boils at the upper end of the gasoline range, increasing T90 and FBP of the blends tested, and slightly depressing the RVP. ASTM tests for Octane Number show a very modest boost of RON, MON, and AKI at the legal limit of 2 volume percent; Octane Number increase was not significantly dependent on the Octane Number of the blend stock. It is worthy of note that the directions provided on the product packaging indicate that 5 ounces of CPS Powershot can treat up to 25 gallons of fuel; at this treatment rate the additive would be at less than 0.2 volume % and would not be expected to show any measureable increase in Octane Number.

[1] ASTM D5191, "Standard Test Method for Vapor Pressure of Petroleum Products," available at http://www.astm.org/Standards/D5191.htm

APPENDIX A: CHEMICAL ANALYSIS

Gas chromatography-mass spectrometry (GC-MS) is widely used for speciation of the volatile and semi-volatile components of biomass-derived liquids. A common method for reporting qualitative GC-MS data of bio-oils is to present the compounds detected based on their percent contribution to the total chromatographic area of all compounds detected in the analysis. A 14% cyanopropylphenyl/86% dimethylsiloxane phase (Restek Rtx-1701, dimensions 60 m x 250 µm, 0.25 µm df) was the column selected for this analysis. Earlier method development showed this system to provide superior resolution of biomass-derived liquids' components compared to other commonly used phases. A sample of CPS Powershot was prepared via a 1000:1 dilution of the additive in trace analytical grade methanol. A methanol blank injection was analyzed to affirm no systemic contamination. The GC-MS instrument parameters were as follows: He carrier gas, 1 mL/min constant flow; injection volume, 1 µL with port temperature 250 °C and a split ratio of 30:1; initial oven temperature of 45 °C, 10 min hold time with an oven ramp rate at 3 °C/min and a final oven temperature 250 °C, 5 min hold time; MSD transfer line, source, and quad set at 280 °C, 230 °C, 150 °C, respectively, with a solvent delay set to 4.0 min for methanol; scan range m/z 29-600.

On a percentage basis estimate, and based on an assumption that the detected compounds have similar instrument response factors (including fully equivalent vaporization in the GC inlet, full passage through the column, and equivalent ionization in the MS), it was found that the CPS Powershot is made up largely of three isomers of the diether form of GTBE (glyceryl tertiary butyl ether, 83% of total mass detected), with small but significant levels of olefinic impurities, perhaps resulting from auto-condensation from an oxygenate to a vinylic bond (16% total mass detected), along with nearly negligible content of two monoether isomers, which would be expected as a reaction side product at some level, regardless of the care taken in the preparative synthesis and purification. A summary of the GC/MS results is shown in Table A.1. Although no molecular ion was detected, based on fragments and literature structures, an example representation of one of the possible diether isomers ($C_{11}H_{24}O_3$, nominal mass = 204 g/mol), along with its IUPAC name, is shown below (2,3-Ditert-butoxypropanol). Exact structural determination among the three major diether isomers was not undertaken, as they are expected to function similarly in the fuel application.



2,3-Ditert-butoxypropanol

Table A.1. GC/MS Results

Diether isomers (3)	Abundance	Percent Composition	
1	16500000	49.3%	
2	2100000	6.3%	Total % Diether
3	9100000	27.2%	83%
Olefinic impurities (2)			
1	4200000	12.5%	Total % Olefinic Impurities
2	1200000	3.6%	16%
Monoether Isomers (2)			
1	190000	0.6%	Total % Monoether
2	190000	0.6%	1%
Total	33480000	100.0%	

APPENDIX B: SOUTHWEST RESEARCH INSTITUTE TEST REPORTS

Test reports from Southwest Research Institute are provided. Table B.1 shows the sample name cross reference for the blends submitted.

Table B.1. Sample Names for SwRI Analyses

Base Fuel	Base Fuel, no Additive	Base Fuel with 2 vol% CPS Powershot	Base Fuel with 4 vol% CPS Powershot
91 RON E0, Run 1	ORNL-GTBE-01	ORNL-GTBE-02	ORNL-GTBE-03
72 RON E0	ORNL-GTBE-04	ORNL-GTBE-05	ORNL-GTBE-06
CPS Powershot (neat)	ORNL-GTBE-07	NA	NA
91 RON E0, Run 2	ORNL-GTBE-08	NA	ORNL-GTBE-09
93 RON E10	ORNL-GTBE-10	ORNL-GTBE-11	ORNL-GTBE-12

