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Blender Pump Fuel Survey: CRC Project E-95-2

A. Williams and T.L. Alleman
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5400-60627
May 2014

Contract No. DE-AC36-08GO28308

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Prepared under Task No. VTP2.0072

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Acknowledgments

The author acknowledges the U.S. Department of Energy's Vehicle Technology Program and the Coordinating Research Council's Emissions Committee for co-funding this project.

List of Acronyms

ASTM	ASTM International
CRC	Coordinating Research Council
EPA	U.S. Environmental Protection Agency
Exx	xx vol% ethanol blended with pure gasoline
MLEB	mid-level ethanol blend
NREL	National Renewable Energy Laboratory
vol%	volume percent

Executive Summary

In 2012, the U.S. gasoline market was about 134 billion gallons [1], and the fuel ethanol market was 13.3 billion gallons [2]. Almost all fuel ethanol is used in gasoline as a 10 volume percent (vol%) blend. A far less significant amount is used as "E85" Flex Fuel (a fuel compliant with ASTM International Specification D5798 and formerly called E85). Mid-level ethanol blends (MLEBs) are an emerging ethanol option that contain more than 10 vol% ethanol but less than 50 vol% ethanol. MLEBs are typically sold as discrete blends, such as 20 vol% (E20), and 30 vol% (E30). The argument for offering MLEBs is to give consumers with Flex Fuel vehicles additional fuel choices at the pump.

The Coordinating Research Council and the U.S. Department of Energy's National Renewable Energy Laboratory conducted a survey of MLEBs in the market, in order to provide a snapshot of selected characteristics of the increasingly diverse array of fuels available to U.S. motorists. A total of 73 fuel samples were collected in February of 2013 from 20 retail stations located in the midwestern United States. Samples included gasoline (E0 or E10), "E85" Flex Fuel, and every MLEB that was offered from each of the 20 stations.

All samples were analyzed by Southwest Research Institute for vapor pressure and ethanol content. For E10 samples there was very little variation in ethanol content. For the MLEB samples variability was higher, typically failing to meet the advertised ethanol level by 3 to 4 vol%, and in one case was off by 10 vol%. One of the 20 "E85" Flex Fuel samples was above the allowable limits for ethanol content. Four of the 20 "E85" Flex Fuel samples had vapor pressures below the minimum requirement.

In addition photographs of each station were taken at the time of sample collection, detailing the dispenser labeling and configuration. The style and labeling of the dispenser, hose and nozzle are all important features to prevent misfueling events. Furthermore, the physical location of the MLEB product relative to the gasoline product can also be important to prevent misfueling. In general there were many differences in the style and labeling of the dispensers surveyed in this study.

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Introduction

In 2012, the U.S. gasoline market was about 134 billion gallons [1], and the fuel ethanol market was 13.3 billion gallons [2]. Almost all fuel ethanol is used in gasoline as a 10 volume percent (vol%) blend. A far smaller amount is used in "E85" Flex Fuel (a fuel compliant with ASTM International [ASTM] Specification D5798 and formerly called E85). Mid-level ethanol blends (MLEBs) are an emerging blend of "E85" Flex Fuel and gasoline. MLEBs contain more than 10 vol% ethanol and less than 50 vol% ethanol and are typically sold as discrete blends, such as 20 vol% (E20), and 30 vol% (E30). The argument for offering MLEBs is to offer consumers with Flex Fuel vehicles additional fuel choices at the pump. The recent U.S. Environmental Protection Agency (EPA) waiver allowing up to E15 in 2001 and newer cars, trucks, and sport utility vehicles should increase the volume of MLEBs in the marketplace.

MLEBs are typically offered at stations with blender pumps. A blender pump draws fuel from two separate storage tanks and mixes the fuels to produce the desired ethanol blend ratio. In traditional gas stations, a blender pump is often used to get midgrade gasoline by mixing the regular and premium grade fuels. In a station that offers MLEBs, the blends are generally made by mixing "E85" Flex Fuel with regular gasoline [3].

With the increasing fuel diversity in the marketplace, the Coordinating Research Council (CRC) and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) conducted a survey of MLEBs in the market. The project assumed that the MLEBs were blended at the dispenser, by a so-called blender pump, from parent gasoline and D5798-compliant "E85" Flex Fuel.

Methodology

Station Identification

The U.S. Department of Energy's Alternative Fuels Data Center was used to identify 20 stations with blender pumps that offered MLEBs. Each station was contacted prior to sample collection to ensure that MLEBs were being sold. While efforts were made to identify stations over a wide geographical area, these stations were all located in the midwestern United States. The relative locations of the stations are illustrated in Figure 1.

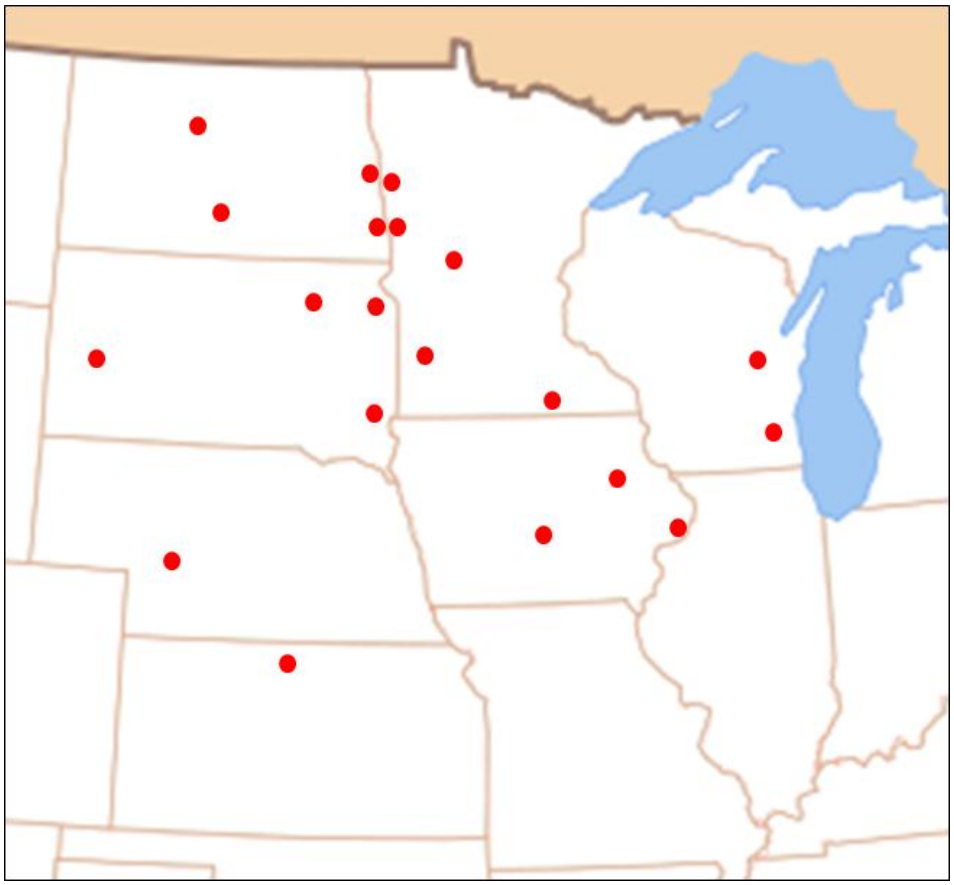

Figure 1. Relative station locations

Sample Collection and Photographs

A contractor was sent to each station to collect the fuel samples. At each station, a 1.5-liter sample was collected from each of the parent fuels (gasoline and "E85" Flex Fuel) along with every MLEB that was offered. In order to prevent sample carry-over, 3 liters of fuel were purged from the pump prior to collection of each individual fuel sample. A total of 73 fuel samples were collected from these 20 retail stations. All fuel samples were collected between February 9th and 26th of 2013, targeting the wintertime class (D5798 Class 4).

In the first E-95 study (2010), samples were collected in ASTM D5798 Class 1, which represents the lowest vapor pressure samples and the warmest months of the year (typically summertime fuels). Between the end of that study and the commencement of the current study, several things changed in the D5798 specification. First, D5798 was updated to reflect the necessity by

blenders to adjust the hydrocarbon portion of the blend across a wider range than previously allowed. This change allowed for a consistent, and generally wider range, of allowable ethanol content in each class, with the goal of blenders being able to meet vapor pressure requirements more easily year-round. The second major change was the addition of a fourth class for the wintertime months. The new Class 4 was added in a further effort to help blends produce on-specification fuels in the winter months.