ORNL-GTBE-01

SwRI Lab ID: oddb-32098

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	13.75
DVPE, *psi*	13.69
ASTM D2699 RON	91.0
ASTM D2700 MON	84.8
ASTM D5599 Oxygen and Oxygenates, *Weight %*	
DIPE	<0.1
ETBE	<0.1
EtOH	<0.1
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	<0.1
ASTM D86 Distillation, *deg. F*	
IBP	75
5%	85
10%	97
15%	107
20%	117
30%	142
40%	171
50%	198
60%	220
70%	239
80%	264
90%	312
95%	345
FBP	398
Recovered, mL	96.3
Residue, mL	0.9
Loss, mL	2.8

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ORNL-GTBE-02

SwRI Lab ID: oddb-32099

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	13.65
DVPE, *psi*	13.58
ASTM D2699 RON	91.4
ASTM D2700 MON	85.1
ASTM D5599 Oxygen and Oxygenates, *Weight %*	
DIPE	<0.1
ETBE	<0.1
EtOH	<0.1
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	<0.1
ASTM D86 Distillation, *deg. F*	
IBP	76
5%	87
10%	99
15%	109
20%	119
30%	144
40%	174
50%	201
60%	222
70%	241
80%	269
90%	322
95%	360
FBP	408
Recovered, mL	96.6
Residue, mL	0.8
Loss, mL	2.6

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ORNL-GTBE-03 *SwRI Lab ID: oddb-32100*

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	13.63
DVPE, *psi*	13.56
ASTM D2699 RON	91.8
ASTM D2700 MON	85.4
ASTM D5599 Oxygen and Oxygenates, *Weight %*	
DIPE	<0.1
ETBE	<0.1
EtOH	<0.1
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	<0.1
ASTM D86 Distillation, *deg. F*	
IBP	76
5%	85
10%	98
15%	108
20%	118
30%	144
40%	174
50%	202
60%	223
70%	243
80%	271
90%	328
95%	368
FBP	414
Recovered, mL	96.5
Residue, mL	0.6
Loss, mL	2.9

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ORNL-GTBE-04

SwRI Lab ID: oddb-32101

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)

RVP, *psi*	10.79
DVPE, *psi*	10.69

ASTM D2699 RON	72.4
ASTM D2700 MON	70.8

ASTM D5599 Oxygen and Oxygenates, *Weight %*

DIPE	<0.1
ETBE	<0.1
EtOH	<0.1
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	<0.1

ASTM D86 Distillation, *deg. F*

IBP	89
5%	109
10%	114
15%	117
20%	120
30%	126
40%	134
50%	143
60%	156
70%	171
80%	191
90%	217
95%	240
FBP	292
Recovered, mL	98.1
Residue, mL	0.5
Loss, mL	1.4

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ORNL-GTBE-05 *SwRI Lab ID: oddb-32102*

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	10.55
DVPE, *psi*	10.45
ASTM D2699 RON	72.4
ASTM D2700 MON	71.5
ASTM D5599 Oxygen and Oxygenates, *Weight %*	
DIPE	<0.1
ETBE	<0.1
EtOH	<0.1
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	<0.1
ASTM D86 Distillation, *deg. F*	
IBP	90
5%	107
10%	114
15%	117
20%	120
30%	127
40%	134
50%	144
60%	157
70%	173
80%	193
90%	221
95%	248
FBP	329
Recovered, mL	97.4
Residue, mL	0.8
Loss, mL	1.8

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ORNL-GTBE-06

SwRI Lab ID: oddb-32103

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	10.50
DVPE, *psi*	10.40
ASTM D2699 RON	73.1
ASTM D2700 MON	72.5
ASTM D5599 Oxygen and Oxygenates, *Weight %*	
DIPE	<0.1
ETBE	<0.1
EtOH	<0.1
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	<0.1
ASTM D86 Distillation, *deg. F*	
IBP	90
5%	106
10%	113
15%	117
20%	121
30%	127
40%	135
50%	145
60%	159
70%	176
80%	196
90%	227
95%	265
FBP	405
Recovered, mL	97.0
Residue, mL	0.8
Loss, mL	2.2

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ORNL-GTBE-07

SwRI Lab ID: oddb-32261

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	4.54
DVPE, *psi*	4.38
ASTM D4052	
API Gravity	33.7
Specific Gravity	0.8565
Density@15°C, *g/mL*	0.8561
ASTM D5185 Metals by ICP-AES, *ppm*[1]	
Boron	22
Phosphorus	1
ASTM D86 Distillation, *deg. F*	
IBP	150
5%	173
10%	193
15%	225
20%	277
30%	398
40%	420
50%	420
60%	423
70%	424
80%	425
90%	427
95%	431
FBP	434
Recovered, mL	97.3
Residue, mL	1.1
Loss, mL	1.6

[1] Metals <1: Aluminum, Antimony, Barium, Calcium, Chromium, Copper, Iron, Lead, Magnesium, Manganese, Molybdenum, Nickel, Silicon, Silver, Tin, Zinc, Strontium, Vanadium, Titanium, and Cadmium. Metals <5: Sodium and Potassium.