In this most recent study Class 4 fuels were targeted in order to draw the largest contrast to the Class 1 fuels sampled in a previous blender pump survey (CRC E-95) and to expand the limited information on commercially available "E85" Flex Fuel in this new class [4]. In the first E-95 study, multiple tests were run on the Flex Fuel only, such as pHe, acidity, chloride, and sulfate. Results from that work, combined with results from CRC's E-85 studies showed very few failures on these properties, even when the samples failed ethanol content and/or vapor pressure requirements. The decision to not test these properties on the Flex Fuel samples was twofold in this study: first, by reducing the number of tests, a larger number of samples could be collected, and second, with the focus of the study on blender pumps, only the critical properties of the parent fuels were collected (ethanol content and vapor pressure). By reducing the number of tests, the study was able to increase the number of stations from the previous project from 15 to 20, increasing the number of MLEB samples from 25 to 33.

Detailed photographs of the dispensers and stations were also taken at the time of sample collection. These included:

- Close-up photograph of dispenser, showing labeling specific to blends offered
- Photograph showing entire dispenser, including hoses
- Photograph of island including dispenser
- Photograph showing island configuration of MLEB dispenser, in relation to other islands at station
- Photograph of station sign, looking for any indication that MLEBs are being sold at station.

Property Analysis

All fuel samples were analyzed by Southwest Research Institute in San Antonio, Texas. The vapor pressure of the gasoline and the "E85" Flex Fuel was analyzed for comparison to their respective requirements in D4814 and D5798 using ASTM D5191. The vapor pressure of the MLEBs was also measured using the same method. The ethanol content of all fuel samples was analyzed and compared to the appropriate ASTM specification and dispenser labeling captured in the station photographs. Gasoline and E15 blends were analyzed using D5599; ethanol content in samples above E20 was measured by D5501. Samples were also analyzed for water content and specific gravity to allow for ethanol content to be reported in vol%.

Fuel Property Results

Gasoline Samples

To simplify sample collection, the contractor was instructed to sample regular unleaded gasoline, the "E85" Flex Fuel, and all MLEBs offered at each station visited. As discussed below, many of the stations offered E0 and E10. Because no additional direction was given to the contractor about what constituted "regular unleaded gasoline", the samples collected varied and could be either E10 or E0 based on the contractor's individual choice during sampling. In addition, it is unknown whether the MLEBs were blended from E0 or from E10.

Of the 20 stations that were sampled, every location offered Flex Fuel labeled as "E-85." E30 was the most commonly available MLEB, offered at all but two stations. E20 was offered at half of the stations, while E15, E40, and E50 were less common. Thirteen of the 20 stations provided multiple options for MLEBs. One of the stations did not offer any MLEBs, although the station claimed to have the blends during the identification phase of the project. Table 1 shows the number of samples that were collected for each fuel type, along with statistics for the vapor pressure and ethanol content. As illustrated in this table, the ethanol content was generally lower than its indicated value.

Many of the stations offered both hydrocarbon gasoline (E0) as well as oxygenated gasoline (E10). The contractors tasked with collecting the fuel samples only collected one of the two gasoline options. Consequently, 11 samples of hydrocarbon gasoline and 9 samples of oxygenated gasoline were collected from the 20 stations. From the information collected, it was unclear which form of gasoline was used as the parent fuel to make the MLEBs in the blender pump.

Table 1. Summary of Results

Property	Fuel Type	# of Samples	Mean	Median	Standard Deviation
DVPE, psi	Gasoline (E0)	11	13.4	13.7	1.44
	Oxygenated Gasoline	9	14.4	14.6	0.70
	E15	3	14.2	14.0	0.41
	E20	10	13.9	13.9	0.69
	E30	18	13.5	13.6	0.92
	E40	1	14.2	14.2	NA
	E50	1	13.1	13.1	NA
	"E85" Flex Fuel	20	10.0	10.5	1.64
Ethanol Content, vol%	Gasoline (E0)	11	< 0.1	< 0.1	< 0.1
	Oxygenated Gasoline	9	10.4	10.3	0.10
	E15	3	16.8	17.3	0.92
	E20	10	18.0	17.3	3.35
	E30	18	26.7	26.9	2.59
	E40	1	29.7	29.7	NA
	E50	1	44.2	44.2	NA
	"E85" Flex Fuel	20	70.9	68.3	7.02

DVPE = dry vapor pressure equivalent
NA = not applicable
psi = pounds per square inch

For each of the fuel samples, the ethanol content was determined by the appropriate test method (D5599 or D5501) based on fuel dispenser labeling. Figure 2 shows the results for ethanol content of all samples. The data are organized by station, showing the ethanol content for each product offered at the 20 locations.

For the E10 samples there was very little variation in ethanol content. However, for the MLEB samples variability was higher, typically failing to meet the advertised ethanol level by 3 to 4 vol%. The fuels tended to be lower in ethanol content than their indicated amount. Those samples that were furthest from their indicated levels were: E40 from Station #13 (30 vol%), E30 from Station #8 (22 vol%), and both E20 and E30 from Station #7 (12 vol% and 22 vol%, respectively). Also of note is that for stations that offered multiple MLEB products, those MLEBs generally trended either high or low in ethanol content together. The most notable exception was Station #3 where E20 was high at 22 vol% and E30 was low at 26 vol%. In this instance, these two fuels were supplied by separate blender pumps at the same fueling island.

Figure 2 also shows the lower and upper ethanol limit for "E85" Flex Fuel (51 vol% to 83 vol%), per ASTM Specification D5798-13a. As can be seen in the figure, all of the samples were within these limits with the exception of Station #6, which contained 94 vol% ethanol. In 2011, the D5798 specification was changed to reduce the minimum ethanol content from 68 vol% down to 51 vol% to allow for more high volatility hydrocarbon in the blends, which should result in an increase in vapor pressure. The E-85-1 and E-85-2 CRC reports both found that samples had difficulty meeting wintertime vapor pressure [5, 6]. The difficulty in meeting winter vapor pressure of "E85" Flex Fuel was one widely cited reason for a cessation of sales of "E85" Flex Fuel by Marathon Petroleum Company in 2009 [7]. In response to general industry difficulties, ASTM reduced the minimum ethanol content for all classes and added the fourth class to help ensure these fuels were fit for purpose.