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ORNL_GTBE-08 *SwRI Lab ID: oddb-32858*

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	13.72
DVPE, *psi*	13.65
ASTM D2699 RON	90.9
ASTM D2700 MON	84.6
ASTM D5599 Oxygen and Oxygenates, *Weight %*	
DIPE	<0.1
ETBE	<0.1
EtOH	<0.1
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	<0.1
ASTM D86 Distillation, *deg. F*	
IBP	75
5%	87
10%	98
15%	108
20%	119
30%	144
40%	173
50%	200
60%	221
70%	241
80%	266
90%	316
95%	349
FBP	399
Recovered, mL	96.8
Residue, mL	1.1
Loss, mL	2.1

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ORNL_GTBE-09 — *SwRI Lab ID: oddb-33859*

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)

RVP, *psi*	13.68
DVPE, *psi*	13.61

ASTM D2699 RON	92.0
ASTM D2700 MON	85.2

ASTM D5599 Oxygen and Oxygenates, *Weight %*

DIPE	<0.1
ETBE	<0.1
EtOH	<0.1
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	<0.1

ASTM D86 Distillation, *deg. F*

IBP	74
5%	92
10%	103
15%	113
20%	124
30%	150
40%	179
50%	205
60%	226
70%	246
80%	275
90%	334
95%	376
FBP	416
Recovered, mL	97.4
Residue, mL	1.1
Loss, mL	1.5

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ORNL_GTBE-10 *SwRI Lab ID: oddb-32860*

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	14.74
DVPE, *psi*	14.68
ASTM D2699 RON	92.6
ASTM D2700 MON	84.7
ASTM D5599 Oxygen and Oxygenates, *Weight %*	
DIPE	<0.1
ETBE	<0.1
EtOH	10.24
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	3.55
ASTM D86 Distillation, *deg. F*	
IBP	74
5%	90
10%	99
15%	107
20%	114
30%	128
40%	142
50%	151
60%	189
70%	236
80%	271
90%	319
95%	360
FBP	405
Recovered, mL	97.0
Residue, mL	1.1
Loss, mL	1.9

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ORNL_GTBE-11 *SwRI Lab ID: oddb-32861*

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)	
RVP, *psi*	14.51
DVPE, *psi*	14.45
ASTM D2699 RON	93.0
ASTM D2700 MON	84.8
ASTM D5599 Oxygen and Oxygenates, *Weight %*	
DIPE	<0.1
ETBE	<0.1
EtOH	10.06
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	3.49
ASTM D86 Distillation, *deg. F*	
IBP	74
5%	89
10%	99
15%	106
20%	114
30%	129
40%	142
50%	152
60%	195
70%	237
80%	277
90%	332
95%	371
FBP	411
Recovered, mL	96.8
Residue, mL	1.1
Loss, mL	2.1

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Southwest Research Institute (PPRD)
Test Summary Report
February 19, 2016
SwRI WO# 74226

ORNL_GTBE-12 *SwRI Lab ID: oddb-32862*

ASTM D5191 Vapor Pressure of Petroleum Products (Mini Method)

RVP, *psi*	14.48
DVPE, *psi*	14.42

ASTM D2699 RON	93.5
ASTM D2700 MON	85.1

ASTM D5599 Oxygen and Oxygenates, *Weight %*

DIPE	<0.1
ETBE	<0.1
EtOH	9.76
iBA	<0.1
iPA	<0.1
MeOH	<0.1
MTBE	<0.1
nBA	<0.1
nPA	<0.1
sBA	<0.1
TAME	<0.1
tBA	<0.1
tPA	<0.1
Total Oxygen	3.39

ASTM D86 Distillation, *deg. F*

IBP	77
5%	92
10%	101
15%	109
20%	116
30%	131
40%	144
50%	153
60%	203
70%	243
80%	284
90%	342
95%	384
FBP	421
Recovered, mL	96.9
Residue, mL	1.1
Loss, mL	2.0

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