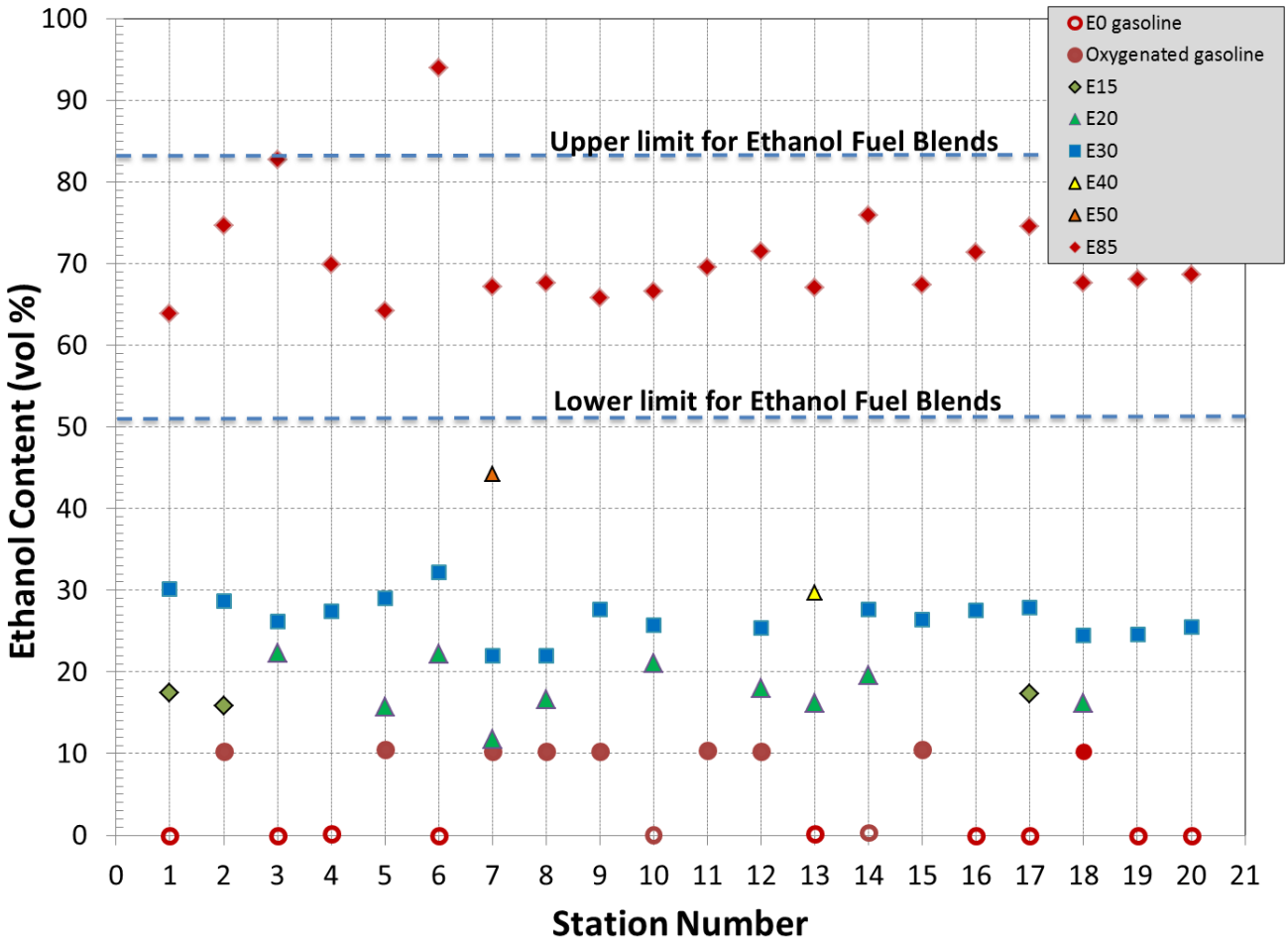

Figure 2. Ethanol content for all fuel samples

Gasoline and "E85" Flex Fuel are required to meet specifications for fuel vapor pressure that are dependent on location and time of year. All but one of the "E85" Flex Fuel samples in this survey would fall under D5798-11 Class 4, with a vapor pressure requirement of 9.5 to 15.0 psi. The one exception would be sample #14, collected in Kansas, which is listed as Class 3/4 for the month of February. The Class 3 vapor pressure requirement is 8.5 to 12.0 psi. Figure 3 shows the vapor pressure for all of these fuel samples along with the vapor pressure requirements for "E85" Flex Fuel. Four of the 20 "E85" Flex Fuel samples collected have vapor pressure below their minimum requirement, for a failure rate of 20%. For comparison, of the 37 Class 3 "E85" Flex Fuel samples collected in a previous fuel survey, the failure rate was 70% [6]. The extremely low vapor pressure of "E85" Flex Fuel collected at Station #6 is explained by the high level of ethanol (94 vol%).

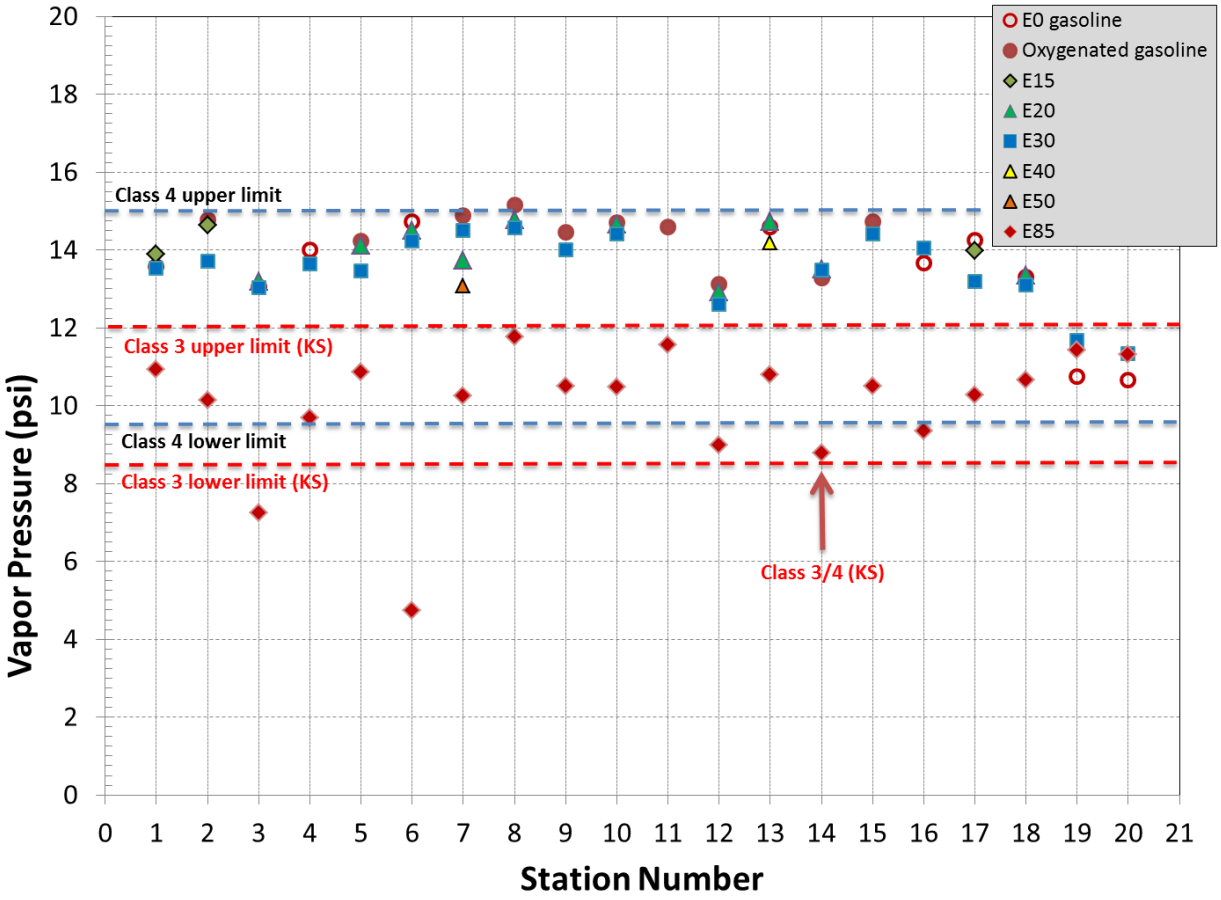

Figure 3. Vapor pressure for all fuel samples

Station Photos

An additional objective of this survey was to understand MLEB dispenser labeling. To make this assessment, detailed photographs of the stations and dispensers were taken at the time of sample collection. The style and labeling of the dispenser, hose, and nozzle are all important features to minimize the probability of misfueling events. Furthermore, the physical location of the MLEB product relative to the gasoline product can also be important to prevent misfueling. As part of the E15 partial waiver, the EPA requires obligated parties to submit a Misfueling Mitigation Plan [8]. In March of 2012, the EPA concluded that a model plan developed by the Renewable Fuels Association was sufficient to satisfy this partial waiver requirement. As part of this model plan, the Renewable Fuels Association describes three configurations where blender pumps are used to produce E15. They are as follows:

1. A dedicated E15 dispenser or a dedicated E15 hose at a multiple fuel dispenser.
2. E15 from the same nozzle and hose as E10. This creates the potential for a vehicle not included under the E15 partial waiver to receive residual amounts of E15 when fueling with E10.
3. E15 from the same nozzle and hose as higher ethanol blends. This creates the potential for non-Flex Fuel vehicles to receive residual amounts of higher ethanol blends when being fueled with E15.

While the Renewable Fuels Association's Misfueling Mitigation Plan was written specifically for E15, we make an assessment here of how the stations in this survey offer MLEBs in comparison to the model plan guidelines. Three of the 20 stations in this survey offered E15 from the same nozzle and hose as higher ethanol blends (Configuration #3). Photos of this dispenser configuration as represented by these three stations are shown in Figures 4, 5, and 6. In addition, two of the 20 stations offered higher ethanol blends from the same hose as E10 (similar to Configuration #2). Photos of the dispensers in these two stations are shown in Figures 7 and 8. Each of the dispenser configurations in these five stations create the potential for introduction of residual amounts of higher ethanol fuel than is acceptable in non-Flex Fuel vehicles. Photographs of the other stations are included in the appendix.

Figure 4. Station #1 offered E15 from same nozzle as higher ethanol blends

Figure 5. Station #2 offered E15 from same nozzle as higher ethanol blends

Figure 6. Station #17 offered E15 from same nozzle as higher ethanol blends

Figure 7. Station #3 offered higher ethanol blends from the same hose as E10

Figure 8. Station #14 offered higher ethanol blends from the same hose as E10

Photographs of each station can be found in the appendix. Other general observations that can be noted from these photographs are listed below.

- Most of the pumps that offered "E85" Flex Fuel were labeled as "minimum 70% ethanol," which was not the case in 11 of the 20 survey samples analyzed (see Figure 2) and likely represents old labeling from 2010 or earlier, when D5798 set minimum ethanol content at 70%.
- While yellow color coding is common for MLEB dispenser nozzles and hoses, it is not universal. Four of the 20 stations did not have yellow dispenser nozzles and hoses for MLEB fuels.
- Six of the stations which offered a single MLEB alongside "E85" Flex Fuel, offered the two products from separate hoses.
- Three of the stations listed an octane number for the MLEBs that they offered.

Table 2 lists the MLEB offerings and blender pump configurations for each station sampled.

Table 2. Description of Blender Pump Station Configuration

Station #	MLEB offerings	Notes on Dispenser Configuration
1	E15, E30	E15 offered from the same hose as E30 and “E85” Flex Fuel
2	E15, E30	E15 offered from the same hose as E30 and “E85” Flex Fuel
3	E20, E30	E10 offered from the same hose as E20 and “E85” Flex Fuel
4	E30	Dedicated MLEB hose
5	E20, E30	Dedicated MLEB hose
6	E20, E30	Dedicated MLEB hose
7	E20, E30, E50	Dedicated MLEB hose
8	E20, E30	Dedicated MLEB hose
9	E30	Dedicated MLEB hose
10	E20, E30	Dedicated MLEB hose
11	NA	No MLEB was offered at this station
12	E20, E30	Dedicated MLEB hose
13	E20, E40	Dedicated MLEB hose
14	E20, E30	E10 offered from the same hose as E20, E30 and “E85” Flex Fuel
15	E30	Dedicated MLEB hose
16	E30	Dedicated MLEB hose
17	E15, E30	E15 offered from the same hose as E30 and “E85” Flex Fuel
18	E20, E30	Dedicated MLEB hose
19	E30	Dedicated MLEB hose
20	E30	Dedicated MLEB hose

Conclusions

In this work, 73 samples were collected from 20 separate blender pump stations located in the midwestern United States. Class 4 was targeted, with samples collected in February of 2013. This study was a follow-up to an earlier MLEB fuel survey (CRC E-95), which focused on Class 1 fuels. Samples were analyzed by Southwest Research Institute for ethanol content and vapor pressure. In addition detailed photographs of the stations were collected at the time of sampling. Key findings in this survey are listed below:

- For the E10 samples there was very little variation in ethanol content.
- For the MLEB samples variability in ethanol content was higher, typically failing to meet the advertised ethanol level by 3 to 4 vol%, and in one case was off by 10 vol%.
- One of the 20 "E85" Flex Fuel samples was above the allowable limits for ethanol content.
- Four of the 20 "E85" Flex Fuel samples had vapor pressure below the minimum requirement for Class 4.
- In general, there were many differences in the style and labeling of the dispensers surveyed in this study. Five of the 20 dispensers offered higher MLEBs (>E15) from the same hose as E10 or E15. These five dispensers create the potential for introduction of residual amounts of higher ethanol fuel than is acceptable in non-Flex Fuel vehicles.

Both the E-95 and E-95-2 study focused on MLEBs offered in the midwestern United States. Although the surveys were somewhat limited by where the stations were located, the goal was to find states with the highest number of stations, then sample a subset in each state. Thus, states with only one or two blender pumps were excluded from sampling.

The station locations in the previous study were rural, in areas that were not required to meet any of the footnotes in Table 4 in D4814, the gasoline specification. The footnotes in D4814 cover vapor pressure requirements during summer months for Federal ozone non-attainment areas, areas requiring reformulated gasoline, and/or areas that have state implementation plans for control of air quality. Future work may consider another summertime survey, particularly in areas where specific requirements are in place for gasoline, to determine if these gasolines have any impact on "E85" Flex Fuel properties compared to gasolines found in rural areas. Future work may also consider a wider distribution of sampling locations, including states where only one or two blender pumps may be located.

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Appendix A: Station Photographs

Figure A.1 Station #4

Figure A.2 Station #5

Figure A.3 Station #6

Figure A.4 Station #7

Figure A.5 Station #8

Figure A.6 Station #9

Figure A.7 Station #10

Figure A.8 Station #11

Figure A.9 Station #12

Figure A.10 Station #13

Figure A.11 Station #15

Figure A.12 Station #16

Figure A.13 Station #18

Figure A.14 Station #19

Figure A.15 Station #20

Appendix B: Tabulated Fuel Property Data

Table B.1 Fuel Properties

Station Number	Indicated Nominal	Ethanol Content (D5501/D5599) vol%	DVPE (D5191) psi	Water (D6304) vol%	SPGr@60F (D4052)
1	E85	63.9	10.9	0.63	0.77
1	E15	17.4	13.9		0.73
1	E30	30.2	13.5	0.35	0.74
1	E0	<0.1	13.6		0.72
2	E15	15.8	14.6		0.73
2	E30	28.6	13.7	0.33	0.74
2	E85	74.7	10.1	0.76	0.76
2	E10	10.3	14.8		0.73
3	E20	22.4	13.2	0.23	0.73
3	E85	82.7	7.2	0.80	0.78
3	E0	<0.1	13.1		0.72
3	E30	26.2	13.0	0.28	0.74
4	E85	69.9	9.7	0.72	0.77
4	E0	0.2	14.0		0.72
4	E30	27.4	13.7	0.29	0.74
5	E10	10.5	14.2		0.73
5	E85	64.2	10.9	0.57	0.76
5	E30	29.0	13.5	0.23	0.74
5	E20	15.7	14.1	0.17	0.73
6	E20	22.2	14.5	0.23	0.73
6	E0	<0.1	14.7		0.72
6	E85	93.9	4.7	0.81	0.79
6	E30	32.2	14.2	0.31	0.74
7	E30	22.0	14.5	0.33	0.74
7	E20	11.8	13.7	0.12	0.73
7	E10	10.3	14.9		0.73
7	E85	67.1	10.3	0.52	0.77
7	E50	44.2	13.1	0.44	0.75
8	E20	16.7	14.8	0.17	0.73
8	E10	10.3	15.2		0.73
8	E30	22.0	14.6	0.23	0.73
8	E85	67.6	11.8	0.72	0.75
9	E10	10.3	14.5		0.73
9	E85	65.8	10.5	0.62	0.77
9	E30	27.6	14.0	0.27	0.74

Station Number	Indicated Nominal	Ethanol Content (D5501/D5599) vol%	DVPE (D5191) psi	Water (D6304) vol%	SPGr@60F (D4052)
10	E0	<0.1	14.7		0.72
10	E85	66.6	10.5	0.63	0.77
10	E20	21.1	14.7	0.21	0.74
10	E30	25.7	14.4	0.25	0.74
11	E10	10.4	14.6		0.73
11	E85	69.6	11.6	0.56	0.75
12	E10	10.3	13.1		0.73
12	E20	17.9	12.9	0.18	0.73
12	E85	71.4	9.0	0.53	0.77
12	E30	25.4	12.6	0.23	0.74
13	E40	29.7	14.2	0.34	0.74
13	E0	0.1	14.6		0.72
13	E20	16.2	14.7	0.17	0.73
13	E85	67.0	10.8	0.66	0.77
14	E30	27.7	13.5	0.22	0.74
14	E20	19.6	13.5	0.15	0.73
14	E85	75.8	8.8	0.61	0.78
14	E0	0.3	13.3		0.72
15	E10	10.5	14.7		0.73
15	E30	26.4	14.4	0.27	0.74
15	E85	67.4	10.5	0.75	0.77
16	E85	71.3	9.4	0.76	0.78
16	E0	<0.1	13.7		0.73
16	E30	27.6	14.1	0.28	0.74
17	E30	27.8	13.2	0.26	0.73
17	E0	<0.1	14.3		0.72
17	E15	17.3	14.0		0.73
17	E85	74.5	10.3	0.58	0.76
18	E30	24.5	13.1	0.28	0.74
18	E10	10.2	13.3		0.73
18	E20	16.2	13.4	0.18	0.74
18	E85	67.6	10.7	0.40	0.77
19	E0	<0.1	10.7		0.73
19	E85	68.0	11.4	0.47	0.75
19	E30	24.6	11.7	0.26	0.74
20	E85	68.6	11.3	0.57	0.75
20	E30	25.5	11.3	0.19	0.74
20	E0	<0.1	10.7		0.73